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World J Gastroenterol 2006 May 28; 12(20): 3139-3145
World Journal of Gastroenterology ISSN 1007-9327

TOPIC HIGHLIGHT

John Geibel, MD, Dsc and Walter Longo, MD, *Series Editors*

Advances in alimentary tract imaging

Dean DT Maglinte, Kumaresan Sandrasegaran, Mark Tann

Dean DT Maglinte, Kumaresan Sandrasegaran, Mark Tann, Department of Radiology, Indiana University School of Medicine, Indianapolis, United States
Correspondence to: Dean DT Maglinte, MD, UH 0279, Department of Radiology, 550 N, University Blvd, Indianapolis, IN 46202, United States. damglint@iupui.edu
Telephone: +1-317-2741837
Received: 2006-03-29 Accepted: 2006-04-16

Abstract

Advances in imaging techniques are changing the way radiologists undertake imaging of the gastrointestinal tract and their ability to answer questions posed by surgeons. In this paper we discuss the technological improvements of imaging studies that have occurred in the last few years and how these help to better diagnosing alimentary tract disease.

Key words: Imaging; Alimentary tract

Maglinte DDT, Sandrasegaran K, Tann M. Advances in alimentary tract imaging. *World J Gastroenterol* 2006; 12(20): 3139-3145

http://www.wjgnet.com/1007-9327/12/3139.asp

INTRODUCTION

Advances in imaging techniques are changing the way radiologists undertake imaging of the gastrointestinal tract and their ability to answer questions posed by surgeons. Technologic advancements in CT have dramatically improved the detection and characterization of a wide variety of intestinal diseases before and after surgery. In the first part of this paper we review some of the advances in imaging technology. In the second part we discuss how these technical advances improve diagnosis of gastrointestinal disease.

ADVANCES IN IMAGING TECHNOLOGY

Multislice computed tomography

CT is now more commonly performed than fluoroscopic studies in analyzing the gastrointestinal tract. Several generations of CT scanners have become available, starting with 4-slice scanners in 1998 to 64-slice scanners in 2005. With each generational advance more rapid scans are possible with better tailored vascular phase acquisition, and thinner slices. When the resolution of the voxels that make the scanned volume is equal in the longitudinal and transverse (axial) dimensions, the study is considered to be isotropic. In an isotropic resolution scan of the abdomen and pelvis the slice width should typically be less than 1 mm. With such scans the reformats in coronal or sagittal planes will have the same image quality as axial images (Figure 1). Using 64-slice scanners, the entire abdomen and pelvis could be scanned in 5-8 s with isotropic resolution. Modern scanners have software that would almost instantaneously create coronal or sagittal reformats. In our practice every abdominopelvic CT is reconstructed routinely in at least the coronal plane in addition to transverse scans. This plane optimizes assessment of organs such as the mesenteric small bowel which have a tortuous and unpredictable course (Figure 2). Three dimensional image sets such as volume rendering may also be created when deemed helpful prior to surgery[1]. Radiologists are gradually moving away from reading axial slices of CT scans to viewing the abdomen as a three dimensional structure, similar to what the surgeon would see during an operative procedure (Figure 3). Several changes to CT techniques have become accepted in the last few years. In the past positive oral contrast, usually dilute iodinated contrast media or dilute barium, were widely used. These were safe and allowed adequate opacification of the small bowel. The current approach is to favor neutral oral contrast with intravenous contrast when there suspicion of small bowel tumor or inflammatory disease[2]. Advantages of this technique include fewer dilution and admixture artifacts with enteric contents, better visualization of enhancing bowel tumors and inflammation, easier processing of CT angiogram and 3D techniques. One disadvantage of orally administered contrast is the reduced distention of the distal small bowel. This disadvantage could be overcome by either infusion of the enteral contrast under hydrostatic pressure using a nasoenteric tube (CT enteroclysis, see below) or by drinking large volumes of contrast, usually more than 2 liters, in predetermined aliquots over a period of time (CT enterography). Water is the most commonly used neutral enteral contrast; other propriety preparations include (VoLumen, EZ-EM, Westbury, NY) which contains agents to reduce absorption and to add flavor.

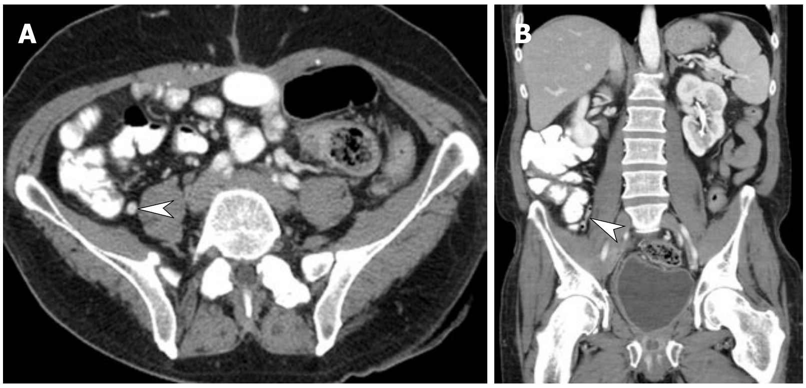

Figure 1 Sixty-three years old man with right lower quadrant abdominal pain. Note the equivalent resolution of the axial image (**A**) and coronal reformat (**B**). In addition it was easier to appreciate the vertically oriented normal appendix (arrowhead) on the coronal reformat.

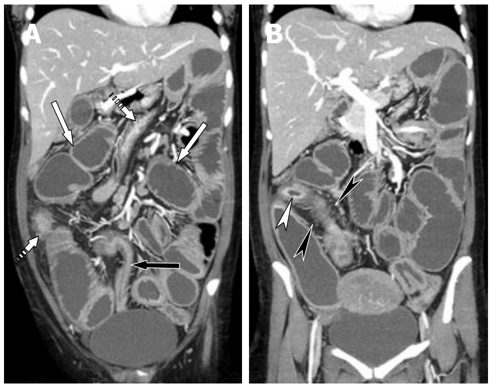

Figure 2 Abdominal pain and fever in 23 years old female. **A, B**: Coronal reformats with neutral enteral contrast (water) showed dilated proximal loops of small bowel (white solid arrows), and nondistended colon (dashed arrows). A segment of distal ileum (black arrow, image **A**) showed stenosis with mucosal enhancement, consistent with inflammatory stricture causing small bowel obstruction. A second noncontiguous segment of terminal ileum showed intense mucosal enhancement (white arrowhead, image **B**) and comb sign due to mesenteric hypervascularity (black arrowhead, image **B**). The appearances were consistent with acute Crohn's disease. The diagnosis of wall enhancement and thickening is made easier by using water as oral contrast. The coronal perspective also allows easier evaluation of length of involved segments.

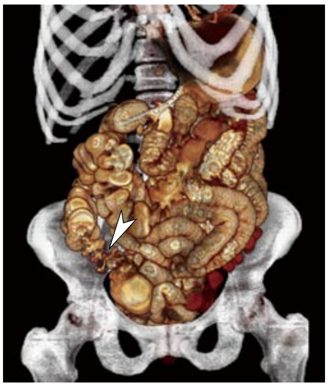

Figure 3 Three dimensional volume rendered image of small and large bowel in 46 years old female with diarrhea. There was no evidence of bowel obstruction. The apparent narrowing of ascending colon (arrowhead) was likely to be due to passage of peristalsis, there was no evidence of mass on two dimensional axial and coronal images. Three dimensional images may be more commonly used in the future to help plan surgery.

CT enteroclysis

CT enteroclysis was first reported in 1992 in an effort to overcome the individual deficiencies of CT and barium enteroclysis and to combine the advantages of both into one technique[3]. In this technique a nasoenteric tube is inserted preferably under conscious sedation and enteric contrast infused under pressure till the entire small bowel is filled. The patient is then taken to a CT scanner to complete the study. As with conventional CT, the choice of enteric contrast is either positive or neutral contrast and depends on the indication[4]. For diagnosing leaks, fistula, peritoneal abscess and low grade small bowel obstruction we prefer positive contrast. For all other indications including assessment of tumors and the inflammatory activity of Crohn's disease we use neutral contrast (Figure 2). CT enteroclysis has several advantages over conventional CT including better assessment of low grade obstruction, enteric fistula, and bowel wall thickening. However this technique has disadvantages of requiring a significant amount of radiologist time, insertion of nasoenteric tube and risks of conscious sedation.

Magnetic resonance enteroclysis

Magnetic resonance enteroclysis is advocated primarily in Europe as a method of interrogating the small bowel without using ionizing radiation. In many ways the technique is similar to CT enteroclysis, except that the nasoenteric tube is inserted in the MRI scanner room prior to the MRI examination. Improvements in magnet technology allow fast scans that could be performed in a reasonable breath-hold. Currently, the poor spatial resolution and motion artifacts impair its value. When compared to CT enteroclysis MR enteroclysis was found to have lower sensitivity and inter-reader agreement in diagnosing a variety of small bowel diseases[5].

CT colonography (virtual colonoscopy)

In this paper we will call CT colonography by its more familiar name, virtual colonoscopy. In this technique very thin slices are obtained in prone and supine positions though the abdomen and pelvis. The resulting images are treated in many ways (Figure 4): (1) Two dimensional reformats in coronal and axial planes; (2) Three dimensional fillet view, where the colon is displayed as if it has been dissected; (3) Endoluminal fly though view. The production of such views requires sophisticated software and appropriate workstation. In our practice, we initially survey the colon on the three dimensional fillet view. Suspected abnormalities are correlated with the axial and coronal two dimensional views, and on the endoluminal view. This approach reduces the time for image interpretation. Measurement of polyp size is made on the endoluminal view, which is considered the most accurate[6]. Subsequently, axial slices are reviewed to diagnose extracolonic abnormalities.

Software programs in routine use include book marking of polyps for correlation with subsequent scans, automatic center line navigation which allows easier fly through, missed patch tool to keep track of surfaces that are not optimally visualized on automatic center line navigation and electronic stool tagging and fluid removal. Currently we prescribe laxatives taken a day prior to the study to reduce the stool burden. However many recent papers have commented on the accuracy of virtual colonoscopy

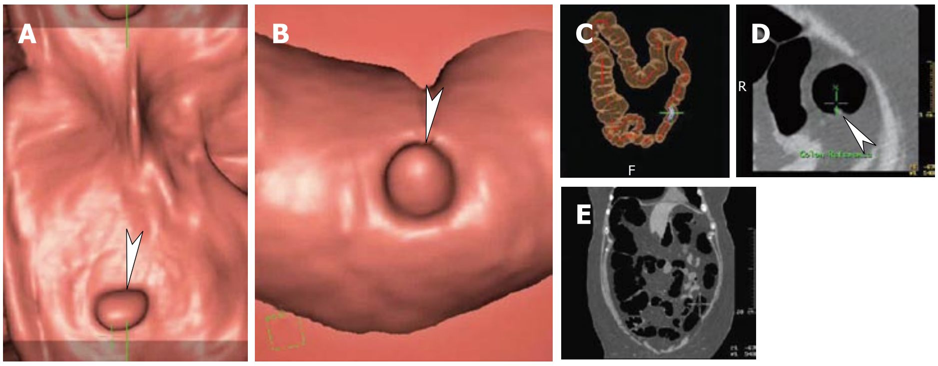

Figure 4 Virtual colonoscopy images in 62 years old female with incomplete optical colonoscopy. **A**: Dissection or fillet view; **B**: Endoluminal fly-through view; **C**: Transparent localizing view; **D**: Two dimensional axial view; **E**: Two dimensional coronal view. At our institution the initial read is the 3 dimensional fillet and endoluminal views in antegrade and retrograde fashion. Sites of concern are correlated with axial or coronal two dimensional views. The entire interpretation including assessment of extracolonic structures takes about 30 min. Note the 6 mm polyp (arrowhead). Its location was confirmed as distal descending colon on image C.

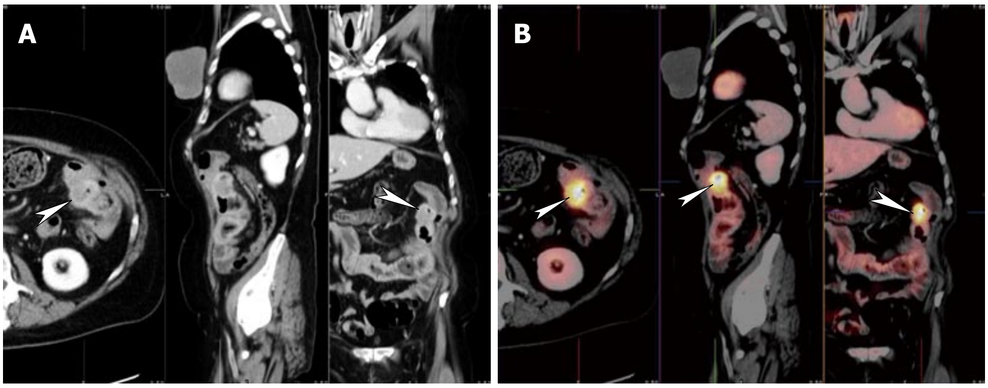

Figure 5 Thirty-nine years old female with prior sigmoid colectomy for cancer, presented with rising CA-125. **A**: Axial, coronal and sagittal images of CT raised concern for possible mass adjacent to the splenic flexure (arrowheads); **B**: Fused images of PET and CT showed hypermetabolic focus (arrowheads) in the mesocolon adjacent to splenic flexure, indicating recurrent tumor. No other sites of tumor were found. While PET is sensitive for recurrent disease it has poor spatial resolution and it would have been difficult to determine if the recurrence was in the colon, mesentery or adjacent spleen. Fusion of PET and CT images allowed accurate anatomical localization.

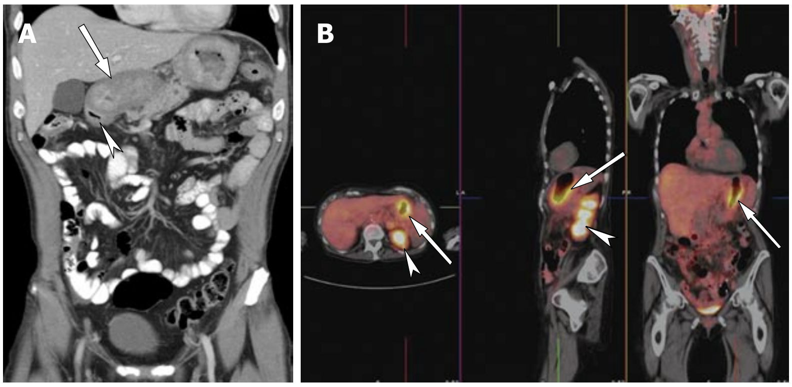

Figure 6 Sixty-nine years old male with dyspepsia. **A**: Coronal reformat showed diffuse thickening of the gastric wall (arrow). The duodenal cap was normal (arrowhead); **B**: Fused PET-CT images showed hypermetabolic activity of the gastric wall indicating cancer. No other foci of abnormal uptake were identified. Note the normal increased activity in the renal collecting systems (arrowheads) due to excretion of radiopharmaceutical.

without using laxatives but instead using low residue diet and tagging feces with dilute contrast[7,8]. The possibility of performing the study without laxative preparation will be a significant advantage of virtual colonoscopy over optical colonoscopy.

Positron emission tomography with CT

Over the past decade positron emission tomography (PET) has changed from a research tool to a full fledged clinical tool excelling in oncological applications. The concept of this technology is based on the fact that tumor cells have a greater avidity for using glucose via glycolysis than most non-cancerous cells[9]. By administering deoxyglucose labeled with a fluorine-18 which is a positron emitting radionuclide (resultant radiopharmaceutical is fluoro-18-deoxyglucose or FDG), it is possible to visualize the location of a tumor. In the first few years of development of PET improvements were made in scanner and detector crystal design. The most significant recent change has been incorporation of PET and CT in the same unit and fusion of the anatomical information from CT and the physiological information from PET (Figure 5)[10]. Both imaging modalities have individual strengths that complement each other. The newer generations of PET-CT scanners utilize multislice CT that allow oral and intravenous contrast information, obviating the need for a separate staging CT scan.

In the gastrointestinal tract PET-CT is used mainly for oncological applications and has been shown to have greater overall accuracy and cost-effectiveness compared to other imaging modalities[11]. PET-CT in the GI tract is commonly used for initial staging, response to therapy and detection of recurrence of esophageal, gastric (Figure 6), colorectal, and gastrointestinal stromal tumors. Additional applications that are showing initial promise include the evaluation of Crohn's disease[12].

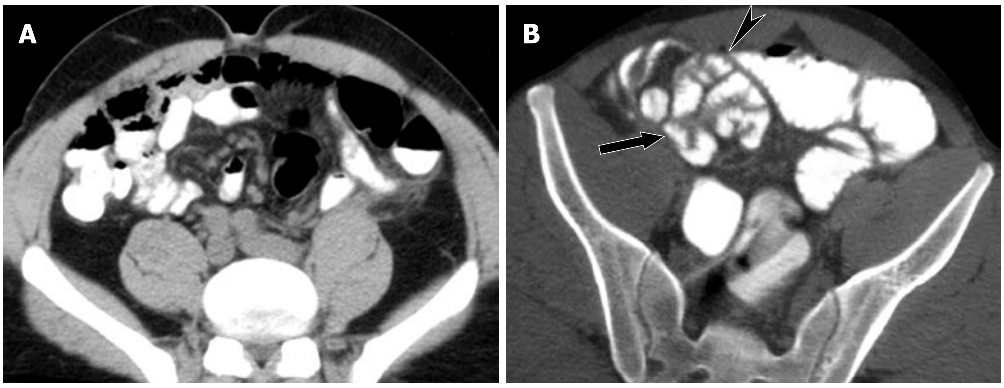

Figure 7 Fifty-four years old with prior hysterectomy presented with abdominal bloating and nausea. **A**: Conventional CT did not show distended bowel or transition point and was interpreted as normal; **B**: CT enteroclysis performed a day later shows distended small bowel loop with beaking (arrowhead) adjacent to anterior parietal peritoneum. Distal small bowel loops were nondistended (arrow). The appearances were of low grade small bowel obstruction due to adhesions.

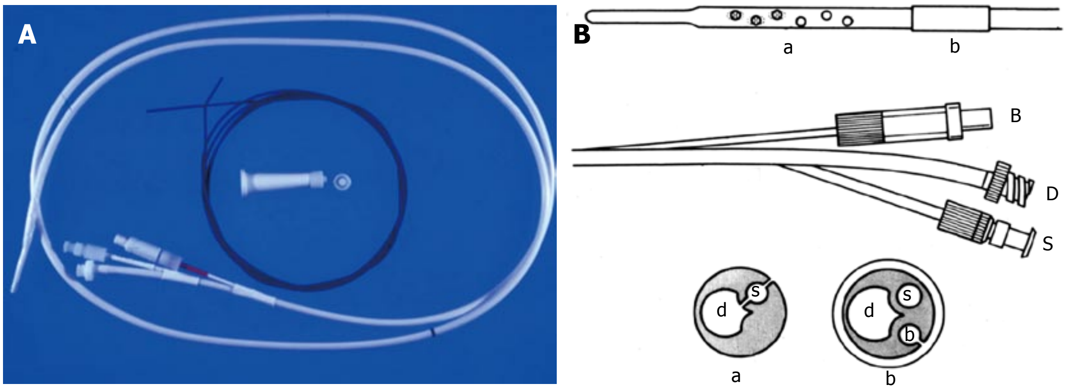

Figure 8 A: Image of MDEC decompression and enteroclysis tube with stiffening wire that helps maneuvering the tube into the proximal jejunum; **B**: Line diagram of the tube. B = balloon port, D = drainage port, S = sump port (helps prevent the tube from becoming obstructed by debris). The inset figures show the cross sectional appearances of the tube at positions a and b.

DIAGNOSIS OF MAJOR ALIMENTARY TRACT DISEASE

Gastric tumors

Currently gastric cancer is diagnosed using endoscopic biopsies and locally staged using endoscopic ultrasound. CT is used or more distant staging. Improvements in CT may allow better detection of local invasion of gastric tumor. In a recent study multislice CT had an accuracy of 88.9% in T staging and 70.4% accuracy in N staging, making it comparable to EUS[13]. Virtual gastroscopy, transparency rendering, and 3D mapping of the tumor can help in surgical planning[14]. These techniques however require significant additional time for image creation and interpretation[15].

Small bowel obstruction

Initial studies of conventional CT in small bowel obstruction reported sensitivities of above 90% to 96%, and accuracy of 95%[16,17]. However, these studies were only included patients with high-grade obstruction. In assessing low grade small bowel obstruction, CT enteroclysis is clearly superior to conventional CT (Figure 7)[18]. In addition to identifying the etiology, severity and probable location of small bowel obstruction, CT is useful for determining the presence of closed loop obstruction and strangulation[18]. Recognition of these complications is of great concern to surgeons, particularly those who believe that a trial of conservative nonoperative management is warranted in simple mechanical small bowel obstruction[19]. With the use of multiplanar and 3-dimensional imaging the confidence of accuracy of answering pertinent clinical questions has considerably improved. The development of a multipurpose long tube (MDEC 1400, Cook Inc, Bloomington, IN) has improved the nonsurgical management of uncomplicated partial small bowel obstruction (Figure 8)[20]. Such long tubes have sump ports that are less likely to be occluded and are designed to be used with suction devices currently used in hospitals. Following adequate decompression of the small bowel, a CT enteroclysis may be performed to detect the site and etiology of obstruction.

Crohn's disease

The main groups of Crohn's disease are active inflammatory, fibrostenosing, chronic smoldering and fistulous types[21]. Differentiation of these groups is important in deciding therapy with immunosuppressant, anticytokine drugs and surgery. For instance, inhibitors of the cytokine tumor necrosis factor-alpha have been shown to useful in healing fistulous disease[22] but have no known beneficial effect on, or may exacerbate, fibrostenotic segments. Such drugs are expensive and careful patient selection is required. Multislice CT is quite sensitive in detecting unexpected active Crohn's disease in patients presenting with nonspecific abdominal pain. In determining the severity and extent of known active Crohn's disease neutral oral contrast with intravenous iodinated contrast is the optimal technique. Mucosal hyperenhancement, submucosal edema, wall thickening, and mesenteric hypervascularity ("comb sign") are well demonstrated by this technique (Figure 2). Enteric fistula, fibrostenotic segments and abscess are also diagnosed by this technique. Isotropic imaging with multiplanar reformats is helpful for diagnosis and surgical planning. The important differentiation of small

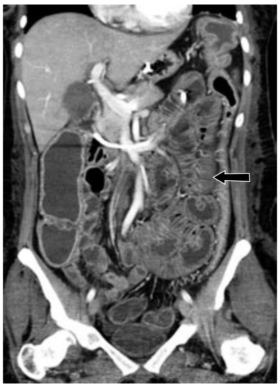

Figure 9 Neutral enteral contrast CT enteroclysis in 27 years old female presented with chronic diarrhea and anemia. There was a prior history of systemic lupus erythematosis. Coronal reformat showed diffuse smooth small bowel wall (arrow) and fold thickening. Small bowel biopsy showed vasculitis.

Figure 10 Sagittal reformat of CT enteroclysis in 63 years old female with unexplained gastrointestinal (GI) bleeding showed 3 cm hypervascular submucosal mass (arrow) arising from mid small bowel, proven as a gastrointestinal stromal tumor at surgery. Prior capsule endocsopy had shown no abnormality, other than jejunal angioectasia.

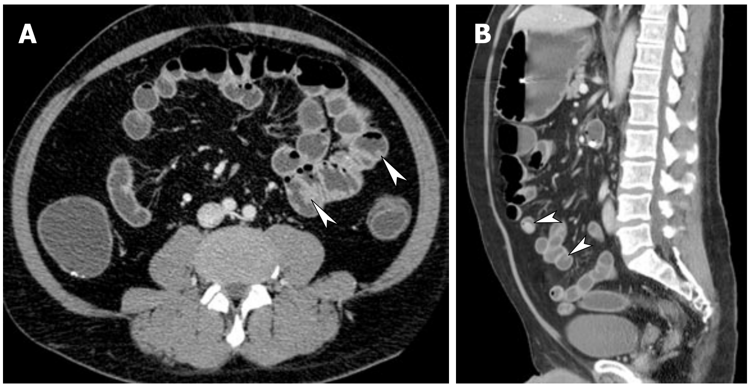

Figure 11 Fifty-two years old male with known Peutz-Jeghers syndrome. Axial (**A**) and sagittal (**B**) images showed multiple polyps of varying sizes in the small bowel (arrowheads). Information regarding the location and sizes of polyps was valuable in performing double balloon endoscopic polypectomy.

Figure 12 Metastatic carcinoid in 59 years old female presenting diarrhea and wheezing. Coronal reformat of isotropic resolution CT enteroclysis performed with neutral enteral contrast showed 3 cm hypervascular mass in distal ileum (arrowhead) and hypervascular liver metastases (arrow).

bowel obstruction due to active inflammation and fibrostenotic disease is accurately performed by CT enteroclysis. Aphthoid lesions of suspected early Crohn's disease, increasingly diagnosed by capsule endoscopy, are usually not visible on CT. If radiological investigation is required in such cases we use barium and carbon dioxide double contrast fluoroscopic enteroclysis. CT is also useful in showing inflammatory small bowel disease other than Crohn's disease (Figure 9).

Small bowel tumors

In the investigation of small bowel mucosal lesions, imaging techniques have had to adapt to the advent of capsule endoscopy. In our institution CT enteroclysis is used to exclude luminal stenosis prior to capsule endoscopy. Where capsule endoscopy is negative despite the high suspicion of tumor, e.g. unexplained gastrointestinal bleeding with positive occult blood, we recommend CT enteroclysis. Capsule endoscopy may miss submucosal lesions (Figure 10). Other reasons for false negative capsule endoscopy include focal lesions at sites where bowel is angulated, where there is rapid or very slow intestinal transit.

The ability to detect polypoid small bowel lesions, as in Peutz-Jeghers, is important when considering double balloon endoscopic polypectomy. In this regard the multiplanar imaging with 16-slice or higher generation CT is useful (Figure 11). In carcinoid tumors the site and number of primary tumors (30% have multiple primary sites) are best diagnosed with CT enteroclysis[23]. Because of its ability to evaluate the small bowel wall and the presence of liver metastases, CT enteroclysis with neutral enteral and intravenous contrast is the preferred technique (Figure 12). Nuclear medicine tests have been used to diagnose and stage carcinoid tumors. Indium-111 or iodine-123 labeled DTPA octreotide, a long acting analogue of somatostatin, has been shown to have a sensitivity of 80%-100% in diagnosing carcinoid[24]. Anatomic localization is improved with the use of single photon emission tomography (SPECT). Fluorine-18 deoxyglucose (FDG) positron emission tomography (PET) may be used for detection of poorly differentiated primary tumors that are not seen with other techniques. However for most small bowel carcinoid tumors, which have slow proliferation, FDG PET is of limited value[24]. PET scanning with fluorine-18 dopa, gallium-68 labeled octreotide or carbon-11 labeled tryptophan has been shown to be very sensitive in localizing tumor extent[24,25]. Small bowel lymphoma is another tumor where FDG PET has been found to be useful. Despite the mild

physiologic uptake in the gastrointestinal tract, a positive FDG PET scan after the completion of chemotherapy in patients with small bowel lymphoma is a strong predictor of relapse[26].

Colonic cancer

The application of virtual colonoscopy to colorectal cancer screening caught the attention of the lay and professional communities following a seminal publication[27] which showed that with modern CT technology, virtual colonoscopy compares favorably with optical colonoscopy. Sensitivity of 94% and specificity of 96% for polyps larger than 1 cm were reported[27]. There remain several hurdles before virtual colonoscopy becomes part of the mainstream of colorectal cancer screening methods. These include limited reimbursement by third party payers, size threshold above which suspected colonic polyps will be investigated, ra-

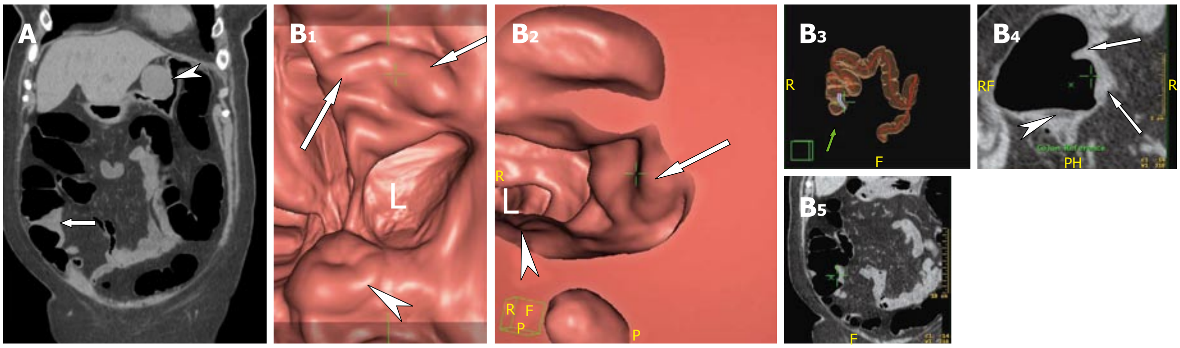

Figure 13 Fifty-eight years old male with incomplete optical colonoscopy. **A**: Coronal reformat showed a mass in the medial right colon (arrow) consistent with colonic cancer. A second mass (arrowhead) showed exophytic growth from the stomach and was subsequently proven to be a gastrointestinal stromal tumor; **B**: Images of virtual colonoscopy showed the mass (arrows) adjacent to the ileocecal valve (arrowheads). L = colonic lumen.

tionale for further work up of incidental findings, such as small low density renal and liver lesions. Currently, virtual colonoscopy is used clinically in patients with incomplete or failed optical colonoscopy (Figure 13) and those with contraindications to sedation. This test has been shown to affect treatment strategy in 7.5 to 19% of patients by identifying additional adenomas and carcinomas[28,29]. The use of virtual colonoscopy in known colon cancer is helpful in evaluating the whole colon for possible missed polyps and stage the cancer at the same time.

In conclusion the practice of alimentary tract imaging will continue to change. Details of the viscera which in the past were only diagnosed by indirect manifestations on barium examination are now demonstrated in exquisite detail by multislice CT. Functional information afforded by PET scanning adds further to the utility of CT in diagnostic imaging. Further developments in 3D imaging for the entire alimentary tube will add to presurgical mapping of many disorders. The modern era of gastrointestinal radiology is here. Active collaboration among surgeons and radiologists will ensure efficient utilization of the various advances discussed in this article.

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