



Gastrointestinal Imaging Pictorial Essay

Added value of iodine-specific imaging and virtual non-contrast imaging for gastrointestinal assessment using dual-energy computed tomography

Madison R. Kocher¹, Mark D. Kovacs¹, William Stewart¹, Brian P. Flemming¹, Shaun Hinen¹, Andrew D. Hardie¹

¹Department of Radiology and Radiological Science, Medical University of South Carolina, Charleston, South Carolina, United States.



***Corresponding author:**
Madison R. Kocher,
Department of Radiology,
Medical University of South
Carolina, Charleston, South
Carolina, United States.

kocherm@musc.edu

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ABSTRACT

Dual-energy computed tomography (DECT) has become increasingly available and can be readily incorporated into clinical practice. Although DECT can provide a wide variety of spectral imaging reconstructions, most clinically valuable information is available from a limited number of standard image reconstructions including virtual non-contrast and iodine overlay. The combination of these standard reconstructions can be used for specific diagnostic tasks that provide added value over traditional CT protocols. In this pictorial essay, the added value of these standard reconstructed images will be demonstrated by case examples for diseases specifically related to the gastrointestinal system.

Keywords: Dual-energy computed tomography, Gastrointestinal, Iodine map, Virtual non-contrast

INTRODUCTION

Dual-energy computed tomography (DECT) can be acquired through many different CT hardware setups, often specific to different manufacturers. Although a review of the different methods of DECT data acquisition is beyond the scope of this article, the cases presented here were all acquired using a dual-source technique. This method obtains DECT data from two different CT source emitters positioned at 90° to each other (one with a low kVp setting and the other a high kVp). The subsequent post-processing of this data allows for a greater degree of material characterization because of the differing relative X-ray absorption characteristics at high and low energies.^[1,2] As such, post-processed DECT image sets can be of significant value when optimized for specific applications.

Although more advanced than traditional CT, DECT can be readily adapted to clinical workflow, particularly when standardized post-processed reconstructed images are incorporated into a routine CT protocol. Specifically, a prior published study has demonstrated that DECT increased diagnostic confidence when used in routine emergency department studies and leads to a reduction in unnecessary follow-up studies.^[3] In our experience, the standardized reconstructions that have the most value for routine CT protocols include a blended 120 kVp single-energy equivalent, a virtual non-contrast (VNC) series, and an iodine

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overlay (iodine map superimposed on a VNC) to identify the presence of iodine.

In this manuscript, we will highlight some of the features of DECT that aid in the evaluation of gastrointestinal structures and diseases. DECT specifically allows marked improvement in the ability to identify intravenous or orally administered iodinated contrast which improves diagnosis of bowel perfusion abnormalities, active gastrointestinal bleeds, and extraluminal contrast leaks. Applications for material characterization in the gastrointestinal system will also be reviewed.

INTRAVENOUS CONTRAST

Acute bowel ischemia

Acute bowel ischemia is an abdominal surgical emergency with prompt treatment highly reliant on timely diagnosis and imaging findings. One of the limiting imaging findings includes the increased density of the ischemic bowel wall which is likely secondary to hemorrhage in the setting of developing necrosis.^[4] This finding may cause ischemic bowel to appear as if it was enhancing on routine contrast-enhanced imaging, even though it is not [Figure 1].

Although intramural hemorrhage within the bowel wall with associated hyperattenuation on unenhanced CT is almost 100% specific for the diagnosis of bowel ischemia with necrosis, it would be difficult to make this diagnosis with a single-phase CT. The use of DECT may increase the conspicuity of subtle differences in attenuation between a hypoenhancing segment and adjacent normal bowel wall [Figures 2 and 3].^[5]

Active gastrointestinal bleed

Active gastrointestinal bleed can be difficult to diagnose on traditional CT because of confounding hyperattenuating bowel contents. When intraluminal material is present, the diagnosis of active gastrointestinal bleeding can be confirmed with the internal presence of iodine and will disappear on the virtual non-contrast reconstructions [Figures 4 and 5], whereas hyperattenuating ingested material such as bismuth will not have any internal iodine and will persist on virtual non-contrast reconstructions [Figure 6]. In addition, multiple phases are needed including non-enhanced and multiple contrast-enhanced images sets to confidently identify and diagnose a gastrointestinal bleed.

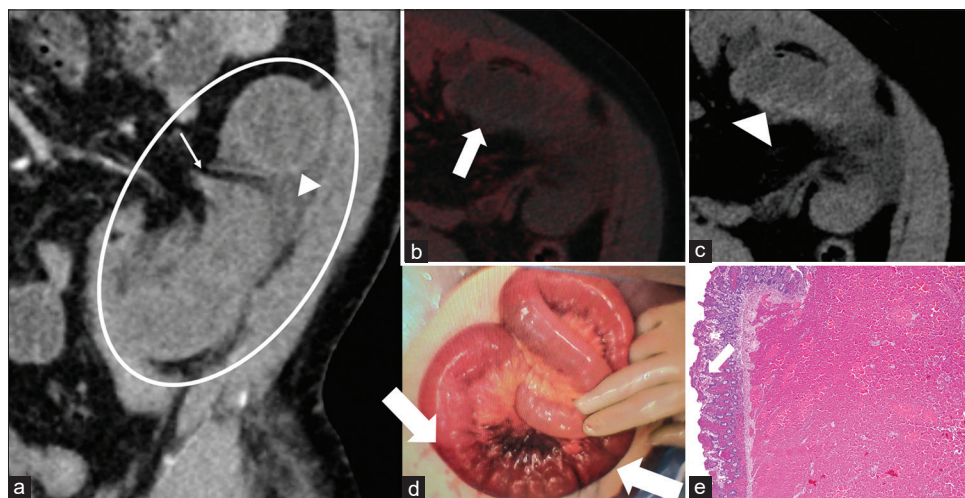


Figure 1: A 69-year-old man who presented with acute abdominal pain, nausea, vomiting, and laboratory values notable for elevated lactate with subsequent diagnosis of closed-loop bowel obstruction. Reconstructed dual-energy CT images of the abdomen and pelvis with intravenous contrast were performed as a part of our routine clinical practice. (a) Coronal contrast-enhanced CT image demonstrates a dilated loop of small bowel in the left lower quadrant with associated mesenteric edema (oval). Focal transition points of both ends of this bowel loop are well visualized (arrow). Of note, the bowel wall on these conventional CT images has some internal hyperdensity which was initially interpreted as an enhancement (arrowhead). (b) Iodine overlay demonstrates a lack of iodine/enhancement in the affected segment of the bowel (arrowhead). (c) The virtual non-contrast image demonstrates intrinsic hyperdensity in the same area, indicative of hemorrhage in the bowel (arrowhead). This finding was initially interpreted as a normal enhancement on the conventional enhanced CT. (d) Intraoperative photograph showing ischemic portion of the small bowel with hemorrhage in the bowel wall and mesentery, corresponding to the findings seen on CT (arrows delineating ischemic portions). The obstruction was secondary to an adhesive band which was identified and lysed. (e) $\times 4$ microscopic image stained with hematoxylin and eosin of ischemic bowel segment demonstrates mucosa to the left (arrow) with the remainder of the normal bowel wall architecture replaced by hemorrhage, corresponding to findings on the dual-energy CT reconstructions.

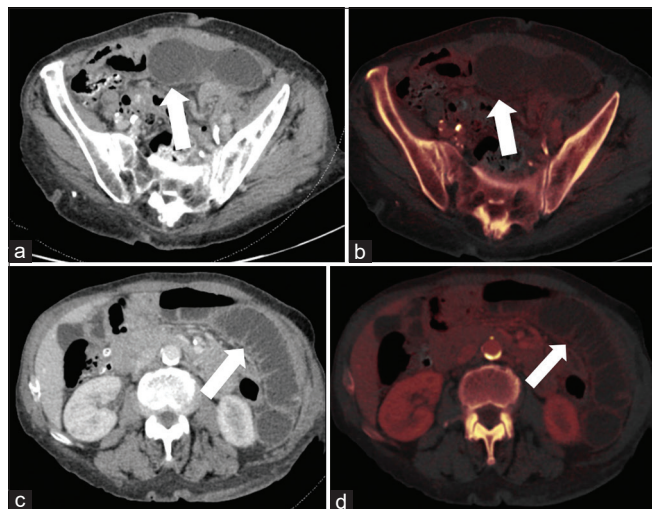


Figure 2: An 82-year-old female presenting with abdominal pain and suspected gastroenteritis with subsequent diagnosis of ischemic bowel. (a) Axial CT abdomen and pelvis with IV contrast demonstrates a closed-loop obstruction in the left lower quadrant with hypoenhancement of the bowel wall (arrow) and lack of iodine on iodine overlay reconstruction (b), which was confirmed intraoperatively. Comparatively, there are normal bowel enhancement (c) and internal iodine content (d) in the upstream loops of the dilated small bowel.

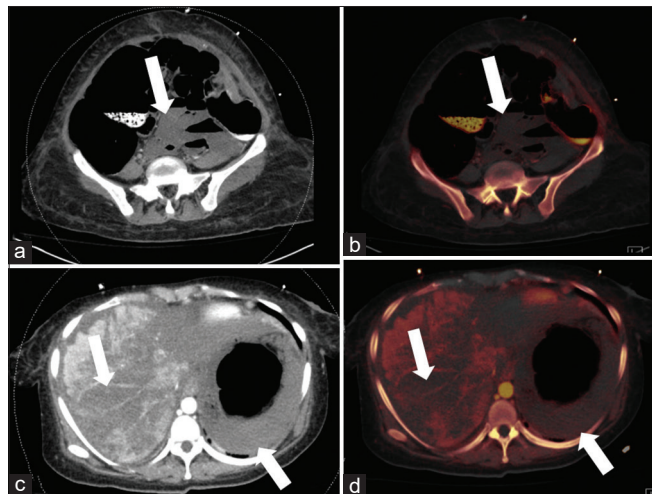


Figure 3: A 41-year-old female with abdominal pain and rising lactate with a subsequent diagnosis of generalized hypoperfusion and abdominal compartment syndrome. (a) Axial CT abdomen and pelvis with IV and oral contrast demonstrates obstruction and massive colonic distension secondary to peritoneal carcinomatosis. There is generalized hypoperfusion of all of the visualized loops of the bowel without any visualized iodine on iodine overlay reconstruction (white arrows) (b). (c and d) There are multiple additional findings of generalized hypoperfusion including non-enhancement of the liver and spleen (white arrows), concerning abdominal compartment syndrome.

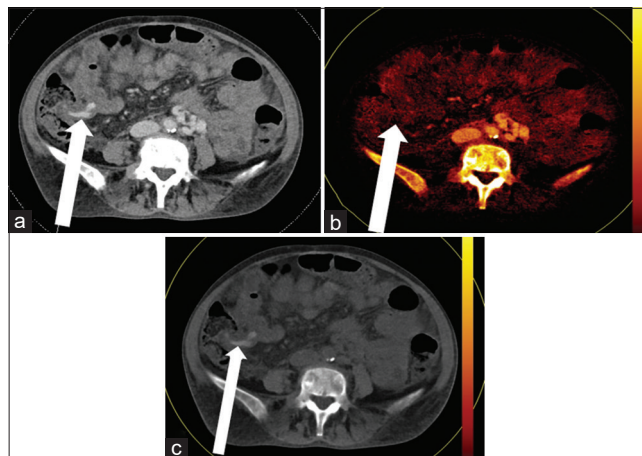


Figure 4: A 58-year-old male with bright red blood per rectum and suspected acute gastrointestinal bleeding, with subsequent diagnosis of acute GI bleed. (a) Axial blended 120 kVp image shows hyperattenuating material within the bowel lumen (arrow), similar to blood pool, which was initially thought to represent active gastrointestinal bleeding. (b) The iodine map reveals that hyperattenuating intraluminal material shown in (a) does not contain iodine (arrow), which is consistent with the presence of ingested material, not active gastrointestinal bleeding. (c) The virtual non-contrast image reveals that the material shown in (a) is hyperattenuated (arrow), which is also consistent with the presence of ingested material. [Kovacs M, Kocher M, Hardie A. Abdominal applications of dual-energy CT: Bowel. In: Bhosale P, Marin D, Morgan D, editors. Practical Dual-Energy CT Throughout the Body: A Busy Radiologist's Primer. Leesburg, VA: ARRS; 2021. p. 93-8].

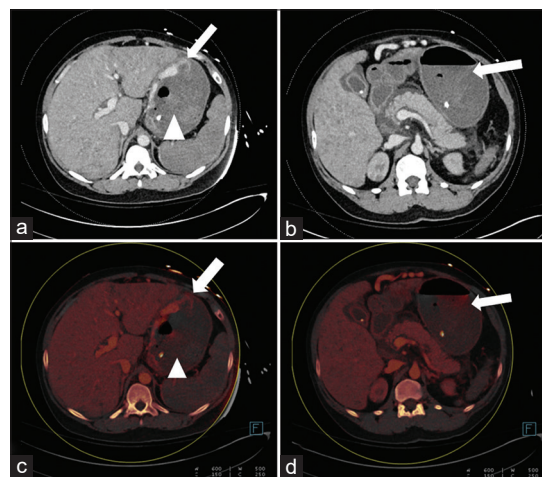


Figure 5: A 48-year-old female was found unresponsive with a reported history of hematemesis and a subsequent diagnosis of active gastrointestinal bleeding. (a and b) Axial CT abdomen and pelvis with IV contrast demonstrates hyperattenuating material in the stomach (arrows) with layering dense products posteriorly (arrowheads). (c and d) Axial iodine overlay confirms the presence of iodine within the hyperdense products, consistent with active extravasation into the stomach through gastric varices. These findings were subsequently confirmed on esophagogastroduodenoscopy.

VNC imaging may act as a surrogate to conventional non-contrast imaging, which can provide additional information when unenhanced images are needed to establish a diagnosis, and could potentially decrease radiation dose from multiphase CT examinations. Prior studies have confirmed that virtual non-contrast reconstructions can allow for the omission of an initial unenhanced scan.^[6,7]

Bowel tumors

Iodine-selective imaging can allow for greater characterization and detection of iodine-containing lesions and can confirm enhancement in otherwise indeterminate lesions in multiple solid organs. Like DECT application for assessing solid organs, a similar approach can be utilized to assess for enhancement within possible gastrointestinal tumors. Non-specific wall thickening on routine CT can be assessed for the presence of focal iodine uptake on DECT, thus increasing specificity [Figures 7 and 8].

ORAL CONTRAST

Bowel leak

Extraluminal oral iodinated contrast medium can be a difficult diagnosis to make. On traditional CT, it can be difficult to differentiate hyperdense extraluminal fluid or

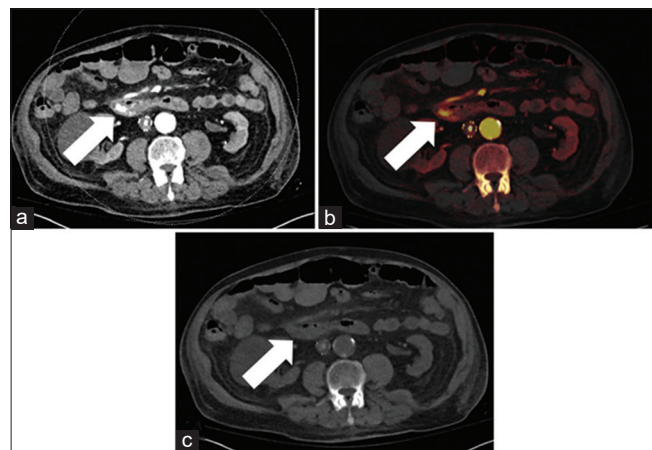


Figure 6: A 78-year-old male with a history of intermittent, low-grade gastrointestinal bleeding and subsequent diagnosis of acute gastrointestinal bleed. (a) Axial blended 120 kVp image shows hyperattenuating focus (arrow) in the duodenum. (b) Iodine overlay image shows that hyperattenuating focus (arrow) is iodinated contrast medium, indicating active arterial extravasation with contrast also extending throughout the duodenum. (c) The axial virtual non-contrast image confirms the lack of hyperattenuation in the region of active arterial extravasation into the duodenum (arrow). [Kovacs M, Kocher M, Hardie A. Abdominal applications of dual-energy CT: Bowel. In: Bhosale P, Marin D, Morgan D, editors. Practical Dual-Energy CT Throughout the Body: A Busy Radiologist's Primer. Leesburg, VA: ARRS; 2021. p. 93-8].

surgical material with extraluminal oral contrast material [Figure 9]. When virtual non-contrast images and iodine overlays can be utilized, the absence of iodine can be confirmed and extraluminal contrast can be confidently excluded from the study.

When iodine can be confirmed extraluminally with iodine maps either with active extravasation from the bowel or within extraluminal fluid collections, the diagnosis of bowel perforation or leak can be made [Figure 10]. Alternatively, if there is no iodine content within the fluid collection, bowel leak will be less likely [Figure 11].

It is important to remember that it is not possible to accurately distinguish barium-based oral contrast materials from iodinated intravenous contrast mediums because of their similar attenuation curves. Therefore, interpretation of bowel leak or extraluminal contrast should be done with caution if both IV and oral contrast are concurrently administered.

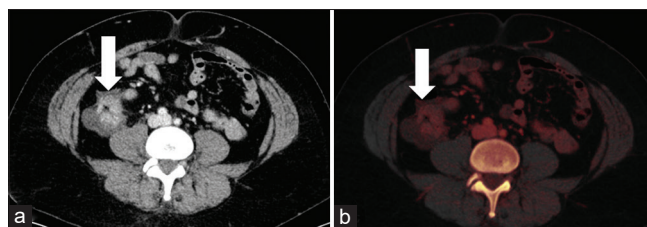


Figure 7: A 41-year-old male presenting with the right lower quadrant pain and suspected acute appendicitis with subsequent diagnosis of appendiceal carcinoma. (a) Initial CT abdomen and pelvis with intravenous contrast demonstrates acute appendicitis and a 3.5 cm enhancing mass at the base of the appendix (arrow), which was missed prospectively. (b) Iodine overlay confirms the presence of enhancement in the cecal mass (arrow). After an appendectomy, the patient re-presented with leak and subsequent CT demonstrated possible metastatic lesions in the liver. The patient underwent a right hemicolectomy, which revealed invasive adenocarcinoma.

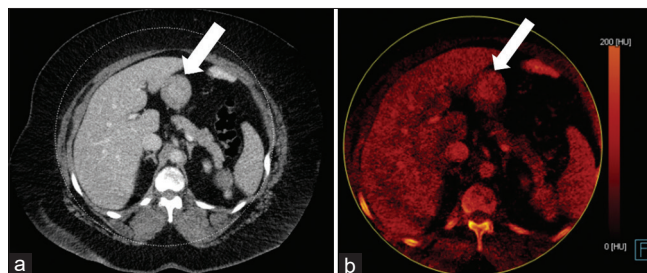


Figure 8: A 48-year-old female presenting with weight gain status post-Roux-en-Y gastric bypass surgery and subsequent diagnosis of GIST. (a) On axial 120 kVp equivalent CT, there was a $9.9 \times 5.4 \times 5.2$ cm mass (arrow), predominantly within the lumen of the stomach with confirmed enhancement on iodine map (arrow) (b), confirmed to be a gastrointestinal stromal tumor after excision.

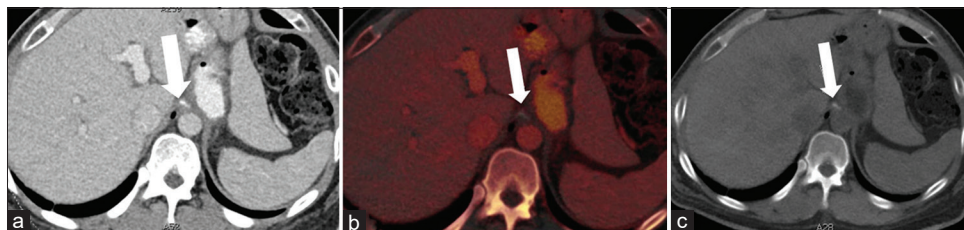


Figure 9: A 50-year-old male status post-laparoscopic sleeve gastrectomy presenting with increasing abdominal pain, nausea, and vomiting with subsequent diagnosis of surgical material and no evidence of oral contrast leak. Contrast-enhanced CT abdomen and pelvis with oral contrast were obtained to rule out the leak. (a) Axial 120 kVp equivalent study demonstrates hyperdense material adjacent to the gastroesophageal junction (arrow). (b) Iodine overlay reconstructions do not demonstrate any iodine content within the hyperdense material (arrow), which would be expected in extraluminal contrast. (c) The virtual non-contrast image demonstrates the presence of the hyperdense material before contrast administration (arrow). The findings were consistent with suture material and the patient was treated conservatively.

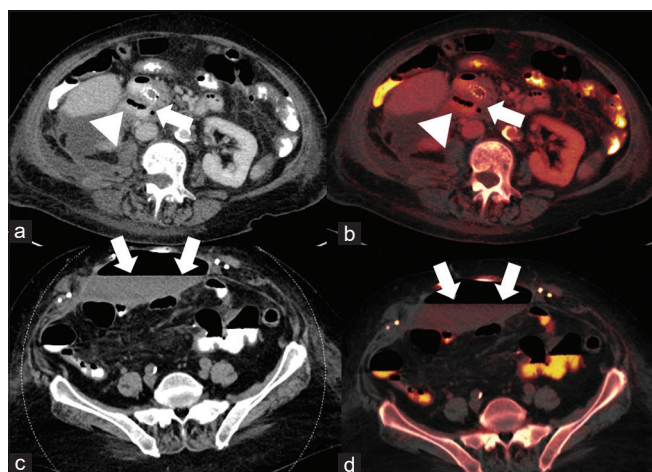


Figure 10: A 77-year-old female with a history of pancreatitis and recent sphincterotomy with stent placement presenting with nausea and vomiting and concern for bowel leak. Subsequent diagnosis of bowel perforation with extraluminal contrast after imaging. (a) 120 kVp equivalent CT abdomen and pelvis with IV and oral contrast demonstrating a defect in the second portion of the duodenum (arrow) with oral contrast extravasation into the right retroperitoneal soft tissues (arrowhead), confirmed on iodine overlay (b). (c) A 63-year-old female with a history of multiple small bowel resections with concern for abscess. 120 kVp equivalent CT abdomen and pelvis with oral contrast only demonstrated a large hyperdense fluid and air collection in the anterior peritoneum suspicious for bowel leak. (d) The iodine overlay confirmed the presence of iodine within the fluid collection.

Bowel fistula

Using similar techniques as described above regarding the detection of extravasated iodinated oral contrast material to detect a leak, the same principles can be applied to the detection of a fistula. The presence of iodinated contrast medium communicating with other loops of the bowel [Figure 12] or outside of the bowel can help definitively diagnose the presence of fistulas [Figure 13].

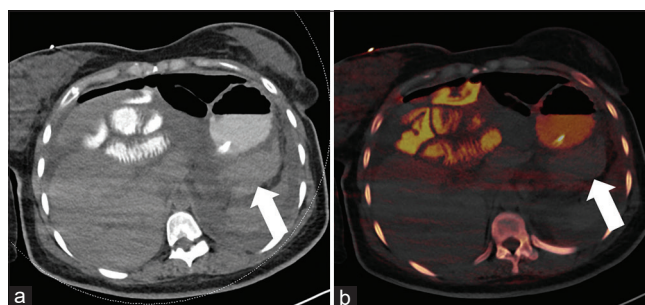


Figure 11: A 37-year-old female status post-exploratory laparotomy, partial omentectomy, and reduction of small bowel volvulus with concern for the leak. After imaging, there was confirmation that there was no evidence of extraluminal contrast to suggest a leak. (a) 120 kVp equivalent CT of the abdomen and pelvis with oral contrast only demonstrated a hyperdense collection throughout the peritoneum, but predominantly in the left upper quadrant posterior to the stomach (arrow). (b) Iodine overlay did not demonstrate any extraluminal iodine within the collection, which favored coagulated blood products (arrow).

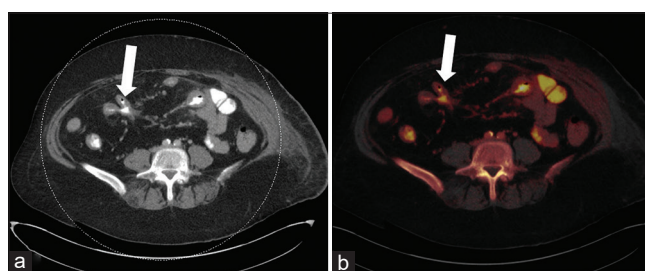


Figure 12: A 48-year-old female with a history of Crohn's disease and multiple abscesses. Subsequent diagnosis of small bowel-small bowel fistula after imaging. Same patient as Figure 17 with the presence of small bowel-small bowel fistulization in the right lower quadrant (a) (arrow) with fistulous connections, confirmed as patent on iodine overlay (b) (arrow).

GALLBLADDER DECT APPLICATIONS

Multiple prior studies have demonstrated the utility of DECT in the evaluation of gallstones. A study by Lee *et al.*

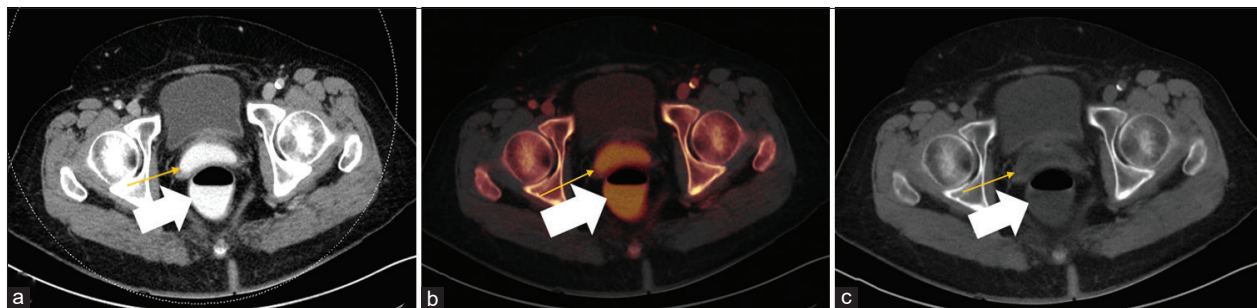


Figure 13: A 34-year-old female with suspected rectovaginal fistula who received rectal administration of iodinated contrast medium during imaging examination. Subsequent diagnosis of rectovaginal fistula was confirmed after imaging. (a) Axial blended 120 kVp image shows hyperattenuating material in the rectum (white arrow) as well as in the distended vagina (yellow arrow). (b) The iodine overlay image confirms the iodine content of the fluid in the rectum (white arrow) and vagina (yellow arrow), which is consistent with a colovaginal fistula. (c) The virtual unenhanced examination did not demonstrate any hyperattenuating material in the rectum (yellow arrow) or vagina (white arrow). [Kovacs M, Kocher M, Hardie A. Abdominal applications of dual-energy CT: Bowel. In: Bhosale P, Marin D, Morgan D, editors. Practical Dual-Energy CT Throughout the Body: A Busy Radiologist's Primer. Leesburg, VA: ARRS; 2021. p. 93-8].

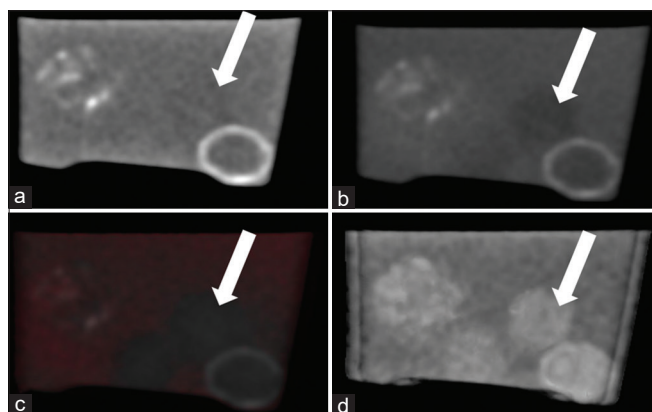


Figure 14: A 56-year-old female with right upper quadrant pain and suspected acute cholecystitis. Subsequent diagnosis of cholelithiasis after imaging. Coronal DECT images of multiple gallstone specimens. (a) 120 kVp image demonstrates the conspicuous calcified gallstones; however, the non-calcified gallstones are not readily identifiable (arrow). (b) 50 keV images with faint visualization of the non-calcified gallstones which is also identified on iodine overlay (arrow) (c). (d) Virtual non-contrast image with clear delineation of both the calcified and non-calcified gallstones. DECT: Dual-energy computed tomography.

(2016) demonstrated that virtual non-contrast images at DECT allow better visualization of cholesterol stones and another prior study showed the benefit of low keV virtual monochromatic imaging to increase the conspicuity of non-calcified stones.^[8,9] [Figure 14] demonstrates the different appearance of cholesterol as well as calcified gallstones in different DECT reconstructions. Routine 120 kVp imaging can often mask the presence of cholesterol gallstones, whereas low keV virtual monochromatic imaging, VNC, and ultrasound imaging can confirm their presence [Figures 15 and 16].

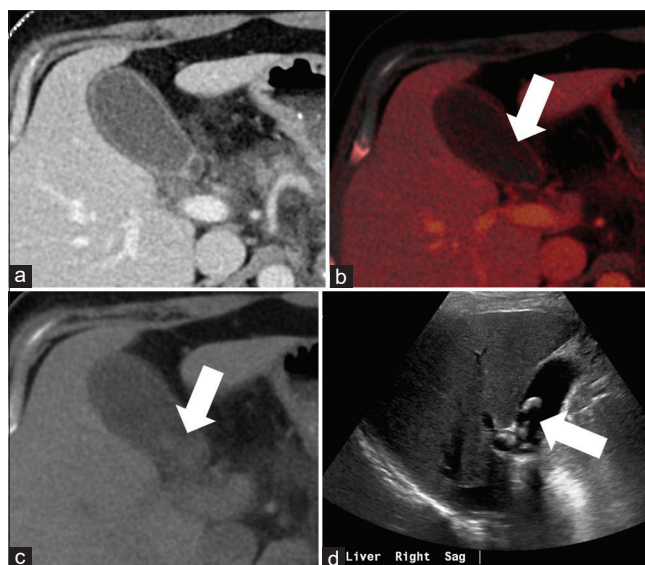


Figure 15: A 62-year-old female with the right upper quadrant pain and upper mid-abdominal pain with concern for pancreatic duct obstruction. The clinical team wanted to know if gallstones were present and the initial scan was interpreted as no evidence for cholelithiasis. Subsequent diagnosis of cholelithiasis and ductal obstruction with resultant pancreatitis after examination of the DECT images. (a) Axial initial contrast-enhanced 120 kVp DECT without definite evidence of cholelithiasis. (b) Iodine overlay demonstrates a faint patchy lack of internal iodine in the region of the neck of the gallbladder (arrow) and virtual non-contrast scan demonstrates hyperattenuating gallstones (white arrow) (c). (d) Follow-up ultrasound imaging confirmed the presence of cholesterol gallstones (arrow). DECT: Dual-energy computed tomography.

MISCELLANEOUS PROBLEM-SOLVING FOR GASTROINTESTINAL APPLICATIONS WITH DECT

While there are many well-defined clinical uses for DECT reconstructions, there are additional problem-solving

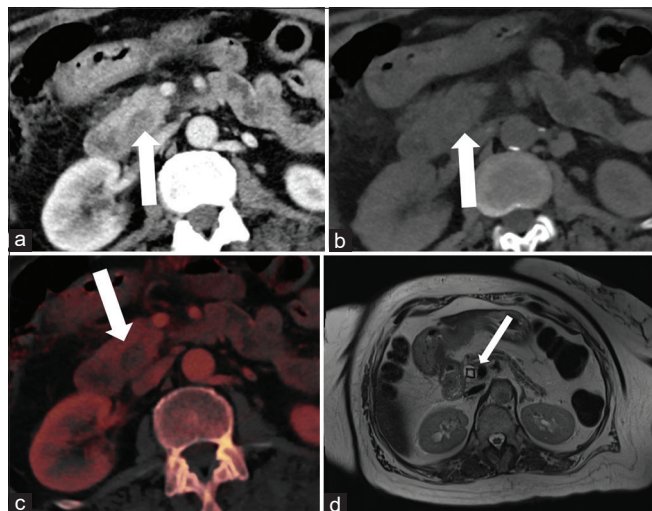


Figure 16: A 58-year-old female with the right upper quadrant pain and subsequent diagnosis of choledocholithiasis. (a) Routine 120 kVp CT abdomen and pelvis with IV contrast demonstrating possible hyperdense contents within the dilated common bile duct (arrow). (b) On virtual non-contrast reconstructions, there are well-visualized hyperdense contents within the dilated common bile duct (arrow) as well as a better delineated stone on iodine overlay (arrow) (c). (d) T2 HASTE MRI demonstrating choledocholithiasis (arrow).

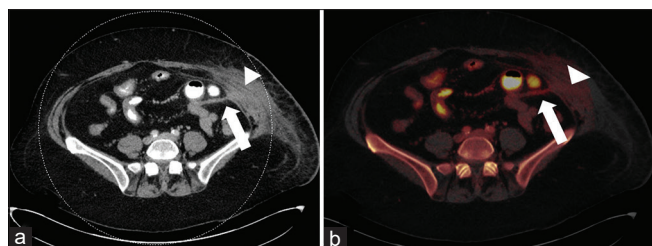


Figure 17: A 48-year-old female with a history of Crohn's disease and multiple abscesses with subsequent diagnosis of subtle enterocutaneous fistula. (a) CT abdomen and pelvis demonstrates a fistula from the left mid-abdominal small bowel loops that extends to the left flank (arrow). There is left lateral abdominal wall/flank soft-tissue stranding with few foci of gas (arrowhead). (b) Iodine overlay helped to confirm the presence of intravenous contrast within the fistula track (arrow) and soft-tissue collection in the left lateral abdominal wall (arrowhead), which improved visualization.

applications to assist search patterns and elucidate pathology. The integration of an iodine overlay search pattern can help quickly pinpoint areas of pathology and further interrogate the presence of abnormal enhancement [Figure 17]. In addition, intraluminal contents can be further characterized [Figure 18].

CONCLUSION

The application of DECT and specifically iodine overlay and virtual non-contrast reconstructions can help improve

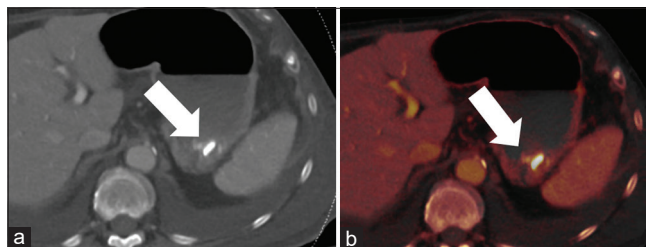


Figure 18: A 67-year-old male with a history of arrhythmia. Subsequent imaging revealed a tablet in the stomach consistent with a history of amiodarone use. (a) Virtual non-contrast reconstruction of a contrast-enhanced CT abdomen and pelvis demonstrates a hyperattenuating intraluminal pill (arrow) that contains iodine on iodine overlay reconstruction (arrow) (b). The patient confirmed that they are on amiodarone therapy which contains iodine.

the ability to elucidate gastrointestinal pathology. By incorporating these reconstruction search patterns, further information can be gathered to better answer clinical questions. Not only can DECT reconstructions help to identify intravenous and orally administered iodinated contrast but they can also improve the detection of gallstones and intraluminal contents.

Declaration of patient consent

Patient consent is not required as patient's identity is not disclosed or compromised.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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