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ADVANTAGES OF DUAL-ENERGY CT OVER CONVENTIONAL IMAGING TECHNIQUES IN THE ASSESSMENT OF GASTROINTESTINAL HAEMORRHAGE

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Abstract
Gastrointestinal bleeding is a life-threatening medical emergency that can be a cause of morbidity and mortality. In the case of gastrointestinal bleeding, the first choice for diagnosis is endoscopy. However upper endoscopy has the limitation of detecting the source of bleeding in the small intestine due to various etiologies. Therefore, contrast-enhanced computed tomography (CECT) can be performed as the first choice. However, it can be difficult for the conventional CT scanner to identify active gastrointestinal bleeding and differentiate between two materials having the same or very similar CT numbers. In addition, non-enhanced and several contrast-enhanced images are needed as multiple-phase scans to identify and diagnose gastrointestinal bleeding. This issue can be overcome by using dual-energy CT, which can acquire the changes in attenuation measurement by using two different spectra. As a result, it can be easy to differentiate between two material compositions.
Additionally, it offers a variety of post-processing applications like iodine mapping, virtual non-contrast (VNC) imaging, and low-energy monochromatic images. The purpose of this article is to describe the basic principles of dual-energy CT with post-processing applications and its modified scanning protocol in comparison with conventional CT scans, which can significantly reduce patient dose. It will also discuss the potential advantages of dual-energy CT in comparison with the various recommended imaging modalities in order to diagnose GI bleeding.

Introduction
Patients with active gastrointestinal hemorrhage are the most common medical condition in the emergency department, which can result in high mortality rates in critical conditions of up to 5–10% **(Gaiani et al., 2018; Sun et al., 2015)**. Depending upon the anatomical site of bleeding, it can be categorized into upper and lower GI bleeds. Upper GI bleeding refers to the bleeding present between the mouth and the Trietz ligament, whereas lower GI bleeding is present below the Trietz ligament up to the anus **(Gaiani et al., 2018)**. It is clinically classified into three categories overt, occult, and obscure bleeding. Overt (acute) bleeding can be seen as hematemesis (vomiting of blood), melena (black-colored stool), or haematochezia (rectal bleeding). Occult (chronic) hemorrhage can be identified by iron deficiency anemia or the basis of fecal occult blood test (FOBT) **(Federica et al., 2018)**. Obscure bleeding is defined as a recurrent type of bleeding in which the bleeding site is unidentified after the initial evaluation by endoscopy or colonoscopy **(Kim et al., 2019)**.It may be presented in overt or occult form **(Bull-Henry and Al-Kawas, 2013)**. Several factors such as bleeding site, bleeding rate, and amount of blood loss should be assessed to prioritize the correct diagnostic tool and intervention technique **(Steiner et al., 2011)**. The initial step in the diagnostic evaluation of acute gastrointestinal hemorrhage is to confirm the exact

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bleeding site as early as possible because it is necessary for effective haemostatic treatment **(Martin et al., 2017; Wells et al., 2018)**. Endoscopy is considered the primary diagnostic tool for upper gastrointestinal bleeding. While colonoscopy can be used in cases of lower gastrointestinal bleeding in more than 70% of patients, this data is reported in a wide range of 8-100% **(Artigas et al., 2013)**. There are several limitations regarding endoscopy and colonoscopy, such as the inability to reach the small intestine, obscure gastrointestinal bleeding (OGIB) by a clot, significant patient comorbidity like shock, and massive haemorrhage **(Mohammadinejad et al., 2021)**. The clinical utility of colonoscopy is limited due to inappropriate bowel preparation **(Strate and Gralnek, 2016; Wells et al., 2018)**. Capsule endoscopy can be recommended after negative results of endoscopy and colonoscopy, but detection of the bleeding source can be difficult **(Kim et al., 2019)**. Scintigraphy is a non-invasive procedure that can be a method of choice for diagnosing GI bleeding. However, it has several drawbacks, such as limited availability in emergencies, being time-consuming (Soto et al., 2015a), and undetected causes of bleeding **(Raman and Fishman, 2016)**. According to ACR (American College of Radiology) appropriateness criteria (2016), CT angiography is recommended as the next diagnostic tool after endoscopy procedures for non-variceal upper gastrointestinal bleeding **(Nimarta Singh Bhinder et al., 2017)**.CT angiography can detect the arterial and venous sources of bleeding with the use of multiphasic protocols.

Additionally, it does not need any oral contrast and bowel preparation. Thus, it can be performed without any delay in an emergency situation **(Wells et al., 2018)**. The images acquired by the conventional CT protocols may increase the patient dose, and several other problems like displacement of organs or bowels due to respiration, low diagnostic efficacy in cases of minor bleeding, and misinterpretation by inexperienced clinicians have been associated. Multiphasic scans can be avoided by the use of dual-energy CT scanners, resulting in a reduction in patient dose. Additionally, it can eliminate the need for non-enhanced images by replacing them with virtual non-contrast images **(Carney et al., 2019)**. In order to confirm gastrointestinal hemorrhage, this article will first review the different available imaging modalities to diagnose GI bleeding, then the basic working principles of dual-energy CT and the utility of its postprocessing applications. Additionally, a brief comparison of modified dual-energy CT scanning procedures and regular CT protocols will be included in this review paper.

Initial Assessment and Management Goals

Hospitalization is needed in cases of elderly patients, with severe comorbidities, or hemodynamic instability. The decision and priority of the diagnostic and therapeutic procedure to be performed depending on the clinical manifestation of gastrointestinal haemorrhage **(Steiner et al., 2011)**. A proper clinical history, physical examination, and laboratory testing are recommended to assess the bleeding location and its severity **(Strate and Gralnek, 2016)**. Red blood cells in acutely bleeding patients are typically normocytic. Chronic bleeding is suggested by microcytic red blood cells or iron deficient anemia **(Mortensen et al., 1994).** Confirmation of the bleeding site is important for management. UGIB is confirmed by the presence of hematemesis (vomiting of blood), melena (black-colored stool), raised blood urea nitrogen-creatinine ratio (>30:1), and positive results of nasogastric tube aspiration (presence of blood in gastric lavage) **(Lee and Laberge, 2004)**. UGIB is excluded in cases of the absence of aspirated bleeding and the presence of bile **(Lee and Laberge, 2004; Steiner et al., 2011; Wells et al., 2018)**. Endoscopy should be performed at the initial stage in cases of suspected upper gastrointestinal bleeding up to the Trietz ligament **(Chang et al., 2011; Kerr and Puppala, 2011)**. Hematochezia is indicative of LGIB or colorectal source of bleeding, but it can be present in the upper gastrointestinal source of bleeding in 10-15% **(Farrell and Friedman, 2005; Zimmerman and Curfman, 1997)**. In acute or overt GI bleeding, rapid evaluation and resuscitation are necessary along with the assessment of hemodynamical stability (Barkun et al., 2010) (27-kim). After the initial endoscopy examination, if the patient is

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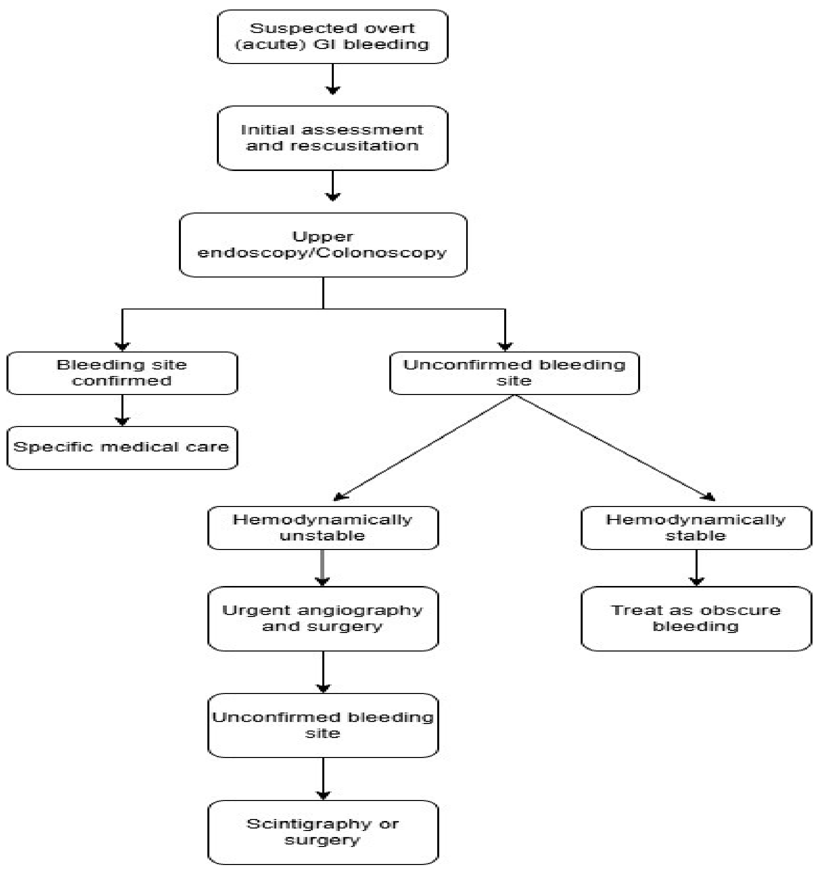
hemodynamically unstable then the patient should go further for urgent surgery or alternate imaging techniques as depicted in Fig.1A **(British Society of Gastroenterology Endoscopy Committee, 2002).** While repeat endoscopy should be considered in hemodynamically stable patients. Occult GI bleeding with positive FOBT and anemia should be evaluated with both upper endoscopy and colonoscopy, whereas FOBT without anemia should be evaluated with colonoscopy only (Fig.1B). A confirmed bleeding site requires particular medical care, while an unconfirmed source requires further investigation **("American Gastroenterological Association medical position statement," 2000)**. Fig. 1C shows that the repeat upper endoscopy and/or colonoscopy is the recommended initial step in cases of obscure bleeding to confirm the source and check the reach of endoscopes **(Mönkemüller et al., 2008)**. Using colonoscopy in conjunction with deep enteroscopy techniques (e.g. Double-balloon enteroscopy) showed better outcomes in the diagnosis of obscure GI bleeding **(Carey et al., 2007; Estévez et al., 2006)**. Deep enteroscopy is generally considered at the time of intervention after capsule endoscopy **(Rockey, 2010)**. Alternate techniques like CT/MRI enterography, radionuclide imaging, laparoscopy, etc. can be used in cases of undetected bleeding sources **(Kim et al., 2019)**.



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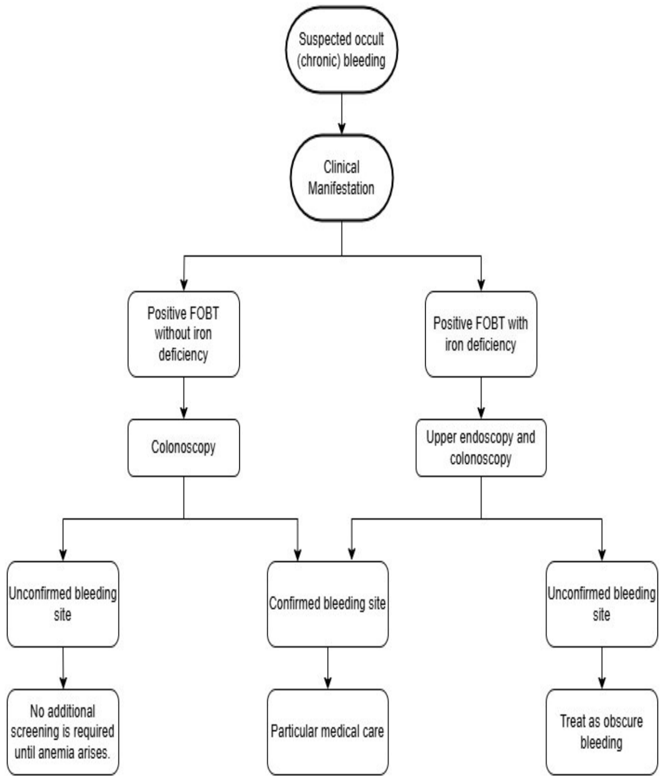

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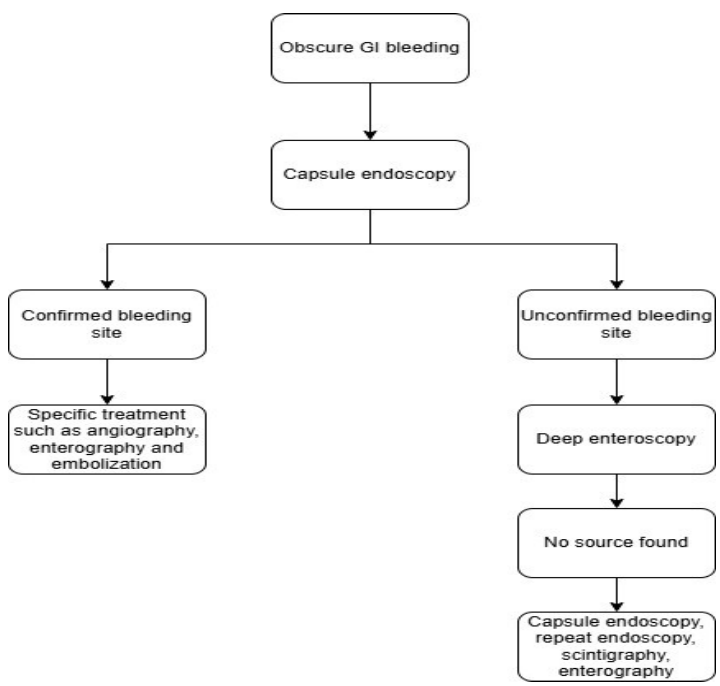

C

Fig.1 Diagnostic approach for the different types of GI bleeding. Suspected acute GI bleed (A); Suspected occult GI bleed (B); Obscure GI bleed (C)

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Endoscopy

Endoscopy is considered an initial diagnostic tool to identify the source of bleeding in cases of upper gastrointestinal bleeding (UGIB), especially in urgent conditions. It allows the collection of histologic specimens and several therapeutic interventions like hemostasis simultaneously for management **(Gralnek et al., 2015; Green et al., 2005; Kerr and Puppala, 2011; Lee and Laberge, 2004)**. Endoscopy has a sensitivity of 92–98% and a specificity of 3-100% **(Wells et al., 2018)**. Although upper endoscopy can be ineffective due to comorbidities, obscure visibility due to the presence of clots, and challenging anatomical locations (Carney et al., 2019). It is ineffective for the distal part of the duodenum (Johnson, 2012; Vreeburg et al., 1997) **(8,9-artigas)**. If the absence of UGIB is confirmed by endoscopy, colonoscopy is recommended for evaluation of lower gastrointestinal bleeding (LGIB) **(Strate and Gralnek, 2016)**. A colonoscopy may be difficult to perform and result in an incomplete evaluation because adequate bowel preparation is needed. Hence, it is not recommended in emergencies **(Wells et al., 2018)**. The detection rate of colonoscopy varies widely, ranging from 8-10 % **(Artigas et al., 2013; Cappell and Friedel, 2008)**. A complication rate of 0.03-2.14% with a mortality rate of 0.3% has been reported, and it can be higher in cases of urgent colonoscopy **(Artigas et al., 2013)**. Due to a failure rate of 8.5%, longer time duration, and difficulty in emergencies, radiological examinations are more feasible options **(Clerc et al., 2017; Jacovides et al., 2015; Rondonotti et al., 2005)**. Capsule endoscopy is another sensitive and non-invasive method to identify small bowel diseases and occult GI bleeding, with a diagnostic yield of 55–92%. **(Amit et al., 2004; Chotiprashidi et al., 2005; Kim et al., 2019; Pennazio et al., 2004)**. It is generally time-consuming and not recommended in cases of small bowel stricture (Barnert and Messmann, 2009a). It can be ineffective and have limited ability to identify bleeding sources due to battery life, poor field of view, and the presence of stools **(Barnert and Messmann, 2009b; Strate and Gralnek, 2016)**. Table 1 represents the advantages and disadvantages of endoscopy procedure

Table 1: Advantages and disadvantages of endoscopy

Advantages	Disadvantages
Safe and effective	Associated risks such as perforation, aspiration and haemorrhage
Widely available	Bowel preparation required for colonoscopy
Assessment of possible risk for recurrent bleeding	Lower detection rate for LGIB.
Allows treatment for the nonbleeding vessels at risk	Unable to examine the majority of the small bowel
Allows extraction of tissue sample from lesion at bleeding site	The bleeding site may become obscured by severe bleeding

Scintigraphy

It is the most sensitive method to detect active bleeding even at a low bleeding rate of 0.1–0.5 ml/min **(Alavi et al., 1977)**. It has a sensitivity of 93% and 98% specificity in the detection of low bleeding rates **(Zuckier, 2003)**. It can be performed by using either technetium-99m (99mTC) sulphur colloid or red blood cells (RBC) based radiopharmaceuticals **(Barnert and Messmann, 2009b; Farrell and Friedman, 2001; Jj and Ls, 2001)**. Labelled RBCs allow frequent scanning for up to 24 hours as compared to sulphur colloid, which has 5–10 minutes of half-life. For imaging with 99mTC sulfur colloid, the patient should be actively bleeding during image acquisition; hence, reinjection may be necessary in the case of a repeat scan with intermittent bleeding **(Kim et al., 2019)**. The main disadvantages of scintigraphy include poor results in visualizing bleeding sites,

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limited availability, pre-procedure delay, and the unavailability of information about the cause of bleeding even when results are positive **(Es et al., 2011; Jm and Me, 1990; Soto et al., 2015)**. It can result in misdiagnosis and errors in therapeutic interventions **(Jm and Me, 1990)**. Table 2 represents the advantages and disadvantages of scintigraphy procedure.

Table 2: Advantages and disadvantages of scintigraphy

Advantages	Disadvantages
Non-invasive	Ionizing radiation
High sensitivity	Non-therapeutic
Detection of intermittent bleeding	Time-consuming procedure
Patient preparation is not required	Inaccurate localization of the bleeding site
Detection of both arterial and venous source.	Not widely available
	Not optimum for UGIB

Catheter Angiography

For catheter angiography to be performed, the bleeding rate should be at least 0.5–1.0 ml/min. It is a beneficial tool that provides diagnostic information and allows therapeutic interventions as well **(Nusbaum and Baum, 1963)**. It has a sensitivity of 42–86% with a specificity of nearly 100%, and bowel preparation is not mandatory. It allows the use of embolic agents and vasoconstrictive drugs at the bleeding site to limit bleeding **(Vernava et al., 1997)**. The celiac artery and superior mesenteric artery are primarily assessed in suspected GI bleeding. Extravasation of contrast into the bowel lumen indicates confirmation of GI bleeding **(Mellinger et al., 2011)**. The main limitations of this study include false negative results, poor results in irregular arterial anatomy, and a slow bleeding rate **(Carney et al., 2019; Soto et al., 2015)**. The major complications have been associated with therapeutic interventions, which include bowel ischemia and non-targeted embolization **(Funaki et al., 2001)**. Several other complications include pseudoaneurysm, access site bleeding, arterial dissection, spasm, and allergic reactions **(Lisa, 2005; Vernava et al., 1997)**. The induction of serious complications is generally rare, with an incident rate of 2-5% **(Tan et al., 2008; Walker et al., 2012)**. Table 3 represents the advantages and disadvantages of catheter angiography technique.

Table 3: Advantages and disadvantages of catheter angiography.

Advantages	Disadvantages
Allows therapeutic interventions	Ionizing radiation
Can be performed in hemodynamically unstable patients	Contrast allergic reactions
Bowel preparation is not required	Low accuracy in slow bleed detection.
Accurate in exact site localization and cause	Low accuracy in irregular arterial anatomy Side effects from embolization and vascular access

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Computed Tomography

Computed Tomography (CT) is a preferred choice for stable patients and is widely available in emergency settings in hospitals **(Carney et al., 2019; Gaiani et al., 2018)**. It is recommended when the diagnostic efficacy of endoscopy and colonoscopy is low in confirming the bleeding site **(Mortensen et al., 1994)**. It is effective in identifying variable anatomical sites and sources of bleeding, either arterial or venous. It is considered the primary diagnostic method in cases of acute lower GI bleeding **(Wells et al., 2018)**. CT is a minimally invasive procedure that has high sensitivity even when the patient is not actively bleeding and allows for the acquisition of data within a short period **(Carney et al., 2019; Gaiani et al., 2018)**. The required bleeding rate to be detected by CT is less than that of CA, 0.3–0.5 ml/min. Hence, it is more sensitive than catheter angiography but less sensitive than scintigraphy **(Tew et al., 2004; Wg and Rg, 2003)**. A sensitivity of 86% and specificity of 95% have been reported in cases of acute GI bleeding **(Chua and Ridley, 2008)**. Two methods can be employed by using this modality: either CT angiography (CTA) or multiphasic CT enterography (CTE). CTA is useful in treatment planning since it is typically chosen in emergencies where quick confirmation of GI bleeding is required. In cases of occult GI bleeding in hemodynamically stable patients, multiphasic CTE is recommended. Additionally, it can be performed on outpatients who can tolerate positive oral contrast media **(Wells et al., 2018)**. Multiphasic CTE uses 1.5–2 liters of neutral contrast agent for adequate distention of the bowel **(Carney et al., 2019)**. Active GI bleeding is confirmed by the presence of hyperattenuating extravasated contrast media in the bowel lumen **(Laing et al., 2007)**. However, these techniques involve some limitations such as no therapeutic benefit and allergic reactions from intravenous contrast media **(Kodzwa, 2019)**. Application of post-processing techniques during abdominal scans has been described; as a result, it can reduce the patient dose significantly and variation in DECT protocols can also be implemented (Im et al., 2013a). Advancement in DECT can play a significant role compared to single-source multidetector CT in the diagnosis of GI bleeds **(Tugce et al., 2020)**. Table 4 represents the advantages and disadvantages of Computed Tomography (CT).

Table 4: Advantages and disadvantages of Computed Tomography (CT)

Advantages	**Disadvantages**
Non-invasive	Ionizing radiation
Rapid imaging	Contrast allergic reactions
High sensitivity Not	optimum for UGIB
Easy to perform	Non-therapeutic procedure
Widely available	Detection of intermittent bleeding
Accurate in exact site localization and cause	False-positive results in pre-existing high-attenuation materials.
Allows better treatment planning	

The basic principle of dual-energy CT

The acquisition of images in CT depends on the attenuation of the x-ray beam transferred through the patient's body. This attenuation is caused by two primary interactions, i.e., the photoelectric effect and Compton scattering. In Compton scattering, an incident radiation photon interacts with the outermost electrons and ejects them from the outermost shell. While in photoelectric absorption, an incident photon interacts with strongly bounded K-shell electrons and transfers their energy. This

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interaction results in the ejection of the innermost K-shell electrons **(Marin et al., 2014)**. The photoelectric effect depends on the binding energy of the K-shell, and the probability of this interaction increases when the energy of the incident photon approaches the K-shell binding energy **(Kruger et al., 1977)**. The energy of photons above the K-shell binding energy results in a sudden rise in attenuation because the probability of absorption increases if photon energy exceeds the K-shell threshold energy level, hence referred to as the "K-edge" **(Ali et al., 2017)**. The dual-energy CT uses two different photon spectra produced by either a single X-ray tube with rapid voltage switching (Fig.2A) or two different X-ray sources (Fig.2C) that generally operate at 80 kVp and 140 kVp **(Johnson, 2012)**. Materials having different K-edge absorption show differences in attenuation at two distinct energy spectra resulting in better separation from each other. Another fundamental requirement for better material differentiation using DECT is adequate spectral separation between the acquired high- and low-energy data **(Heye et al., 2012; Sodickson et al., 2021).**

The difference in x-ray attenuation is expressed by CT numbers in Hounsfield units while using conventional single-source CT **(Curry, 1990)**. The CT number is determined by the linear energy coefficient of the voxel, which is influenced by the mass attenuation coefficient and density of the material. As a result, conventional CT cannot differentiate between two materials due to the overlap of attenuation **(McCollough et al., 2015)**. The difference in CT numbers depends on differences in characteristic CT number ratio, separating high- and low-energy spectrums, and effective atomic numbers of material (Qu et al., 2011). Due to different K-edge absorption in materials like calcium and iodine at different energy spectra, DECT can easily differentiate these materials from soft tissues **(Heye et al., 2012; Marin et al., 2014).**

Five different technical approaches have been developed to produce the dual-energy dataset such as sequential scanning, single source rapid voltage switching, dual source type system, multilayer detectors, and photon-counting detectors. In sequential scanning, two datasets are acquired in different tube voltages. It may be acquired in step and shoot method (axial mode) or spiral mode. The single source rapid switching approach uses a single x-ray source in which voltage is switched between high and low values, and datasets are acquired two times for each projection (Fig.2A)**.** Dual-source CT is a simple method that uses two tubes operating at different voltages and associated detectors positioned orthogonally within a single gantry (Fig.2B). Both systems can acquire data simultaneously with independent voltage, current, and filters. In a layer detector (Fig.2C), the sensitivity of two layers is determined by the scintillator. Another approach is the layer detector technology which uses a detector that can resolve energy and has a single tube's polychromatic spectrum. The scintillator materials like cesium iodide, gadolinium oxysulfide, and zinc selenide in the layer detectors control the sensitivity of the two layers. While photon-counting detectors that use CdZnTe (Cadmium Zinc Telluride) as an example may determine the energy of every single hitting photon. It can distinguish between more than two photon energies **(Johnson, 2012; Marin et al., 2014; Qu et al., 2011).**

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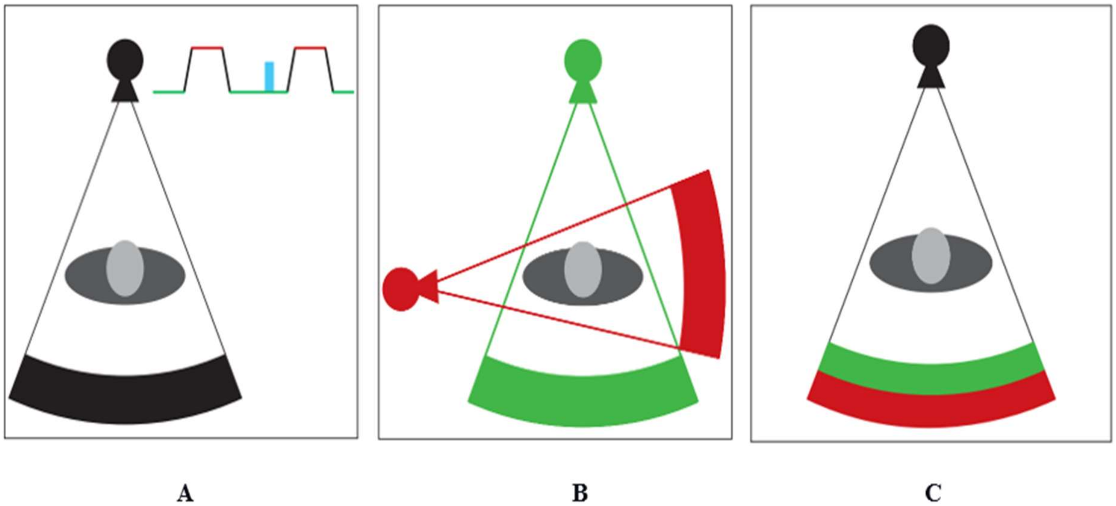

Fig.2 Different technical approaches for dual-energy CT scanner. Single source rapid voltage switching (A); Dual-source CT configuration (B); Layer detector technology (C) (T. R. C. Johnson, 2012)

Standard CT protocols

The standard protocols of CT angiography are designed in a way that shows maximal sensitivity towards active extravasation within the bowel. The procedure is carried out without the administration of oral contrast and images are acquired during multiphasic scanning. Multiphasic scans are usually performed with pre-contrast, arterial, and portal venous phases. **(Carney et al., 2019; Soto et al., 2015; Wells et al., 2018)**. These are the most widely adopted protocols, as there are a wide variety of protocols suggested in different literature **(Fatima et al., 2015)**.

The recommended acquisition parameters for a 64 × 0.625 mm detector configuration include thickness, 1 mm, with a reconstruction interval of 0.8 mm; pitch factor, 0.828; rotation time, 0.5 seconds; and tube voltage, 120 kV, with automatic tube current modulation in the x-, y-, and z-axis directions. The scan should include the complete abdomen and pelvis, from the diaphragm to the inferior pubic ramus **(Artigas et al., 2013; Wells et al., 2018)**.

Intravenous contrast material is administered through an antecubital vein with a power injector at a rate of 4 mL/sec, followed by a chaser of 50 mL of saline, the total volume of contrast material typically varying between 100 and 125 mL of an agent high in iodine concentration (>300 mg of iodine per milliliter). The arterial phase images are usually obtained by using automated bolus triggering, starting when the attenuation coefficient in the proximal portion of the abdominal aorta reaches 150 HU. Late arterial phase is acquired at 10 seconds after bolus tracking followed by portal venous phase images are then obtained 40–60 seconds later (ie, 70–90 seconds after the beginning of the injection of contrast material) (Guimarães et al., 2010; Sun et al., 2015).

Oral contrast is not recommended routinely in the evaluation of acute GI bleed because positive contrast material may result in misinterpretation of bleeding and water or other neutral contrast media may dilute the extravasated intravenous contrast material, thereby decreasing the ability to identify the site of bleeding **(Artigas et al., 2013; Carney et al., 2019)**. It can cause aspiration during sedation and can result in delayed scanning during the urgent intervention **(Dane et al., 2023)**.

Scanning with multidetector CT starts with pre-contrast (unenhanced image) to identify any preexisting intraluminal hyperattenuating material, such as foreign bodies, opaque pills, hemostatic clips, suture material from previous surgery, residual barium **(Geffroy et al., 2011; Johnson, 2012)**, intestinal hematomas; uncoagulated blood generally exhibits 1–16 HU, whereas coagulated

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blood typically exhibits 16–41 HU that might be misinterpreted later as active bleeding (Okamura-Kawasaki et al., 2023).

The arterial phase allows the confirmation of extravasation and is useful for determining the responsible vessel. The portal venous phase can detect slow or delayed bleeding **(Carney et al., 2019)**. The delayed phase confirms the increase or spread of extravasation into the intestinal tract. Table 5 represents the comparison of conventional CT protocols for both overt and occult GI bleeding. While Table 7 represents the comparison between conventional CT protocols and dual-energy CT protocols for GI bleeding.

Table 5: Comparison of conventional CT protocols for overt and occult GI bleeding.

	Overt bleeding (CTA protocol)	**Occult bleeding (CTE protocol)**
Intravenous contrast	80-130 ml (370-400 mg I/mL)	80-130 ml (370-400 mg I/mL)
Rate of injection	3.5-4 ml/sec with 18G cannula	3.5-4 ml/sec with 18G cannula
Use of Normal Saline (N.S.)	40 mL	40 mL
Oral contrast media	No	1350-2000 mL of neutral contrast media 1 hour prior to examination
Scanning coverage	From diaphragm to pubic symphysis	From diaphragm to pubic symphysis
Scanning phases	Arterial phase (bolus tracking) Venous phase (70–90 s after injection) Late phase (5 min after injection) (optional)	Late arterial phase (10 s after bolus trigger) Enteric phase (50 s after injection) Late venous phase (90 s after injection)

Dual-energy CT protocol

The images can be acquired by arterial and portal venous phases without the use of any oral contrast media. Although it may vary according to different institutions **(Wells et al., 2018)**. Neutral oral contrast can be used to evaluate the lumen and bowel wall with better contrast. Generally, oral contrast is avoided because it can dilute the extravasated contrast media and it can delay the study due to waiting time **(Artigas et al., 2013; Ilangovan et al., 2012; Wells et al., 2018)**. **(Tugce et al., 2020)** used the combined protocol of CT angiography and multiphasic CT enterography which used neutral contrast media and images acquired after 45-60 minutes after oral administration. Post-processing is done after CT acquisition to create virtual non-contrast images, iodine overlay images, and virtual monochromatic images. The latest generation of scanners can reconstruct and automatically submit many of these processed images to a picture archiving and communication system (PACS), resulting in a significant reduction in interpretation time **(Tugce et al., 2020)**.
(Okamura-Kawasaki et al., 2023) published their study using protocols for 64 slices dual layer detectors, which include the administration of 530 mg/kg contrast media. The injection time for single-phase CT was 50 sec, while 30 sec for two-phase CT. Scan time starts at 20 sec after injection for single-phase, where arterial phase and delayed phase were performed after 10 sec and 80 sec after injection respectively.
(Wells et al., 2018) used iohexol (350 mg/ml) as contrast media with bolus tracking at the descending aorta. The threshold was set at 150 HU for the arterial phase and portal venous phase acquired at the post-contrast delay of 70 sec.

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(Martin et al., 2017) used Imeron 400 (Iomeprol) as a contrast media with bolus tracking. The arterial phase was acquired at 5 sec after reaching 120 threshold HU in the descending aorta, followed by the portal venous phase at 70 sec after initiation of contrast media injection.

Table 6: Representation of dual-energy CT protocols used by various researchers in their study

Dual-energy CT protocol							
Researcher	**Oral contrast**	**Intravenous contrast**	**Unenhanced phase**	**Arterial phase**	**Portal venous Phase**	**Delayed phase**	**Technique**
Tugce et al.	Yes	Iopamidol 370 mgI/mL	Yes	Yes	Yes	-	Bolus Tracking
Okamura et al.	No	530 mg/kgI	No	Yes	-	Yes	Time Bolus
Wells et al.	No	Iohexol (350 mgI/ml)	No	Yes	Yes	-	Bolus Tracking
Martin et al.	No	Imeron 400 (Iomeprol)	No	Yes	Yes	-	Bolus Tracking

Table 7: Comparison of conventional CT protocols and dual-energy CT protocols for GI bleeding.

Comparison of conventional CT protocols and dual-energy CT protocols		
Phase	Conventional CT	Dual-energy CT
Non-enhanced	Yes	No
Arterial	Yes	Yes
Portal venous	Yes	Yes

Post-processing application

Iodine overlay images

Substances like fat, calcium, iodine, and water can be distinguished by imaging at two different energies using their different linear attenuation coefficients. The chemical composition of objects and their iodine content can be determined and measured by mathematical algorithms: (a) three-material decomposition; (b) two-material decomposition **(Marin et al., 2014; Tugce et al., 2020)**. By using three material decompositions, the iodine composition can be selectively identified from the absorption characteristics of three idealized materials such as soft tissue, fat, and iodine for most of the abdomen cases **(Tugce et al., 2020)**. It is used to create virtual non-contrast-enhanced (VNC) images by subtraction of iodine content from a dataset and display as iodine content separately on iodine maps or can appear as a superimposed color-coded map on the gray-scale virtual non-enhanced image **(Urvi et al., 2016)**. Iodine attenuation can be evaluated in Hounsfeld units (HU) and concentration in milligrams per milliliter, whereas the two-material decomposition algorithm can only demonstrate iodine concentration in milligrams per milliliter **(Tugce et al., 2020)**. Iodine overlay images can be used for both qualitative and quantitative assessments of iodine content by separating the contrast-enhanced Hounsfield unit values into virtual nonenhanced and iodine-enhanced components **(Urvi et al., 2016)**. It can be seen from Fig.3 that iodine content can be differentiated from ingested foreign material (bismuth) having a different material composition. Iodine can be seen as color-coded (yellow arrow), and non-color-coded signals in iodine overlay images represent ingested foreign material, as it is constant in the VNC image **(Sodickson et al., 2021)**.

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A **B** **C**

Fig.3: Elimination of iodine content from VNC images (aron Dickson). In conventional image (A), hyperattenuating signals can be from contrast extravasation or foreign materials. In an iodine overlay image (B), a color-coded signal (yellow arrow) represents iodine content (contrast extravasation), and it can be removed from VNC images (C). The blue arrow in the VNC image represents ingested foreign material (bismuth) (Tugce et al., 2020).

Virtual mono-energetic imaging

Dual-energy CT allows for the acquisition of images using a mono-energetic beam instead of the polychromatic beam that is actually used in conventional CT **(Urvi et al., 2016; Wells et al., 2018)**. At low KeV levels of the virtual mono-energetic beam, the x-ray attenuation of iodine increases specifically when it reaches 33.2 KeV. As a result, radiographic contrast between tissues increases, and iodine can be visualized effectively (Fig.7) **(Agrawal et al., 2014; Yu et al., 2012)**. An energy level of 60–77 KeV is considered optimal for better contrast-to-noise ratio (CNR) of iodine and soft tissue evaluation. While the small bowel can be evaluated effectively with a high CNR at 77 KeV, this energy level represents the halfway point between energies of two x-ray spectra of DECT (80 kVp and 140 kVp) that can be produced either by rapid switching or using two x-ray sources. A minimal amount of noise is produced in monochromatic images by using this energy range. Image quality produced at the same radiation dose using the mono-energetic spectrum is generally higher as compared to single-energy CT using 120 kVp **(Agrawal et al., 2014; Aran et al., 2014; D'Angelo et al., 2019; Matsumoto et al., 2011; Yu et al., 2012, 2011).** Fig.4 describes the better visualization of iodine content at a low KeV level (40 KeV) using VMI, which represents active bleeding.

Fig.4: CT images of 62-year-old women acquired by performing portal venous phase and delayed phase. High attenuating signal (white arrow) observed at gastric pylorus in portal venous phase (a)**. Slight enlargement of a high attenuating area is observed at the delayed phase** (b)**. Better visualization of contrast spread is observed in VMI of the delay phase at 40 KeV (c)**. **(Okamura-Kawasaki et al., 2023)**

Due to better attenuation at low KeV levels, the amount of required contrast media can decrease. Vascular anatomy and vascular lesions can be visualized accurately by VMI. The quality of images

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using conventional CT in patients with metal implants is very poor, and imaging is generally considered challenging. The virtual monochromatic images at higher energy levels (95–150 kVp) can decrease both metal artifacts and beam-hardening artifacts, thus improving image quality in the presence of metal **(Fabian et al., 2011; Lee et al., 2007; Murray et al., 2019; Tugce et al., 2020)**.

Diagnosis of acute GI bleeding with DECT

Fig. 5 describes the interpretation method to diagnose GI bleeding. If the a high-intensity signal (hyperattenuation) is noticed in the low KeV (40-60) enhanced phase but not on VNC images suggests active extravasation of contrast media i.e. active GI bleeding. Hyperattenuating areas on both types of images represent hyperattenuating intestinal contents if their attenuation value (Hounsfield unit) is around or similar to the value of the aorta. If it possesses the attenuation of 45–70 HU, (higher than any typical intraluminal contents and lower than aorta) and does not alter in appearance between the VNC images and the enhanced images, then it can be suggestive of sentinel clots or ingested content **(Guglielmo et al., 2021)**.

If a high-intensity signal is noticed in the enhanced phase and is represented as a color-coded signal in an iodine overlay image, generally it is suggestive of iodine content. Active GI bleeding is confirmed if it is eliminated from the VNC images (Fig.6,7,8). Active GI bleeding is unlikely to occur if the hyperattenuating signal does not disappear from VNC images and negative iodine content is observed in iodine overlay images (Fig.10) **(Tugce et al., 2020; Urvi et al., 2016)**.

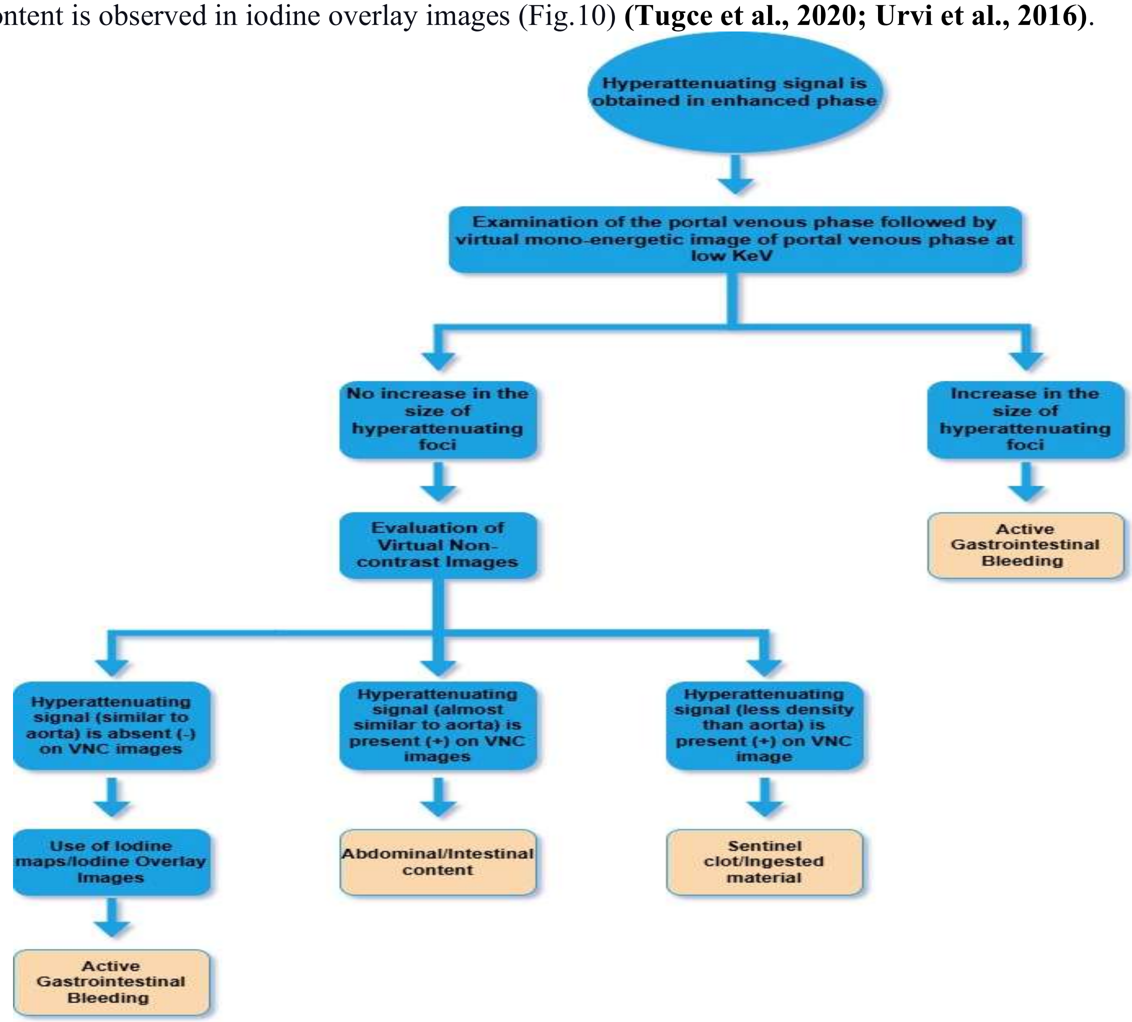

Fig.5 The flowchart represents the suggested interpretation method for the diagnosis of overt GI haemorrhage.

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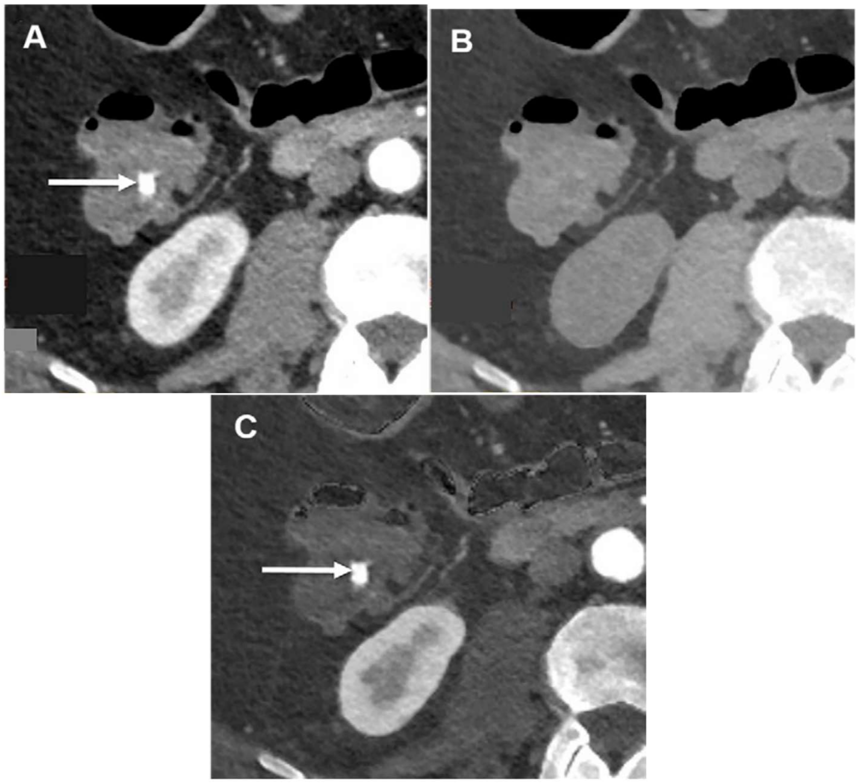
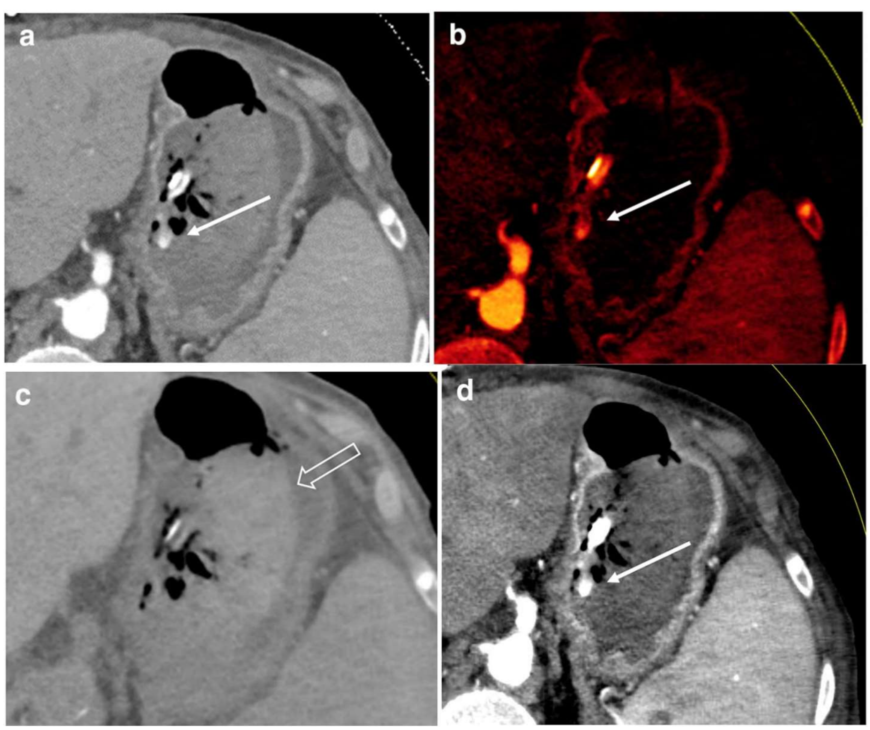


Fig.6 Identification of GI bleeding in a 60-year-old man experiencing severe stomach discomfort. A hyperattenuating signal in the ascending colon is observed during single-phase CT image acquisition (A). **Virtual non-contrast images do not show the hyperattenuating signal at the exact location in ascending colon** (B). **The iodine map confirms the presence of iodine content**, **which confirms the active contrast extravasation i.e. active gastrointestinal bleeding (C). (Dane et al., 2023)**



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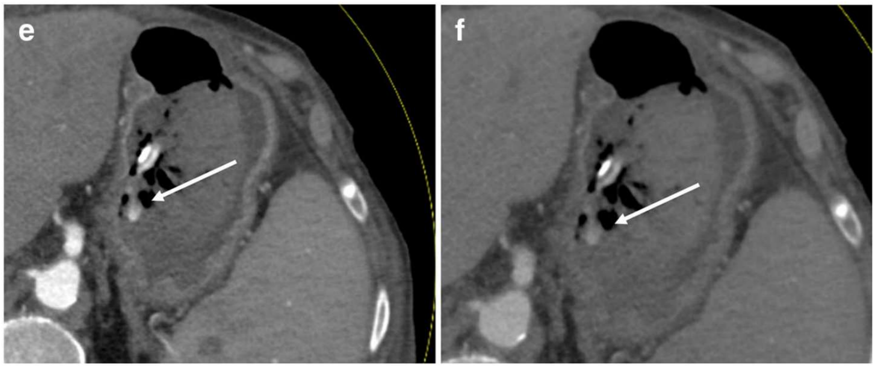

Fig.7 Diagnosis of active gastrointestinal bleeding in a 92-year-old female patient arrived with hematemesis and decreased hemoglobin. The hyperattenuated (white arrow) signal on the axial enhanced phase (arterial) CT image is suggestive of active bleeding (a). The iodine mapping displays the iodine concentration within the hyperattenuating area, (b) which is removed from the VNC image (c). At 40 keV VMI images (d), active extravasation is more evident (high-intensity signals) than with VMI at 70 keV (e) and 100 keV (f) due to high attenuation at low KeV radiation photon. (Tugce et al., 2020)

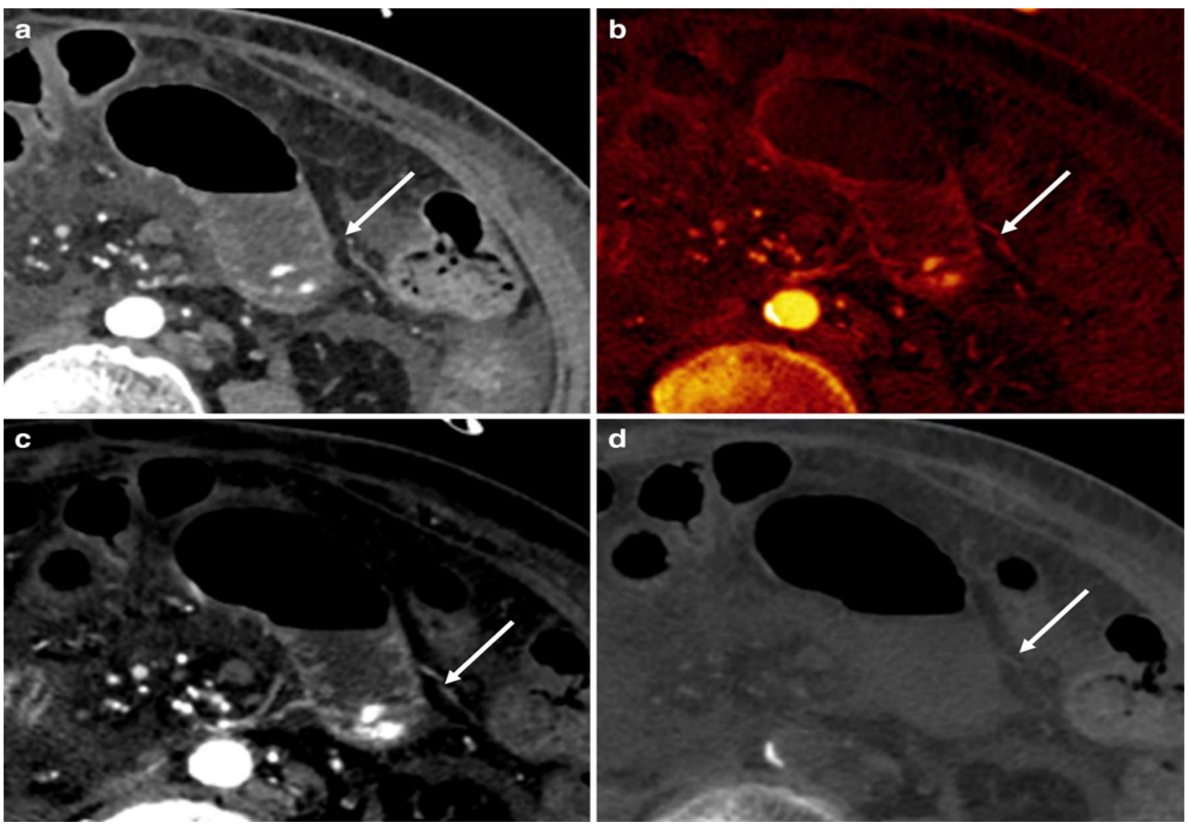

Fig.8 Confirmation of active GI bleeding in a 63-year-old female. Hyperattenuation observed in arterial phase (a) iodine uptake is confirmed in the iodine overlay image (b) visualization of iodine extravasation from the bleeding source is enhanced in the 40 KeV virtual monoenergetic image (c) iodine signal is removed from the VNC image (d). (Tugce et al., 2020)

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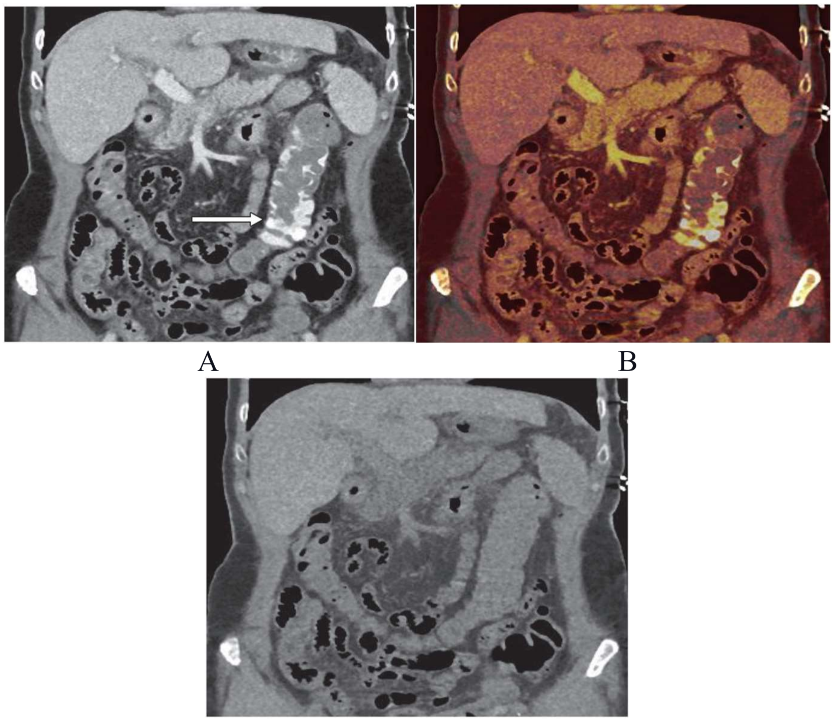

C

Fig.9 Detection of active lower gastrointestinal bleeding. The coronal image of the portal venous phase shows hyperattenuating signals (white arrow) in the distal transverse colon (A)**. These signals endure in the coronal plane iodine overlay image** (B) **but disappear on the coronal virtual non-contrast image (C). (Urvi et al., 2016)**

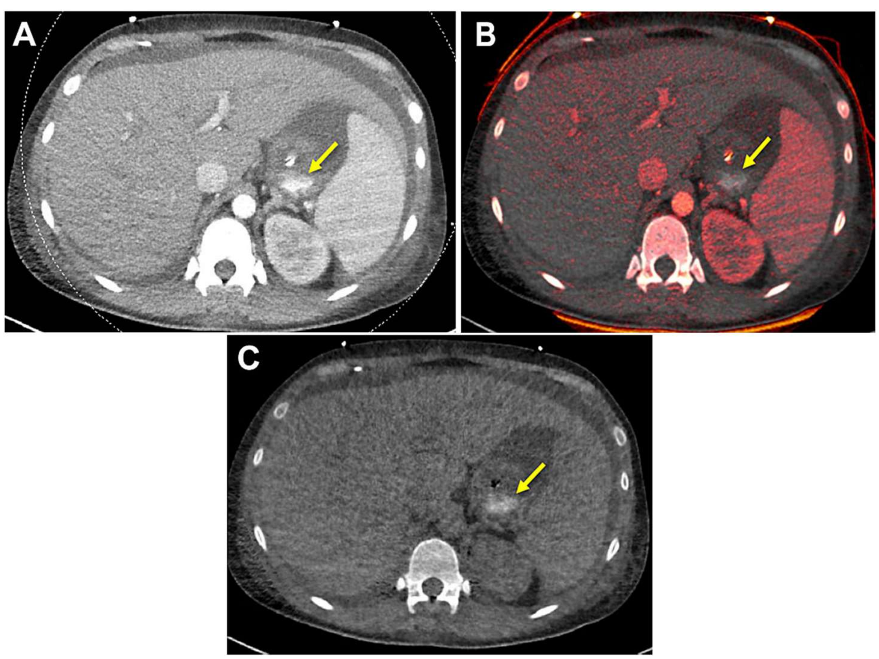

Fig.10 Confirmation of the presence of hyperattenuating material. Enhanced phase shows the hyperattenuating material present in the gastric lumen (yellow arrow) (A). Iodine overlay image confirms the absence of iodine content on the same exact location (B). VNC image

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represents the hyperattenuating signal in the corresponding region which confirms the absence of contrast extravasation. (Shaqdan et al., 2019)

Advantages of dual-energy CT

DECT is extremely beneficial when assessing gastrointestinal hemorrhage. Further post-processing methods, such as color iodine overlay pictures, low-kiloelectron voltage virtual monoenergetic images, and reconstructing iodine maps, can enhance the visibility of contrast material extravasation **(Dane et al., 2023; Urvi et al., 2016)**. Pre-contrast unenhanced images can be virtually created and replaced by VNC images. The location information of the organs in VMIs and iodine maps is analogous to VNC images and can be compared without being affected by bowel movements or breathing. As a result, it can demonstrate extravasation more clearly and allow a more confident diagnosis. These images are reliable without gastrointestinal bleeding (Im et al., 2013a; Mohammadinejad et al., 2021; Sun et al., 2015). In modified DECT protocols, pre-contrast scans can be omitted, whereas conventional CT protocols include pre-contrast and post-contrast two phases. These protocols can reduce the exposure level and decrease patient doses by up to 30% without using the pre-contrast phase **(Im et al., 2013b; Sun et al., 2015)**. However, it can vary in the range of 19% to 50%, depending on the number of phases acquired in the scanning protocol **(Baliyan et al., 2019; Sun et al., 2015; Tugce et al., 2020)**.

Limitations

Dual-energy CT has drawbacks despite offering a number of benefits for assessing gastrointestinal hemorrhage. During imaging of large patients, large image noise can be produced as a result of x-ray beam attenuation at low kilovoltage, especially when there is fast kilovoltage switching since the flux of the x-ray photon cannot be increased. This problem can be solved by using a high energy x-ray beam (use of high voltage kVp) for larger patients **(Parakh et al., 2021; Wortman and Sodickson, 2018)**. Additionally, by using iterative reconstruction methods and lengthening the gantry rotation period, picture noise may be decreased **(Patel et al., 2017)**. At lower kilovoltage peak values, photon starvation and beam hardening are mainly caused by restricted x-ray beam penetration. Low-attenuating streaks occur from this, especially during scanning with the down arms, as well as in close proximity to metallic implants and thick bone surfaces **(Wortman and Sodickson, 2018)**. Additionally metal artifact reduction software can potentially minimize beam-hardening artifact **(Kim et al., 2019)**. A narrower field of view (FOV) is covered by the X-ray beam source with a greater energy level in dual-source CT scanners. The patient can be positioned correctly to solve this issue **(Aran et al., 2014; Dane et al., 2023; Heye et al., 2012; Wortman and Sodickson, 2018)**. A small intestinal lesion may be difficult to differentiate from a bleeding focus because the mean attenuation of the VNC picture and actual unenhanced images are identical **(Kaza et al., 2017)**.

The quantification and presentation of calcium and barium can be inaccurate due to the limitations of post-processing algorithms of DECT. This problem could be overcome with the use of better material decomposition algorithms. Moreover, oral ingestion of iodine from an earlier CT scan could represent a sign of active bleeding **(Kaza et al., 2017; Urvi et al., 2016)**. Additionally, if the amount of iodinated contrast material is large, there may be incomplete iodine elimination in producing VNC images during assessment of GI bleeding. This limitation can be overcome by using venous phase images to create VNC images, where intravascular contrast material is less attenuating **(Parakh et al., 2021; Wortman and Sodickson, 2018)**. Pseudopneumatosis artefact can occur with iodine mapping from rapid kilovoltage-switching CT systems or dual-layer detector systems which can result in false interpretation of iodine content. It can be simply identified and avoided by examining standard CT reconstructions images **(Yeh et al., 2009)**.

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Conclusion

The use of dual-energy CT is gradually changing conventional CT practices. Beyond the limitations associated with conventional single-energy CT imaging, dual-energy CT offers quantitative information on tissue composition by various post-processing tools. Extensive studies have been focused in recent years on utilizing dual energy CT for a range of therapeutic applications. As a result, changes have been made to the CT procedure to reduce radiation exposure, enhance diagnostic performance for the identification and characterisation of various illnesses, and optimize picture quality.

DECT is extremely helpful when assessing gastrointestinal hemorrhage. It provides a significant reduction in radiation exposure by removing the non-contrast acquisition image from a multiphase CT evaluation for GI bleeding. The postprocessing application can enhance the visibility of contrast material extravasation by reconstructed iodine maps, color iodine overlay pictures, and virtual monoenergetic imaging at low-kiloelectron voltage. These features can increase the diagnostic confidence of radiologists and diagnostic efficacy of the images.

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