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REVIEW

# Dual-energy CT evaluation of gastrointestinal bleeding

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**Abstract**
Gastrointestinal bleeding is a common cause for hospital admissions and is an important cause of morbidity and mortality. Although endoscopy is accepted as the standard initial diagnostic modality for the evaluation of gastrointestinal bleeding, multiphasic computed tomography (CT) imaging has become an alternative diagnostic tool. Dual-energy CT with post-processing techniques may have additional advantages over single-energy computed tomography in evaluation of gastrointestinal bleeding. In this article, we discuss the role of dual-energy CT in the evaluation of gastrointestinal bleeding with potential advantages over conventional CT and limitations.

**Keywords** Gastrointestinal bleeding · Dual-energy computed tomography · Computed tomography · Virtual monochromatic imaging · Iodine display techniques

## Introduction

Acute gastrointestinal bleeding is a potentially life-threatening abdominal emergency that causes over 300,000 hospitalizations annually, accounting for 1–2% of all hospital admissions and is an important cause of morbidity and mortality [1, 2]. Gastrointestinal bleeding is anatomically categorized as upper or lower, depending on the location of hemorrhage proximal or distal to the Treitz ligament, respectively [3, 4]. Clinically, gastrointestinal bleeding can be categorized as overt and occult bleeding. Overt gastrointestinal bleeding (GIB) can be presented with bright red or coffee-ground hematemesis, melena, or hematochezia [5]. Occult bleeding term is used if source of the bleeding can only be detected with fecal blood test or iron deficiency anemia. Obscure bleeding defines hemorrhage where the source of the bleeding cannot be identified despite endoscopic evaluations or advanced imaging techniques [3, 6]. Clinical presentation, management, and treatment depend on the source of hemorrhage, the amount of bleeding and the overall condition of the patient [2].

Endoscopy is the initial diagnostic modality for the evaluation of gastrointestinal bleeding. In upper gastrointestinal bleeding, endoscopy can localize the bleeding and allow for the biopsy and therapeutic procedures [2, 7]. However, detecting the source of bleeding in small bowel is the main limitation of upper endoscopy [1, 2]. Capsule endoscopy is a non-invasive tool that enables evaluation of the entire small bowel and is beneficial for finding the source of the obscure gastrointestinal bleeding. However, it has limitations to identify the exact localization of the small bowel lesions [8]. In patients with lower gastrointestinal bleeding, emergent colonoscopy may be challenging. The lack of proper bowel preparation in emergency conditions and the difficulty in visualizing the bowel mucosa in the presence of blood clots limit the utility of colonoscopy in emergency settings [1–3]. For gastrointestinal bleeding where endoscopic examination is inadequate, multiphasic multidetector CT (MDCT) has

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become an alternative diagnostic tool. ACR appropriateness criteria for the imaging of non-variceal upper gastrointestinal bleeding (2016) recommend CT angiography as a next diagnostic study after the endoscopic evaluation [9]. With the emergence of dual-energy CT (DECT), evaluation of gastrointestinal bleeding can be obtained with various advantages over single-energy MDCT. In this article, we review the role of DECT for the evaluation of gastrointestinal bleeding. First, we summarize the role of MDCT for the evaluation of GIB, then we describe DECT image acquisition and post-processing techniques relevant to imaging of gastrointestinal bleeding and describe the potential advantages of DECT compared to conventional single-energy CT. We illustrate DECT findings in gastrointestinal bleeding and discuss the limitations and pitfalls that may hinder accurate diagnosis and how to avoid them.

## Role of multidetector computed tomography in gastrointestinal bleeding

Multidetector computed tomography is a widely available, rapid, and non-invasive imaging tool that does not require specific bowel preparation as in endoscopy in the evaluation of gastrointestinal bleeding [10]. With the technical advances in MDCT, three-dimensional data can be obtained with higher temporal resolution and shorter acquisition times. Shorter acquisition times allow multiphasic and angiographic studies in emergency settings [2]. In addition to the detection of active bleeding, MDCT also characterizes and localizes the underlying cause and assists in the endoscopic, interventional, or surgical treatment [1, 2, 10]. MDCT imaging can be performed with a CT angiography or a multiphasic CT enterography. Generally, CT angiography has been used to evaluate the presence and the location of active and overt bleeding in emergency settings, whereas multiphasic CT enterography with oral contrast has been used to assess occult small bowel bleeding in outpatient settings [3]. In an animal model, it has been shown that, CT angiography can detect active gastrointestinal bleeding in bleeding rates that exceed 0.3 mL/min [1, 3]. In a meta-analysis, CT was shown to be highly sensitive and specific for detecting acute gastrointestinal bleeding with a sensitivity of 85.2% and specificity of 92.1% [11]. Yoon et al. [12] showed that in patients with massive bleeding, MDCT had a sensitivity of 90.9% and a specificity of 99% in detecting gastrointestinal bleeding. However, intermittent bleeding may be missed with MDCT if there is no active bleeding at the time of the CT scan [9].

Multiphasic CT enterography is performed with neutral oral contrast and enables demonstration of the underlying bowel pathology as well as the source of active bleeding [6, 13].

## Findings of acute gastrointestinal bleeding in multiphasic CT

A multiphasic CT examination , including the unenhanced, arterial and portal venous phase, is usually performed for the evaluation of acute gastrointestinal bleeding [5]. The purpose of the unenhanced image is to characterize any preexisting intraluminal high-attenuation material, such as foreign instrumentations, high-attenuation ingested food, surgical suture materials, or residual barium in bowel that might be misconceived later as active bleeding. Multiphasic CT findings of active gastrointestinal bleeding include the detection of active extravasation of iodine contrast (high-attenuation material) into the bowel lumen on the arterial phase, with changing its morphology on the portal venous phase [2]. Dual-energy CT may introduce potential advantages over routine single-energy multiphasic CT; it enables reviewing material decomposition datasets and evaluating data at different keV settings.

## General review and basic principles of dual-energy CT

In diagnostic radiology, an X-ray beam interacts with a material and an image is formed using two principles: Compton scattering and photoelectric effect [14]. In single-energy CT, elements or materials with different compositions may have similar attenuation values. The basis of DECT is to generate an image from two different energy levels from the same anatomic region [15]. DECT uses the k-edge variabilities of the electrons and differences in photoelectric interactions. Due to differences in attenuations observed at different energy levels, it is possible to distinguish elements from each other and determine their relative proportions. For instance, although iodine and calcium have high CT attenuation numbers (Hounsfield unit), it is possible to distinguish iodine from calcium with DECT [16, 17]. Some investigators prefer using the term multi-energy CT instead of dual-energy CT. Data from DECT can be acquired with different techniques: dual-source, fast kilovoltage switching, and spectral detector techniques [15, 18, 19].

In clinical practice, DECT is used with blending/mixing in which information from each low- and high-energy image spectrum is combined to obtain images with a similar appearance as a 120 kVp image [14, 16]. For the evaluation of gastrointestinal bleeding, other post-processing methods are used including: 1) material-specific methods—iodine display techniques and 2) energy-specific methods-—virtual monochromatic images.

## Processing methods for the DECT evaluation of gastrointestinal bleeding

### Material-specific display methods (iodine display technique)

By using the unique linear attenuation coefficient of substances, specific materials such as iodine can be distinguished from other materials. Moreover, with utilizing mathematical algorithms, iodine content can be determined. Thus, iodine content of a tissue or a lesion can be visually demonstrated as color-coded images with iodine maps and iodine overlay images. By subtracting iodine content, virtual non-contrast (VNC) images can be generated. Also, iodine concentration within a tissue or a lesion can be calculated quantitatively [16, 20]. To assess the iodine content, dual-source DECT uses three-material decomposition algorithm, and single-source DECT uses two-material decomposition algorithm. Three-material decomposition algorithm enables to demonstrate iodine concentration both in Hounsfield units (HU) and in mg/mL, whereas two-material decomposition algorithm enables to demonstrate iodine concentration only in mg/mL [15, 16].

### Energy- specific display methods (virtual monochromatic imaging)

The X-ray source used in single-energy computed tomography is a polychromatic beam that contains photons with different energy levels. In a polychromatic beam, kilovoltage peak (kVp) indicates the highest energy level. With DECT, it is possible to create virtual monochromatic images that simulate images that are obtained from a monochromatic source. Energy level in virtual monochromatic imaging (VMI) is demonstrated with kiloelectron volts (keV) [21, 22]. At lower keV levels, which are closer to the k-edge energy level of the iodine (33.2 keV), contrast of the iodine increases. Visualization of iodine improves and contrast differences between the tissues increase [21, 23]. Thus, the use of VMI at low keV levels may lead to reduction in the amount of iodinated contrast media required [15, 24]. However, along with iodine contrast, image noise also increases [21, 23]. The use of iterative reconstruction algorithms in combination with DECT leads to reduction in image noise observed in lower energy levels [25]. It has been reported that the optimal energy levels for soft tissue evaluation are between 60 and 77 keV and optimal contrast to noise ratio (CNR) is obtained at 70 keV for evaluation of small bowel [15, 21, 26]. Moreover, with noise-optimized reconstructions of virtual monochromatic imaging (VMI+), further improvement in image quality can be obtained at lower energy levels when compared to

**Table 1** Dual-energy CT protocol for gastrointestinal bleeding

| | |
|---|---|
| Oral contrast material | Neutral oral contrast, 1350 mL, 45 min before scanning |
| Intravenous contrast material | Iopamidol, 370 mgI/mL |
| Volume and rate | 125 mL, 5 cc/s |
| Saline volume and rate | 50 mL, 5.0 cc/s |
| Delay | Bolus tracking |
| Image acquisition | |
| Precontrast phase | Single energy (100 kV) |
| Arterial phase | Dual-energy (100/Sn140 kV or 100/Sn150 kV) |
| Venous phase | Single energy (120 kV) |
| Image reconstruction | |
| Precontrast phase | Axial plane, 1 mm slice thickness with 1 mm intervals |
| Arterial phase | Axial plane, 1 mm slice thickness with 1 mm slice intervals |
| | Coronal and sagittal planes, 2 mm slice thickness with 2 mm slice intervals |
| | Coronal MIP plane, 4 mm slice thickness with 2 mm slice intervals |
| | Axial plane VNC, 40 keV-VMI images, and iodine overlay images |
| Venous phase | Axial, coronal and sagittal planes, 2 mm slice thickness with 2 mm slice intervals |

*VNC* virtual non-contrast, *VMI* virtual monochromatic image, *MIP* maximum intensity projection

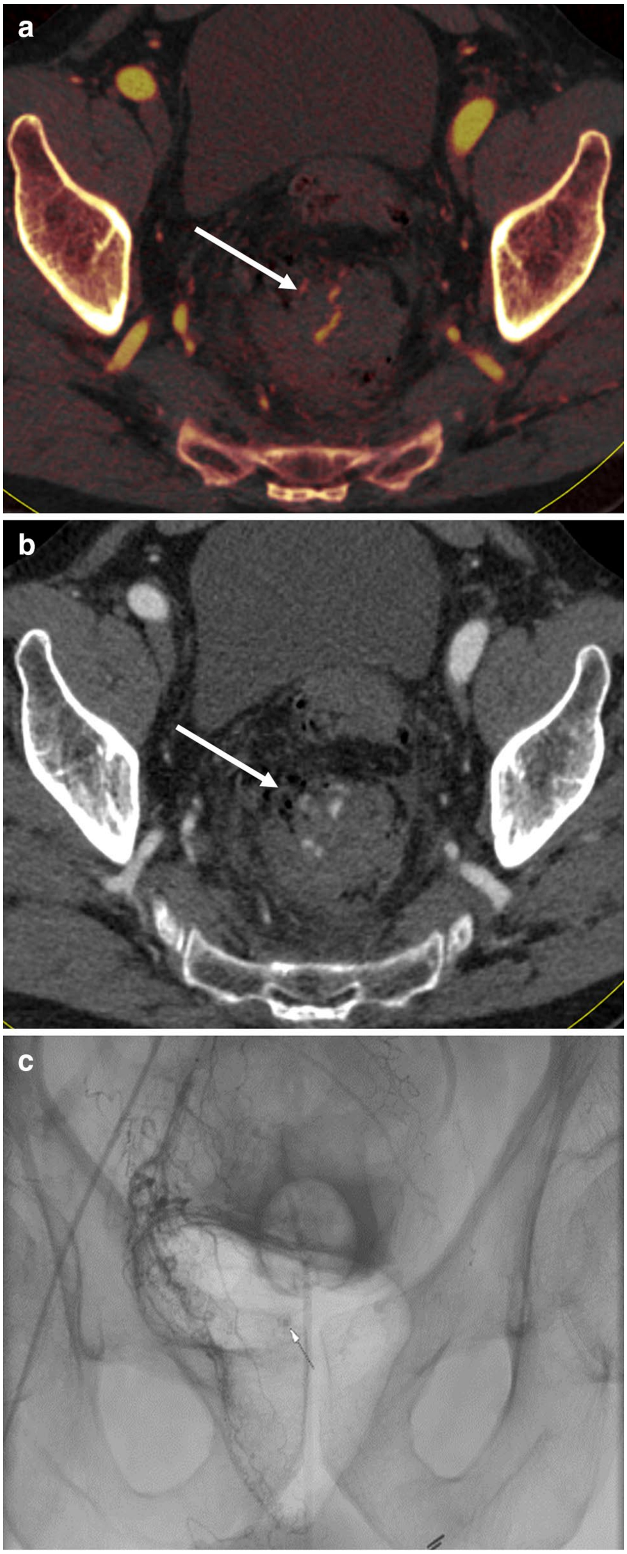


**Fig. 1** CT images of a 70-year-old man with abdominal pain and lower gastrointestinal bleeding. Axial arterial-phase dual-energy CT images show perforated diverticulitis and a prominent vessel at the active bleeding site on the iodine overlay image (**a**) and virtual monoenergetic image at 90 keV (**b**). No iodine was seen on the virtual non-contrast image (VNC). With VNC images, the need for true unenhanced images can be eliminated, which will result in a significant reduction in radiation dose. Posteroanterior arteriogram (**c**) of inferior mesenteric artery confirms extravasation at superior rectal artery

traditional virtual monochromatic imaging [27–30]. Diagnostic performance of DECT in acute abdominal bleeding can be improved with the use of 40 keV-VMI+ images when compared to conventional VMI images [30].

Image noise decreases along with the contrast between the tissues with VMI at high keV levels [21]. VMI at high-energy levels has been shown to be useful in reducing metal artifacts caused by orthopedic hardware. Moreover, VMI at high-energy levels may reduce the pseudoenhancement of lesions by reducing beam hardening [22].

## Dual-energy CT protocol for gastrointestinal bleeding

DECT protocol for evaluation of gastrointestinal bleeding may vary among institutions. DECT angiography can be acquired in two phases (arterial phase and portal venous phase) without using oral contrast media [6]. Although there is no consensus on which phase should be scanned with DECT, many radiologists believe that performing DECT in arterial phase or in both arterial and venous phase would be valuable for gastrointestinal bleeding evaluation [31]. The use of neutral oral contrast provides a better evaluation of the bowel as it enables a better contrast between the lumen and the bowel wall [32]. However, it may be avoided in DECT for acute gastrointestinal hemorrhage as it may dilute extravasated contrast material and hinder visualization of active bleeding. It may also delay start of CT scan because of the waiting period needed for drinking the neutral contrast material [2, 6].

Multiphasic DECT enterography is acquired 45–60 min after the administration of neutral oral contrast agent. Timing of the acquisition of the phases also varies among institutions [6, 13]. Arterial and portal venous phase images are typically included. With DECT protocol, true unenhanced images may be excluded, as virtual [6]. After CT acquisition, post-processing is done to create virtual non-contrast images, iodine overlay images and virtual monochromatic images at the scanner console by the technologist. The latest generation of scanners can reconstruct and automatically submit many of these processed images to picture archiving and communication system (PACS), resulting in significant reduction in interpretation time. Our DECT protocol for gastrointestinal bleeding is a combination of CT angiography and multiphasic CT enterography, as demonstrated in Table 1.

## Advantages of dual-energy CT over single-energy CT

Active gastrointestinal bleeding can be detected with analysis of iodine maps, iodine overlay images and virtual non-contrast images with potential advantages over single-energy CT. In a single-phase contrast-enhanced CT scanning,

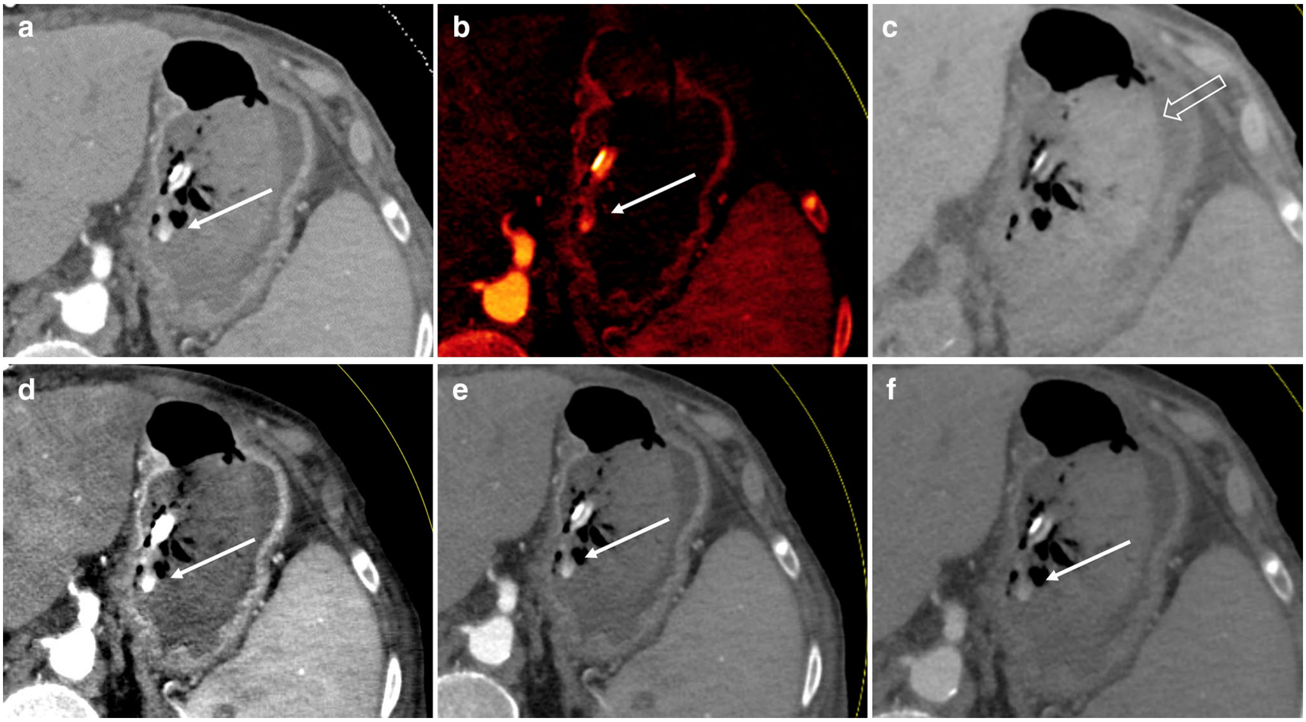


**Fig. 2** A 92-year-old female patient presented with hemoglobin drop and hematemesis. Axial arterial-phase CT image (**a**) shows hyperattenuated (white arrow) focus suspicious for active bleeding. Iodine content within the hyperattenuation is seen on iodine map image (**b**) that disappears on VNC image (**c**). VNC image also shows high-attenuation material within the gastric lumen (transparent arrow) which may represent blood products. Active extravasation is better seen with VMI at 40 keV (**d**) and becomes less visible at 70 keV (**e**) and 100 keV (**f**)

hyperattenuation observed within the bowel lumen can be due to active bleeding or other causes such as intestinal content or surgical materials. Therefore, an additional unenhanced phase is needed to assess possible gastrointestinal bleeding. In dual-energy CT, demonstration of iodine content within the hyperattenuation on iodine maps or iodine overlay images that disappears on virtual non-enhanced images indicates active gastrointestinal bleeding. Thus, with DECT, the need for true non-contrast image can be eliminated. It has been shown that the image quality of the VNC images is similar to true unenhanced images, and in patients with intraabdominal bleeding, VNC images could be used as a replacement for true unenhanced images [33]. There is no report that compares radiation dose between single-energy triphasic CT and biphasic DECT for gastrointestinal bleeding in the literature. However, it has been reported that in abdominal imaging, dual-energy is feasible without a dose penalty and without altering image quality [34–36]. Thus, eliminating unenhanced phase will decrease the required number of CT acquisition phases and radiation dose. Moreover, diagnostic performance of CT in detecting active bleeding can be improved with iodine maps and VMI at low keV levels as they accentuate the visualization of iodine (Figs. 1, 2) [18, 20]. In an animal model, it has been shown that the use of iodine map increased both the diagnostic accuracy and the diagnostic confidence in determining extravasated iodinated contrast when compared to conventional CT [37]. This may be even more important for evaluation of small bowel bleeding in which endoscopic evaluation can be limited (Fig. 3).

If the hyperattenuation observed within the bowel lumen in the mixed (virtual 120 kVp) images shows no iodine content on iodine maps and does not disappear on virtual non-contrast images, it does not reflect active bleeding and is consistent with a radiodense ingested debris [20] (Fig. 4). Sun et al. [38] reported that for the detection of active gastrointestinal bleeding, in multiphasic CT studies, the virtual non-enhanced images can replace the true unenhanced images, which will lead a reduction in radiation

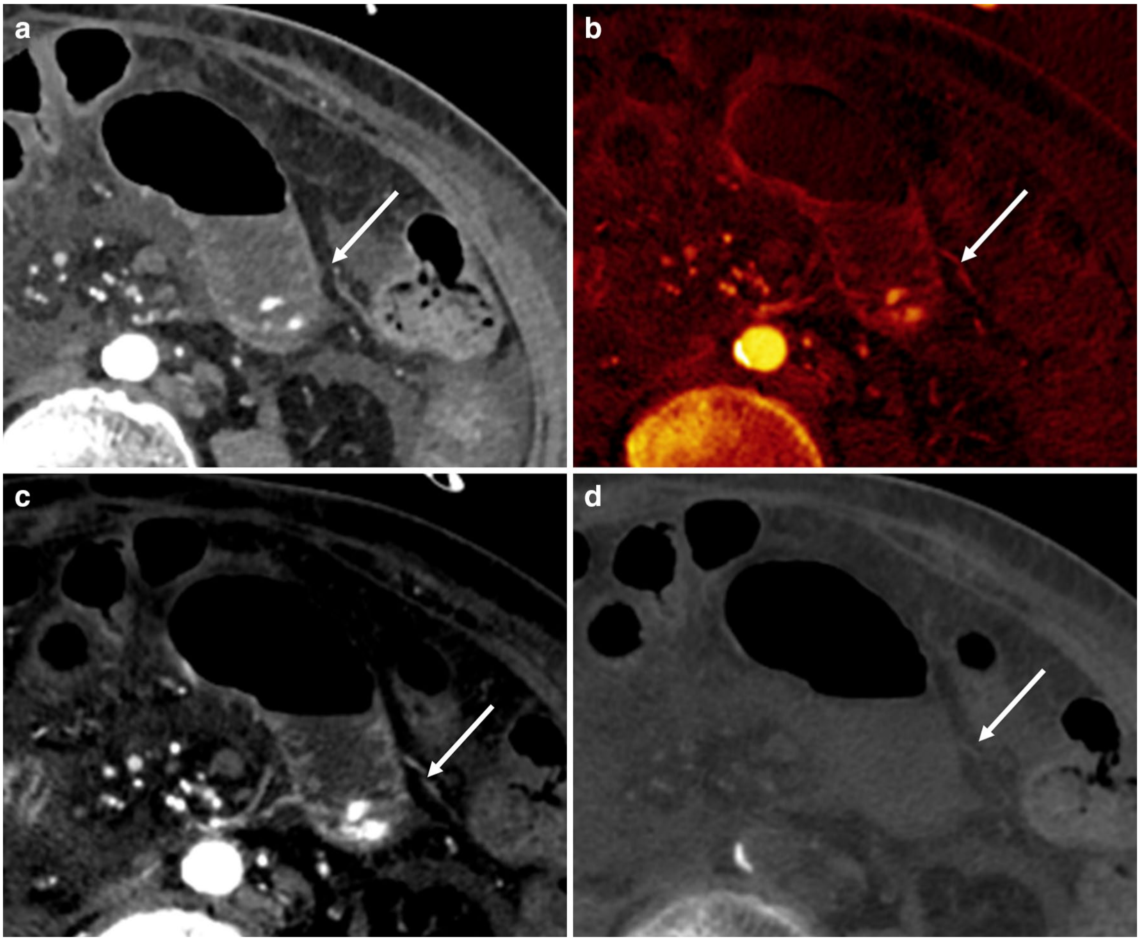


**Fig. 3** Active gastrointestinal bleeding in a 68-year-old female who presented with maroon-colored stools and decrease in hemoglobin. Arterial-phase mixed CT image equivalent to 120 kVp image (**a**) shows active contrast material extravasation (arrow) within jejunum. The visualization of active bleeding is improved with iodine map (**b**), virtual monochromatic image at 40 keV (**c**), and disappeared with virtual non-contrast image (**d**). Detection of active bleeding can be made without the need for true unenhanced images

dose by 30% in dual-energy CT. They reported that sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of DECT with VNC images and iodine maps were 94.3%, 95.8%, 98.8%, 82.1%, and 94.6%, respectively, and diagnostic performance of DECT did not show statistically significant difference when compared to triphasic CT angiography.

Moreover, when active bleeding is not present, DECT may help determine the possible underlying cause of bleeding better than single-energy CT with the use of VMI and iodine maps.

## Common causes of gastrointestinal bleeding

### Upper gastrointestinal bleeding

Major causes of upper gastrointestinal bleeding include peptic ulcer disease or erosions, vascular lesions, Mallory–Weiss tears, and neoplasms [1, 6, 7].

#### Peptic ulcer disease and gastric erosions

Peptic ulcer disease and erosions are major causes of upper gastrointestinal bleeding that accounts for over 50% of cases and endoscopy remains as the first diagnostic tool [1, 2, 6]. However, evaluation of distal duodenum with endoscopy

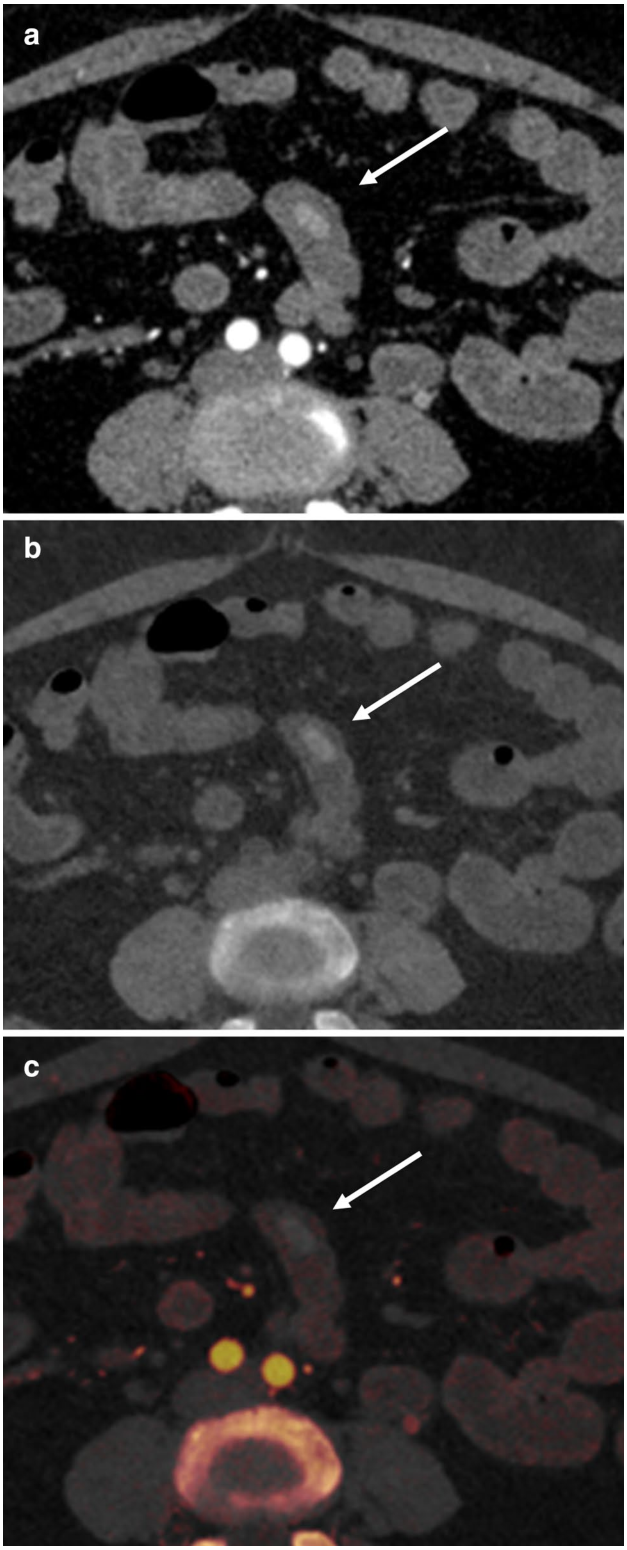


**Fig. 4** Ingested material in a 58-year-old patient with suspected lower gastrointestinal bleeding. Axial contrast-enhanced arterial-phase mixed CT image (**a**) shows suspicious hyperattenuated focus (arrow) in a small bowel loop. The hyperattenuation persists on the axial virtual non-enhanced image (**b**) and does not show iodine uptake on the axial iodine overlay image (**c**). These findings confirm that the hyperattenuated focus represents ingested material and does not represent active extravasation of iodine

may be difficult [6]. DECT with iodine maps and VMI can improve assessment of inflammation by accentuating alterations in bowel wall enhancement.

### Vascular diseases

Vascular causes of upper gastrointestinal bleeding include arteriovenous malformations, variceal lesions, and pseudoaneurysms [1, 6]. With VMI at low keV levels and iodine selective imaging, the conspicuity of vascular structures can be increased and delineation of vascular pathologies of upper gastrointestinal tract can be improved when compared to single-energy CT (Fig. 5) [19, 25].

### Neoplasms

Neoplasms are one of the important causes of upper gastrointestinal bleeding. Approximately, 5% of acute upper gastrointestinal bleeding is caused by neoplasms [1]. Gastric cancer has been reported to be the most common site for tumoral upper gastrointestinal bleeding [39].

## Lower gastrointestinal bleeding

Major causes of lower gastrointestinal bleeding include diverticular disease, vascular lesions, neoplastic, inflammatory, and ischemic conditions [1, 3, 6].

### Diverticular disease

Diverticular disease is the most common cause of lower gastrointestinal bleeding and responsible for 30–65% of lower gastrointestinal bleeding in adults [6]. It is especially common in elderly patients and usually self-limited [1]. With the use of DECT, detection of bleeding secondary to diverticular disease can be done without the need for colonoscopy and bowel preparation.

### Vascular diseases

Vascular causes of lower gastrointestinal bleeding include angiodysplasia, arteriovenous malformations, hemorrhoids, and pseudoaneurysms [1, 6]. Angiodysplasia is a common cause of lower gastrointestinal bleeding especially in elderly patients and responsible for approximately 40% of cases over 60 years old. In contrast to diverticular hemorrhage, bleeding secondary to angiodysplasia is prone to re-bleeding. Thus, it is crucial to distinguish angiodysplasia from other etiologies [1]. With VMI at low keV levels and iodine selective imaging, the conspicuity of vascular structures can be increased and delineation of vascular pathologies of abdomen can be improved when compared to single-energy CT [19, 25] (Fig. 6). It has been shown that monochromatic

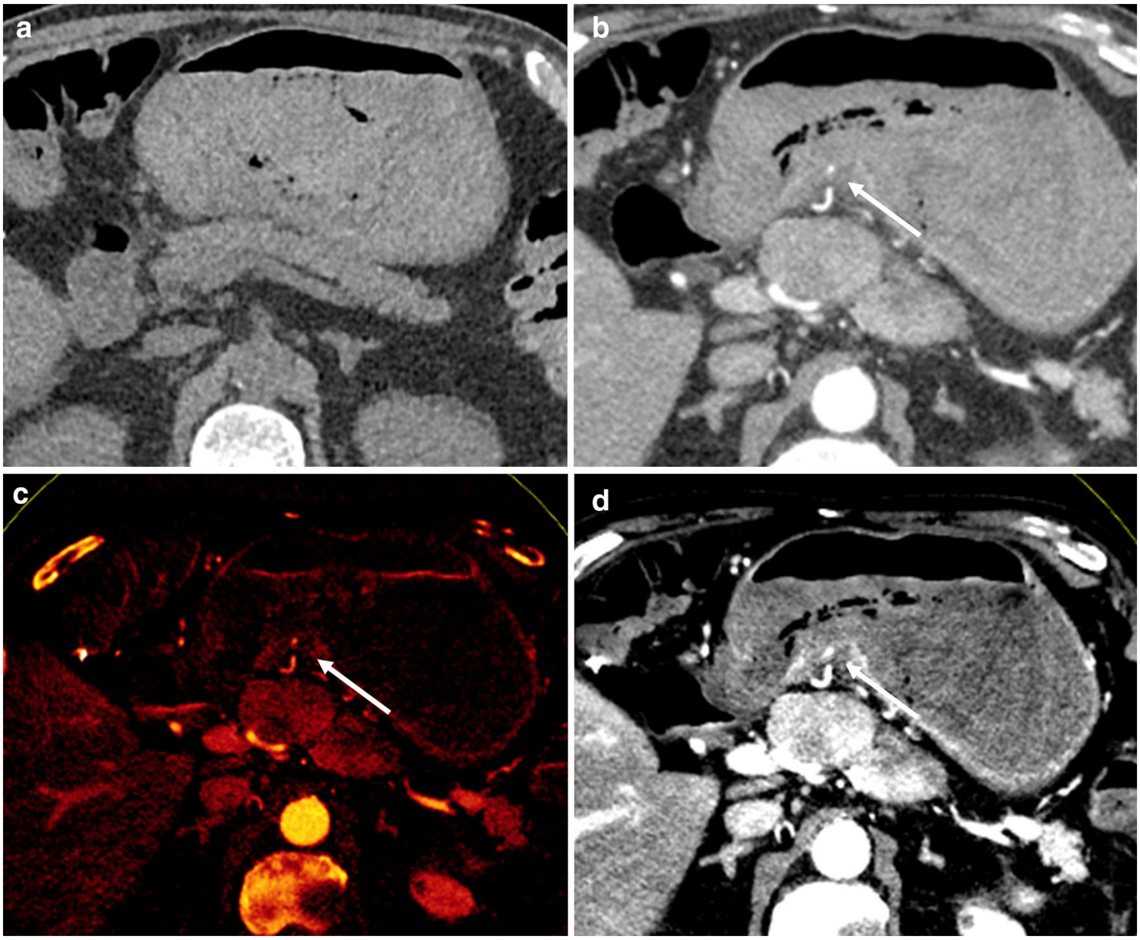


**Fig. 5** A 75-year-old male with a history of gastric adenocarcinoma who presented with melena and hematemesis. Axial unenhanced CT image (**a**) shows high-attenuation material within the gastric lumen that may represent hematoma (mean attenuation within the lumen is 67 HU). Axial arterial-phase mixed image (**b**), iodine map image (**c**), and 40 keV-VMI (**d**) show a punctate-enhancing focus (arrow) at the posterior wall of the gastric antrum. No contrast pooling is seen in the venous phase. Findings are compatible with a pseudoaneurysm. Pseudoaneurysm is better visualized with iodine map image and 40 keV-VMI. No evidence of contrast extravasation is seen within the gastric lumen. Increased conspicuity of vascular structures on VMI and iodine maps is a major benefit of dual-energy scanning

imaging at 50 keV is more advantageous in demonstrating distal branches of the superior mesenteric artery with a better image quality [40].

## Neoplasms

2–15% of acute lower gastrointestinal bleeding is caused by colorectal neoplasms [3, 6]. Detection of gastrointestinal tract tumors with CT imaging can be challenging due to lack of distension of bowel or the presence of intestinal content [41]. With the use of DECT, evaluation of neoplastic processes of gastrointestinal tract may be improved. With iodine maps and VMI, demonstration of iodine uptake within the tumor can increase the diagnostic confidence of CT (Fig. 7) [18, 20, 42]. Also, iodine content can be calculated quantitatively with DECT (Fig. 8) [20]. Boellaard et al. [43] showed that the use of DECT is feasible in determination

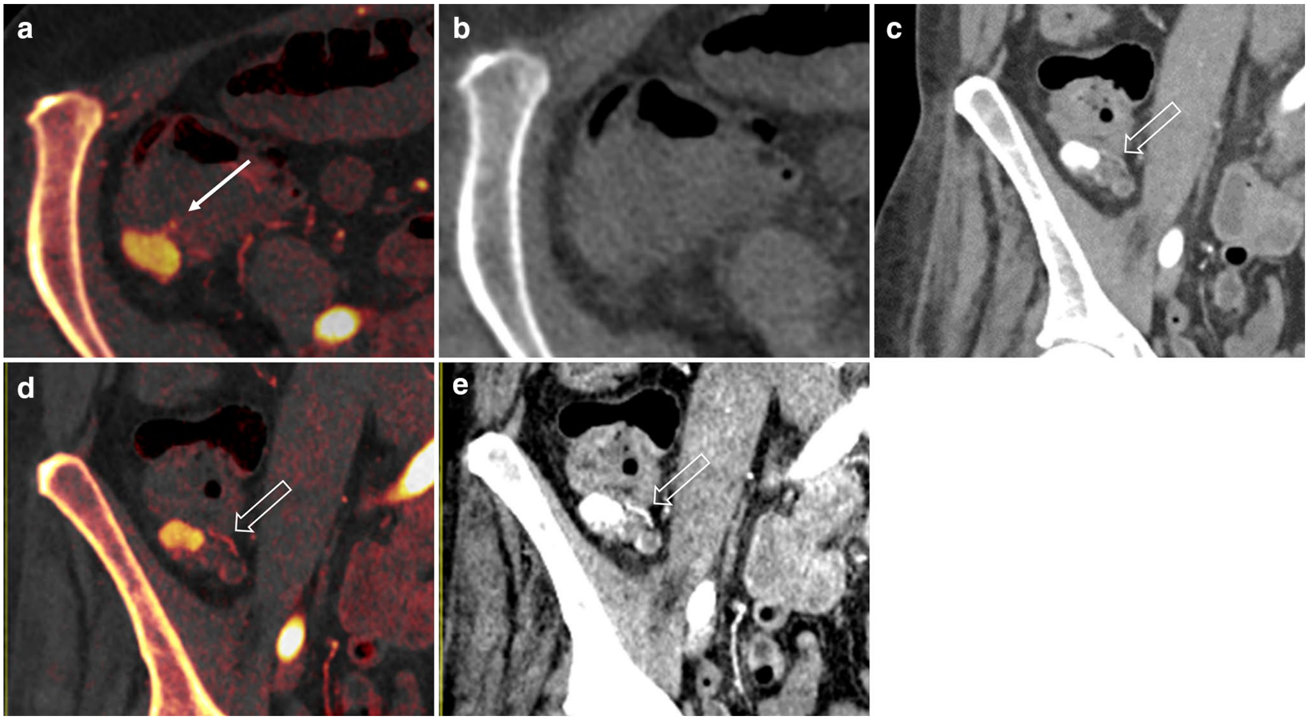


**Fig. 6** A 85-year-old female patient with hematochezia. Axial arterial-phase iodine overlay image (**a**) shows active extravasation that disappears in virtual non-contrast image (**b**), compatible with active gastrointestinal bleeding. Note that the need for true enhanced images can be eliminated with virtual non-contrast images. Coronal arterial-phase mixed CT image (**c**) shows a small vessel adjacent to the extravasation. Visualization of the vessel is more pronounced with coronal iodine overlay image (**d**) and coronal 50 keV-VMI (**e**). Bleeding angiodysplasia was suspected and confirmed with mesenteric angiogram. Patient was treated with coil embolization successfully

of colorectal cancer without the need for bowel preparation and distention.

### Bowel ischemia

It has been reported that ischemic colitis is responsible for 5–20% of lower gastrointestinal bleeding [6]. With DECT, visual demonstration of relatively decreased iodine content of ischemic bowel segments with iodine maps or VMI at low keV levels may increase diagnostic confidence of CT in determination of bowel ischemia. Moreover, quantitative assessment of iodine may demonstrate decreased perfusion within the ischemic bowel segment (Fig. 9) [18, 20]. In an animal model, it has been shown that VMI at 51 keV provided increased depiction of ischemic bowel when compared to 120 kV conventional CT images [44].

### Inflammatory conditions

Inflammatory bowel disease and infectious colitis are relatively less common causes of lower gastrointestinal bleeding, responsible for 3–5% and 2–5% of cases, respectively [6]. DECT with iodine maps and VMI can improve the assessment of bowel wall thickening by accentuating alterations in bowel wall enhancement. In addition to the evaluation of bowel wall thickening, DECT may assist in demonstration of the inflammation and changes observed in perienteric or pericolonic fat or mesentery in patients with Crohn's disease

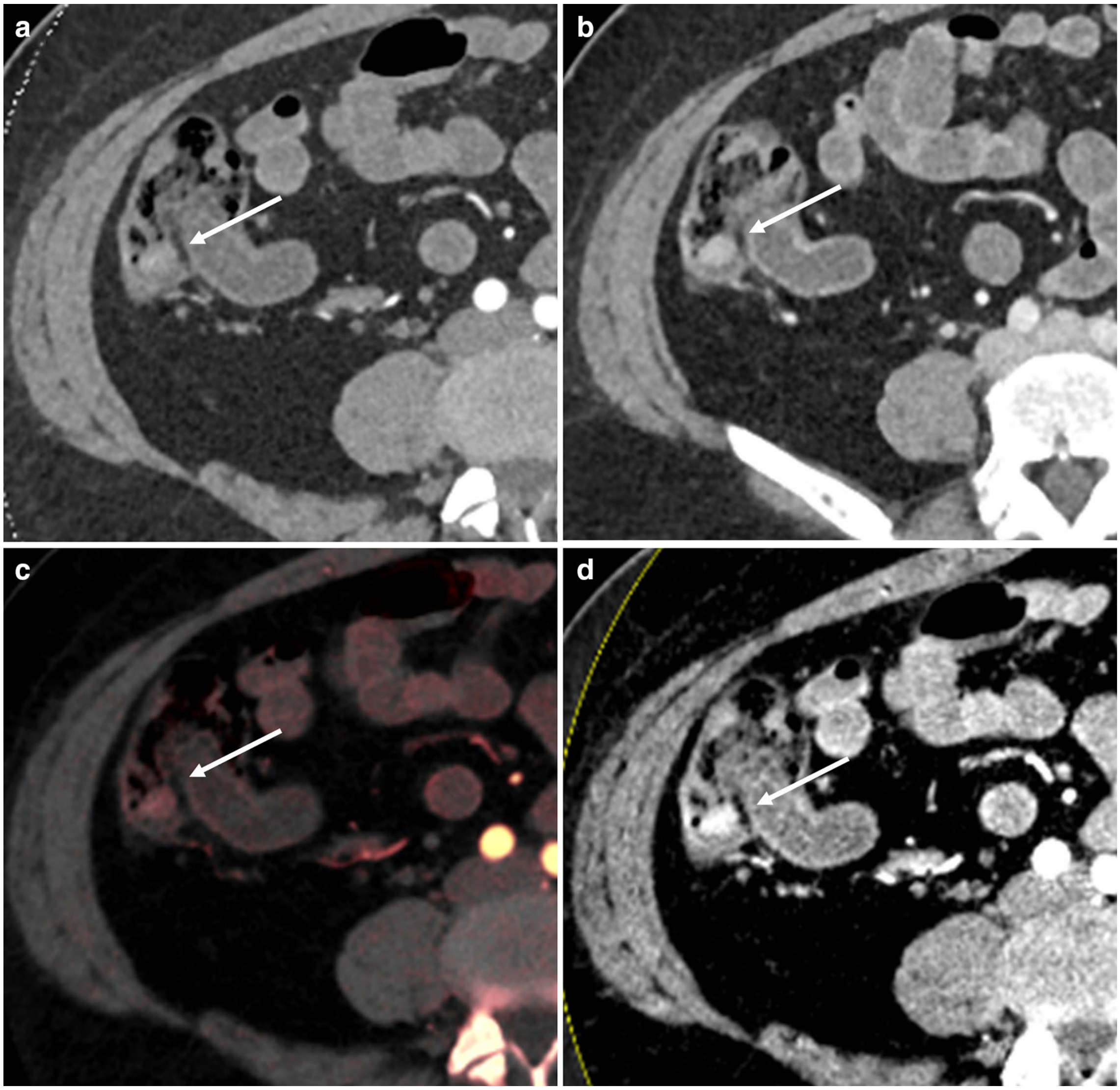


**Fig. 7** Axial arterial- (**a**) and portal venous (**b**)-phase images of a 58-year-old female with suspected gastrointestinal bleeding. Focal nodular enhancement of a polypoid lesion (arrow) is seen in the cecum. Note that the detection of the lesion is improved by the iodine overlay image (**c**) and virtual monochromatic image at low keV energy level (40 keV) (**d**). Without virtual monochromatic and iodine overlay images, this lesion may be mistaken with fecal debris and may be missed on routine MDCT scanning

[14, 20]. It has been shown that, diagnostic performance of CT can be improved if 40 keV-VMI is added to conventional polychromatic 120 kV images in the evaluation of active Crohn's disease [45]. Moreover, it has been demonstrated that iodine quantification with DECT may assist in differentiating active Crohn's disease from normal bowel loops [46].

## Limitations of DECT

Although dual-energy CT provides several advantages for the evaluation of gastrointestinal bleeding, it has its own limitations. Beam-hardening artifacts and photon starvation tend to increase at lower energy levels. In obese patients or in patients with metallic hardware, due to insufficient penetration of low-energy photons, image quality may be decreased [47]. Many institutions use a cut-off value for body size (weight, BMI, or lateral dimensions) for the utilization of DECT to overcome this limitation. In the literature, 260–280 lbs and 38, 42, and 46 cm have been reported for weight and width cut-off values, respectively; however there is no consensus on these cut-off values. Moreover, image

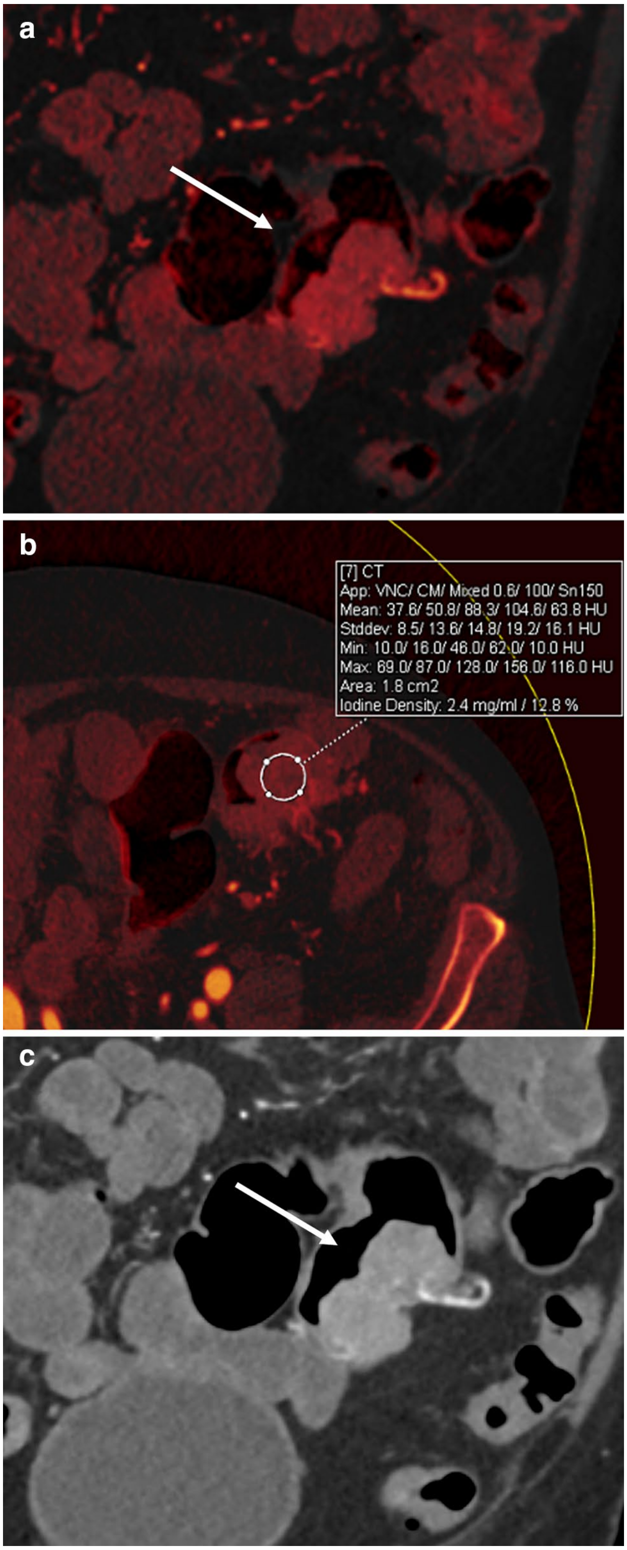


**Fig. 8** A 75-year-old male patient with lower gastrointestinal bleeding. Although active bleeding is not seen, arterial-phase iodine overlay images show a 3.7 cm sized mass which is demonstrated well at coronal (**a**) and axial (**b**) planes and coronal arterial-phase mixed image (**c**) (arrow). Iodine density is calculated to be 2.4 mg/mL within the tumor, while normal colonic wall iodine density is calculated to be 0.5 mg/mL

noise can be reduced by applying iterative reconstruction algorithms and increasing gantry rotation time [31]. Addition of iterative metal artifact reduction software may also help reduce beam-hardening artifact when DECT is used [48].

With dual-source dual-energy CT scanners, the X-ray beam source with higher energy level covers a smaller field of view (FOV). This problem can be overcome with the correct positioning of the patient [15, 17, 47].

Although it has been shown that the mean attenuation of VNC was similar to the mean attenuation of true unenhanced images, a difference between 5 and 20 HU has been reported previously. Thus, during interpretation of abdominal organs with VNC images, this difference should be taken into account [49]. Thus, it may be difficult to distinguish an underlying small bowel lesion from a focus of hemorrhage.

Moreover, the iodine density thresholds for the assessment of the enhancement ranges between 0.5 and 2 mg/mL, likely due to a combination of phase of imaging, type of scanner, and image processing algorithm. Thus, during the quantitative evaluation of bowel mass or ischemia, iodine uptake thresholds should be adjusted based on the type of scanner used and may not be applied universally [49].

Due to the limitations in DECT post-processing algorithms, calcium and barium may be quantified and displayed incorrectly. Improved material decomposition algorithms may help resolve this limitation [20, 49]. Also, oral ingested iodine from a previous CT study may mimic active bleeding.

Application of post-processing techniques to create virtual monochromatic images, virtual non-enhanced images, and iodine maps previously required additional work by the technologist or by the radiologist but has been automated in newer scanners [20]. These images can now be sent to PACS automatically, significantly improving workflow in image interpretation.

## Summary

The use of DECT with post-processing techniques offers several advantages over conventional CT for the evaluation of gastrointestinal bleeding. With the use of virtual non-enhanced images, the need for true unenhanced images can be eliminated, resulting in significant reduction in radiation dose. The use of iodine selective imaging and virtual monochromatic imaging may improve diagnostic confidence for the evaluation of gastrointestinal bleeding.

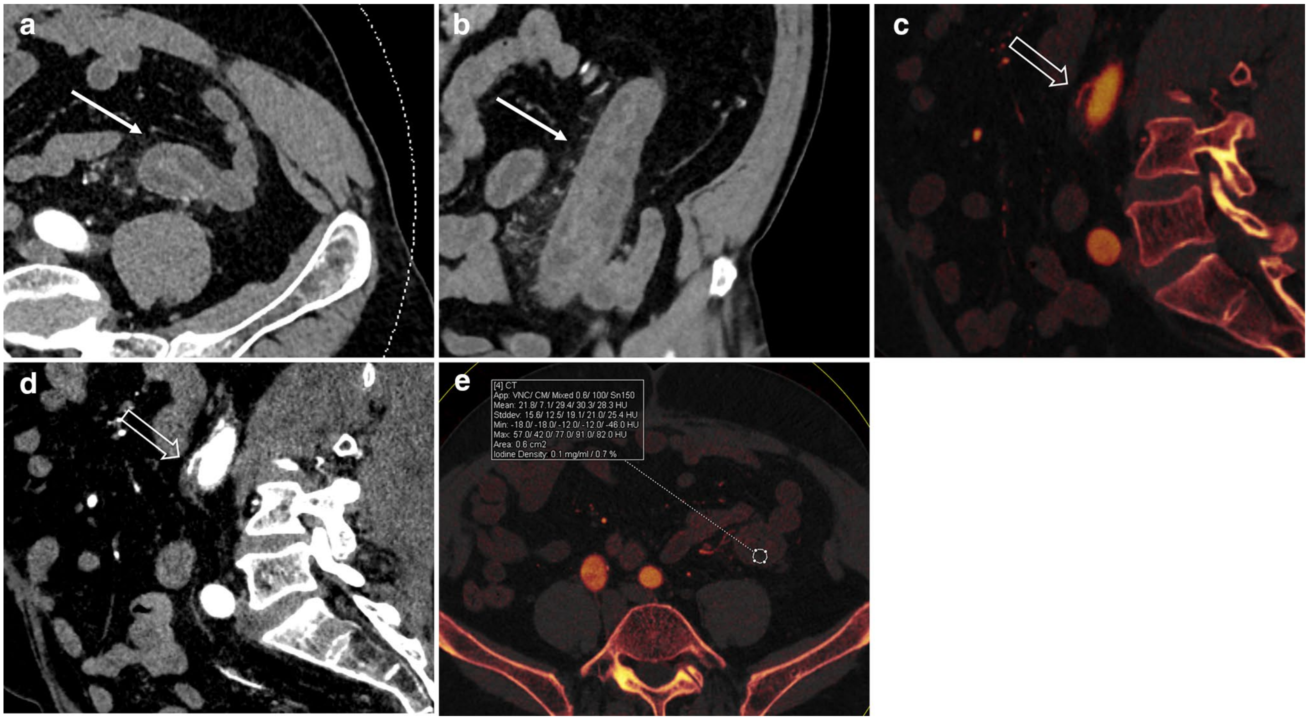


**Fig. 9** A 71-year-old male patient with a history of proctosigmoidectomy was presented with hematochezia. Diffuse wall thickening with surrounding fat stranding involving the distal descending colon (white arrow) is seen on axial (**a**) and coronal (**b**) arterial-phase mixed CT images. Also, sagittal iodine overlay image (**c**) and 40 keV-VMI (**d**) show occlusion of the inferior mesenteric artery (transparent arrow). On iodine overlay image (**e**), quantitative analysis of the iodine shows low iodine content within the thickened bowel loop. Iodine density is calculated to be 0.1 mg/mL within the thickened bowel loop, relatively decreased when compared to adjacent normal bowel loops (0.8 mg/mL). Colonoscopy revealed moderate to severe altered vascularity, congestion, erythema, friability, and shallow ulcerations, suspicious for ischemic colitis

## Compliance with ethical standards

**Conflict of interest** Authors Tugce Agirlar Trabzonlu and Amirhossein Mozaffary have received educational grants from Siemens Healthineers. Other authors declare that they have no conflict of interest.

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