US of Gastrointestinal Tract Disease[1]

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Abbreviation: GIST = gastrointestinal stromal tumor

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See discussion on this article by Wilson (pp 69–70).

SA-CME LEARNING OBJECTIVES

After completing this journal-based SA-CME activity, participants will be able to:

- Describe the optimal US technique for bowel evaluation.
- Discuss the basic physiology of bowel motility and how it may be altered in different pathologic states.
- Recognize the US appearance of normal and abnormal bowel on static and dynamic US images.

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The potential use of ultrasonography (US) in evaluating gut disease has been underappreciated in most diagnostic imaging departments in North America. The impression that US has a questionable role in bowel assessment is related to the operator-dependent nature of the modality, the technical challenges of performing bowel US examinations, and the lack of familiarity of radiologists and technologists with the US appearances of normal and abnormal bowel. However, with development of technical experience by the sonographer and integration of a clinical focus at patient evaluation, US can become a powerful tool for bowel assessment. Unlike computed tomography and magnetic resonance imaging, it provides a widely available, noninvasive, inexpensive method for evaluating the gut without the use of ionizing radiation. These factors are of particular importance in young patients and those who require recurrent follow-up imaging. Because US is performed with real-time imaging, the modality also allows the sonographer to view and assess the motility properties of the bowel, a feature that has not been previously used to its full potential. Color Doppler US can yield useful information about mural vascularity in bowel disease when used in conjunction with gray-scale findings and clinical symptoms. Radiologists should be familiar with the static and dynamic US appearances of the normal and abnormal bowel, recognize features of various pathologic conditions, and understand potential errors at imaging interpretation. *Online supplemental material is available for this article.*

Introduction

The use of ultrasonography (US) in evaluating gut disease has been underappreciated in most diagnostic imaging departments in North America. Traditionally, the role of US in bowel assessment has been limited to diagnosis of appendicitis and examination of the rectum, anal sphincters, and surrounding tissues with endorectal or endovaginal imaging. In children, US is also commonly used to examine patients with suspected intussusception and hypertrophic pyloric stenosis. This narrow focus has been perpetuated as radiologists and US technologists have become unfamiliar with the use of US to provide high-quality images of other regions of the gastrointestinal tract in normal and pathologic states. The impression that US has a questionable role in bowel assessment is related to the operator-dependent nature of the modality as well as the technical challenges of performing bowel US.

Although visualization of the bowel may be difficult because of factors that limit any abdominal US examination, such as body habitus and patient cooperation, evaluation of the gut may be particularly challenging because of decreased visibility due to overlying intraluminal bowel gas and gas-related artifacts, a factor that could lead to

TEACHING POINTS

- Most commonly benign conditions are associated with preservation of the gut signature and involve long segments of bowel, while malignant conditions are associated with destruction of the gut signature and involve short segments of bowel. Occasionally, aggressive inflammatory processes may result in focal disruption of the gut signature.
- Although it may not be possible to diagnose the precise disease entity producing a change in bowel motility, alterations in motility can be used to support a diagnosis as well as to suggest the severity of disease involvement.
- US is often the first imaging modality used to assess patients with undiagnosed abdominal pain and can demonstrate a wide variety of bowel-related diseases.
- Evaluation of the bowel with US begins with the patient history, followed by US assessment of the wall thickness, gut signature, and motility.
- Although US should not be considered a replacement for CT, there is value in a multimodality imaging approach when assessing and following up patients with acute or subacute abdominal symptoms.

frustration and misinterpretation by less experienced sonographers. Furthermore, in complicated cases, meticulous imaging may be required, which can increase the imaging time and overall duration of the examination. The technical difficulty of performing bowel US, coupled with occasional prolonged imaging times and overall lack of familiarity with the technique, can lead some imagers to question the value of US for assessment of the gastrointestinal tract. Nevertheless, with development of technical experience by the sonographer and integration of a clinical focus in patient evaluation, US can become a powerful tool for bowel assessment in patients with known or suspected gut-related disease.

The value of US in these patients is not limited to initial evaluation of the bowel at presentation but includes continued follow-up in conjunction with clinical symptoms and monitoring of treatment response. Furthermore, US often is the first cross-sectional imaging modality that is used in patients with undiagnosed abdominal pain. Knowledge of the use of US in bowel assessment, coupled with technical expertise in visualizing the gastrointestinal tract, permits the imager to localize gut-related disease in patients in whom bowel disease was not clinically suspected.

Computed tomography (CT) with or without small bowel enterography is often the modality of choice for imaging of patients with gut-related disease. However, the use of ionizing radiation is a concern, particularly in young patients and those who require multiple repeated CT examinations during recurrent exacerbations of their underlying conditions or for monitoring. Although the full impact of radiation exposure from multidetector CT has yet to be determined, there does appear to be an associated risk for future development of fatal malignancies (1,2). Peloquin et al (3) estimated the total effective dose of ionizing radiation from the date of onset of symptoms in a population-based cohort of patients with inflammatory bowel disease. They showed that generally in this population, the annualized exposure to diagnostic ionizing radiation was equivalent to natural background radiation exposure; a small subset of patients with inflammatory bowel disease showed substantially higher levels of radiation exposure. On the basis of these findings, the authors recommend that medical guidelines be developed to minimize the radiation dose to these patients.

Magnetic resonance (MR) imaging does not entail the use of ionizing radiation and is being used increasingly in the management of patients with inflammatory bowel disease (4). However, MR enterography requires a large amount of oral fluid, intravenous contrast agent injection, and a long examination time, and there may be issues with patient motion and tolerance. The high cost, lack of widespread equipment availability, and subspecialized clinical expertise are other concerns with the routine use of MR imaging in patients with known or suspected bowel disease.

US is a safe, noninvasive, inexpensive method for evaluating the bowel without the use of ionizing radiation. It is widely available, and although experience and technical expertise are more important when assessing the bowel compared with other regions of the abdomen, such skills can be obtained through dedicated training and persistent meticulous imaging (5).

Because US is performed with real-time imaging, the modality also allows the sonographer to view and assess the motility properties of the bowel. Evaluation of gut motility with US has been previously underutilized by sonographers. However, with the advent of high-quality cine clips as an integral component of US studies, documentation of bowel motility abnormalities is now possible.

This article uses static US images and dynamic US cine clips to demonstrate the normal appearance of the bowel, the abnormal appearance of the bowel in various pathologic conditions, and potential errors in imaging interpretation. Because the value of US for diagnosis of appendicitis and for imaging of the rectum and anus has been described in detail previously, this article focuses on abnormalities in other areas of the gastrointestinal tract in adults.

Normal Bowel Morphology

As viewed on a US image, the normal bowel from the stomach to the colon has an average mural thickness of 3–5 mm, depending on the degree

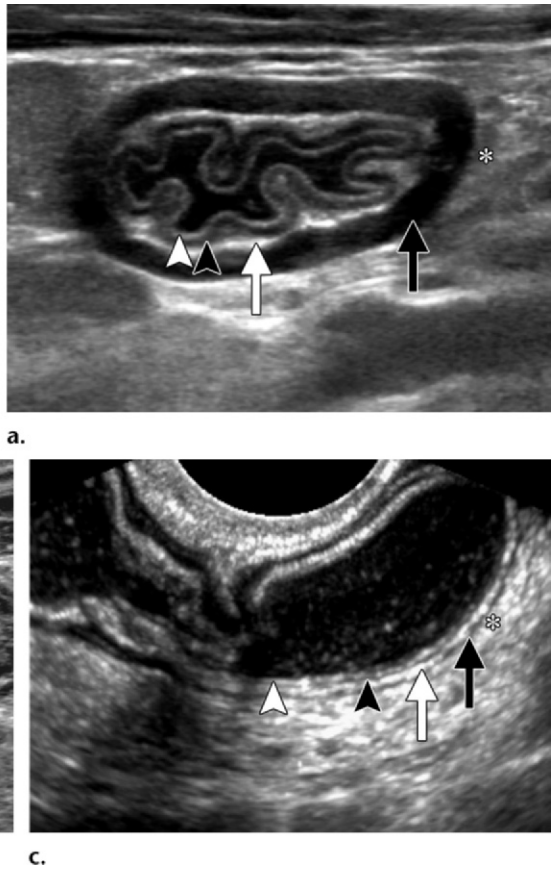


Figure 1. Normal bowel in three patients. Transverse US image of the stomach antrum in a 20-year-old woman **(a)**, longitudinal US image of the ileum in a 40-year-old man **(b)**, and endovaginal longitudinal US image of the sigmoid colon in a 36-year-old woman **(c)** show the five different wall layers that comprise the gut signature. The innermost echogenic layer (white arrowhead) represents the interface between the gut lumen and the mucosa, the adjacent hypoechoic layer (black arrowhead) represents the muscularis mucosa, the adjacent echogenic layer (white arrow) represents the submucosa, the adjacent hypoechoic layer (black arrow) represents the muscularis propria, and the outermost echogenic region (*) represents the serosa.

of distention (6,7). Regardless of its caliber, the bowel shows a stratified morphology consisting of five concentric rings of alternating echogenicity referred to as the gut signature (Fig 1). Each of the rings seen at US examination corresponds to a different layer of the bowel wall seen at histologic analysis. US is the only imaging modality that can depict these histologic layers, which makes it particularly useful in bowel evaluation.

The innermost component of the gut signature is an echogenic line that represents the interface between the bowel lumen and the gut mucosa. This line is commonly referred to as the mucosal layer, despite the fact that it actually is an interface between the mucosa and the intraluminal bowel contents. Adjacent to this is a thin hypoechoic ring corresponding to the muscularis mucosa. Peripheral to the muscularis mucosa is an echogenic ring that represents the submucosa, followed by the hypoechoic muscularis propria and, most peripherally, the echogenic serosa (Fig 1). Most benign conditions are associated with preservation of the gut signature and involve long segments of bowel, while malignant conditions are associated with destruction of the gut signature and involve short segments of bowel (Table). Occasionally, aggressive inflammatory processes may result in focal disruption of the gut signature (8).

Normal Bowel Motility

The terms *bowel motility* and *peristalsis* are used interchangeably in the literature. The pathophysiology of peristalsis is not completely understood and has resulted in the development of various models and theories. All such models, however, are based on the premise that normal gut motility is essential for life. There are different mechanisms throughout the body at both the structural and cellular levels that control bowel motility. These multiple overlapping control systems developed as an evolutionary advantage to ensure that injury or failure of any one system will not automatically lead to intestinal paralysis and eventual death. Although a discussion of the theories describing the control of gut motility at a cellular and subcellular level is beyond the scope of this article, the imager should understand the different types of motility patterns and contractions that can be observed throughout the gastrointestinal tract (9).

Bowel motility is required for mixing and turning over the intraluminal contents, as well as for propulsion of the contents through the bowel. The intensity of mixing and the rate of propulsion vary in different regions of the gut because the digestive and absorptive functions are not constant throughout the gastrointestinal tract. Therefore, the transit of contents in the

Gray-Scale and Color Doppler US Features of Common Bowel Diseases

Disease	Bowel wall thickness	Gut signature	Flow at Color Doppler US
Crohn disease	Increased	Usually preserved; may be disrupted with severe inflammation	Increased during active inflammation
Ulcerative colitis	May be normal or increased	Preserved	Increased during active inflammation
Bowel obstruction (nonneoplastic)	Usually normal; may be thickened	Usually preserved; may be disrupted	Usually preserved
Diverticulosis	May be mildly increased secondary to hypertrophy of the muscularis propria	Preserved	Normal
Diverticulitis	Increased	Usually preserved unless there is severe inflammation	Increased during active inflammation
Bowel hemorrhage	Increased	Preserved or disrupted	Normal or decreased
Bowel ischemia	Increased	Preserved or disrupted	Usually decreased
Bowel neoplasms	Increased focally or circumferentially, depending on the growth pattern of the tumor	Disrupted	Variable, depending on the tumor

tract occurs in irregular incremental steps as opposed to a smooth continuous stream (10).

The motility of the stomach governs its ability to store food in the fundus and gradually move it to the body and antrum, where the food mixes with secretions in preparation for passage into the duodenum and small bowel. The gastric emptying time is dependent on the content of the meal in terms of the proportions of carbohydrates, proteins, and fat, as well as its viscosity. In the proximal small bowel, motility mixes the contents with endocrine and exocrine secretions and rapidly spreads the mixture over the surface to increase absorption. In the distal small bowel, however, motility produces an intensified mixing but slows the propulsion. Although the transit time of the small bowel is determined by the nutritional content of the meal, it takes approximately 2 hours for the food bolus to reach the ileocecal valve. The contents then enter the colon in a liquid form. Because the absorptive rate of the colon is significantly slower compared with that of the small bowel, the colonic motility turns over the contents extensively while maintaining ultraslow propulsion and transit time. In general, as the ingested meal travels through the digestive tract to the rectum, the mixing and turning-over motion increases, while the propulsion rates decrease (10,11).

The various combinations of mixing and propulsion are controlled by the smooth muscle cells of the gut, which produce different types of contractions that may be propagating or nonpropagating. The different types of contractions include rhythmic phasic contractions, giant migrating contractions, retrograde giant contractions, and tonic contractions. These contractions are controlled by both neural and myogenic regulatory systems as well as sensory signals generated from local and distant regions of the gastrointestinal tract (10).

Rhythmic phasic contractions are detected in the postprandial state and produce slow distal propulsion and mixing of the intraluminal contents. Giant migrating contractions occur spontaneously and are often seen during fasting. They are larger in amplitude and longer in duration than rhythmic phasic contractions and rapidly propel the intraluminal contents in an anal direction (Movie 1). Retrograde giant contractions are similar in amplitude and duration to giant migrating contractions; however, they propel the contents in an oral direction in preparation for vomiting. Tonic contractions occur in the circular smooth muscle cells of the sphincters and organ junctions (eg, the ileocecal valve) and maintain the gut lumen in either a partial or completely closed state to prevent reflux (10).

Different bowel pathologic conditions have the potential to alter normal gut motility. Diminished peristalsis is an indicator of unhealthy bowel that is seen in small bowel inflammation, obstruction, ischemia, enteritis, infiltrative processes, and diseases. There is minimal literature regarding documentation of alterations in bowel motility at cross-sectional imaging. However, the real-time imaging capability of US can provide a window into observing the motion of the bowel in patients

with optimal visibility. The findings can be stored as cine images, which can be used for documentation and future reference during follow-up studies. Although it may not be possible to diagnose the precise disease entity producing a change in bowel motility, alterations in motility can be used to support a diagnosis as well as to suggest the severity of disease involvement.

Imaging Technique

US is often the first imaging modality used to assess patients with undiagnosed abdominal pain and can demonstrate a wide variety of bowel-related diseases. In many departments, routine US of the bowel is not performed in all patients. Nevertheless, evaluating the bowel as a routine component of the US study is particularly beneficial in patients with known or suspected bowel disease. In addition, US screening of the bowel may also result in diagnosis of incidental gut disease in patients with no history of bowel disease. This includes the use of abdominal US in patients with nonemergent as well as emergent symptoms, such as patients with suspected cholecystitis and appendicitis. However, imaging and assessment of the bowel with US is dependent on patient body habitus; the presence of intraluminal gas, which can obscure visualization of the underlying gut; and the skill of the sonographer.

Evaluation of the bowel with US begins with the patient history, followed by US assessment of the wall thickness, gut signature, and motility. The patient should first be interviewed to obtain pertinent information regarding a clinical history of bowel disease and the precise location of any abdominal pain or tenderness. Initial imaging of the gut should be performed in all four quadrants with use of a curvilinear probe (3.5–5 MHz) to detect any evidence of thickened bowel and any ancillary findings such as lymphadenopathy, inflamed perienteric fat, and fluid collections. Specific attention should also be focused on the region of tenderness or pain described by the patient. A higher-frequency probe (7–12 MHz) can subsequently be used to further image regions of suspected bowel disease because the higher frequency provides better resolution of the bowel wall layers and surrounding tissues. However, visibility of the bowel with use of higher-frequency transducers depends on the body habitus of the patient as well as the depth of the insonated loop of bowel within the abdomen. In addition to screening the entire abdomen, the imager should give specific attention to focal areas of tenderness or pain that have been identified by the patient.

The bowel should initially be evaluated according to its wall thickness and gut signature, specifically to document whether there has been an interruption in the signature. Loops that appear abnormal should be imaged in orthogonal planes to prevent misinterpretation. The thickness and echogenicity of the perienteric fat in the surrounding tissues should be assessed, as well as any associated fluid collections, fistulas, sinus tracts, lymphadenopathy, or masses. Once an abnormal loop of bowel is identified, the course of the bowel should be traced to document the length of the abnormality and any associated findings.

Assessment of the bowel with color Doppler US can provide additional information regarding mural vascularity. However, accurate evaluation with Doppler US can be challenging because of tissue motion artifacts from peristalsis, as well as low-velocity flow within the wall vasculature, which may be below the detection threshold (12). Mural hyperemia is most commonly observed with inflammatory, or sometimes infectious, conditions of the gut. The absence of flow in a thickened loop of bowel is highly suggestive but not diagnostic of ischemia in the correct clinical context. Findings at color Doppler US should therefore be interpreted in conjunction with gray-scale US findings and the clinical presentation of the patient (13).

Visualization of the gut in the pelvis and lower quadrants is frequently limited by the deep position of the bowel, which is often obscured by intraluminal gas from more superficial loops of gut. Graded compression, as described by Puylaert (14), can improve the ability to visualize and assess the bowel. The application of pressure with the US transducer causes intervening loops of bowel to be either displaced or compressed such that overlying intraluminal gas is removed from the scanning field. Graded compression also reduces the distance between the transducer and the area of interest and allows use of higher-frequency transducers with greater resolution (14). In women, endovaginal US may prove useful particularly when evaluating loops of gut in the cul-de-sac as well as the sigmoid colon, rectum, anus, and appendix located in the deep pelvis (15,16).

The motility pattern of the abnormal loops can be documented with the use of high-quality cine US images. The loop should be observed for the presence or absence of peristalsis. In addition, the direction of intraluminal content flow should be noted (eg, anal or oral direction, stagnant, or to-and-fro motion).

Determining the direction of content flow is often very challenging, as this usually requires imaging of long segments of bowel with a relatively small field of view. In some instances, it may not be possible to determine the direction of content flow because of limited visibility as

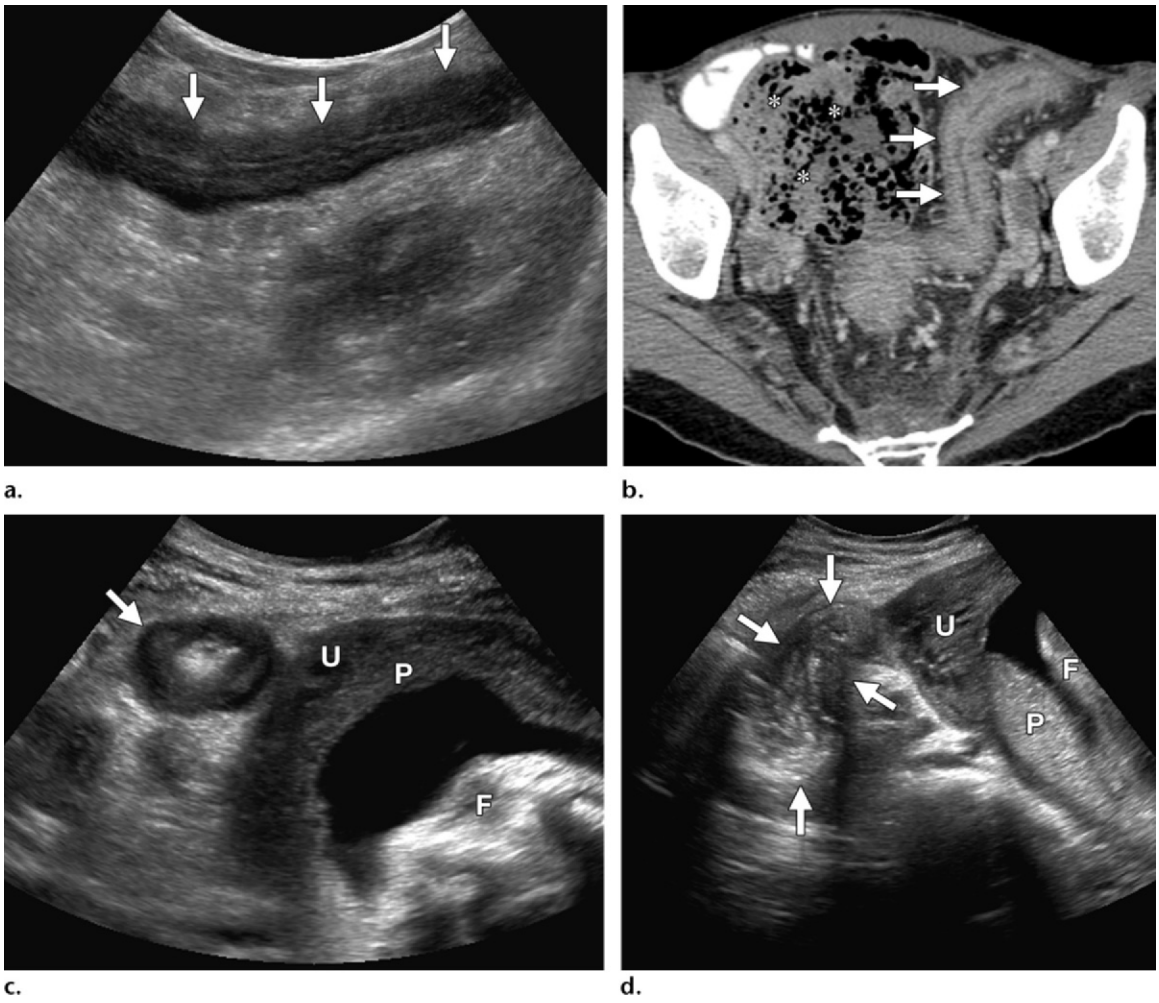


Figure 2. Typical US appearance of uncomplicated Crohn disease. **(a, b)** Longitudinal US image **(a)** and axial CT image **(b)** show continuous wall thickening in a long segment of sigmoid colon (arrows) in a 28-year-old woman with Crohn disease. ∗ in **b** = unopacified bowel loops. **(c, d)** Transverse **(c)** and longitudinal **(d)** US images show a short segment of thickened bowel (arrows) due to Crohn disease in a 30-year-old pregnant woman who presented at 18 weeks of gestation with right lower quadrant pain. The initial clinical impression was that the pain was secondary to appendicitis, but US examination demonstrated Crohn disease. *F* = fetus, *P* = placenta, *U* = uterus.

a result of body habitus, overlying intraluminal gas, and nondistended loops of bowel, which may be difficult to image and trace at US. However, in many instances, if visibility permits, the direction of the contents can be determined at real-time imaging by following long segments of bowel in a continuous fashion. Depending on the proximity of the bowel disease to the duodenum, ileocolic junction, and known regions of anastomosis, these areas can be used as landmarks to assist in determining the direction of content flow.

Inflammatory Bowel Disease

Crohn Disease

Transabdominal US is a highly effective modality for detecting active Crohn disease, with reported sensitivities and specificities of 75%–94% and 67%–100%, respectively (17). Apart from its use in detecting active disease, US can also be used to follow up patients with Crohn disease after medical treatment and to potentially help identify associated complications. Because US does not entail the use of ionizing radiation, it may be a particularly valuable asset in the management of patients with inflammatory bowel disease because they often are young, may be pregnant, and frequently require multiple imaging studies.

The most common US finding in Crohn disease is bowel wall thickening (18). This most frequently occurs in the terminal ileum and cecum but may involve any part of the gastrointestinal tract. The involved segments are usually noncompressible, rigid, and fixed. The wall thickening is circumferential and may be continuous and uninterrupted or intermittent, with intervening regions of nonthickened normal-appearing bowel termed *skip lesions* (Fig 2). A small amount of perienteric free fluid may also

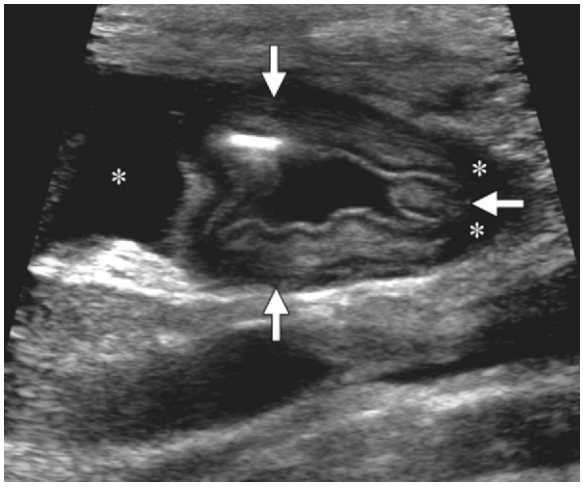


Figure 3. Transverse US image in a 37-year-old man shows a small amount of perienteric free fluid (*) surrounding a thickened loop of terminal ileum (arrows).

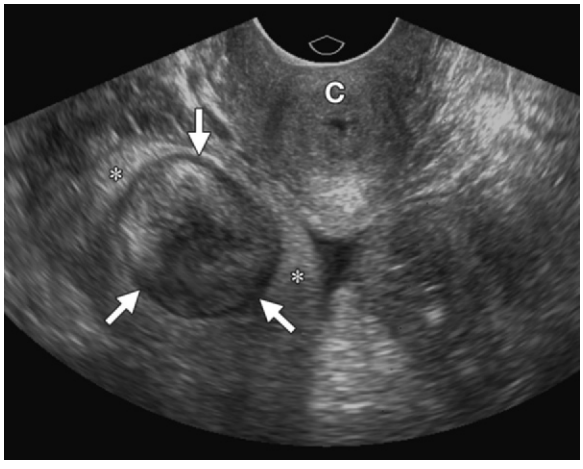
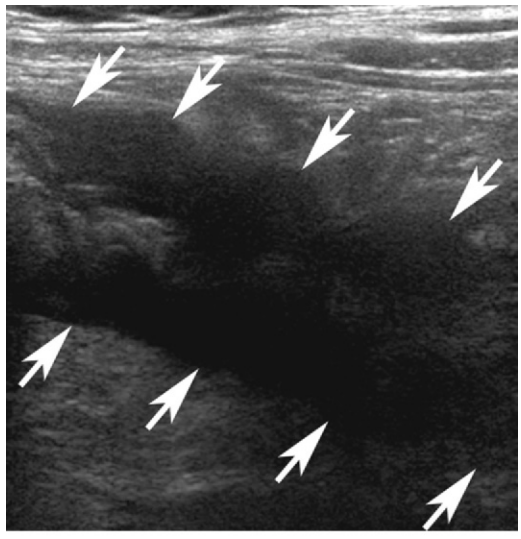
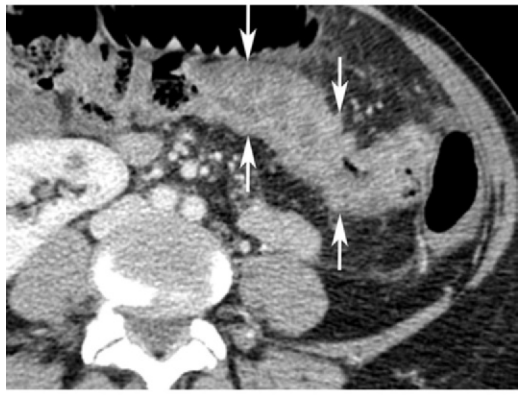


Figure 4. Transvaginal US image in a 28-year-old woman with Crohn disease shows a thickened ileum (arrows) with adjacent echogenic creeping fat (*). *C* = cervix.



a.



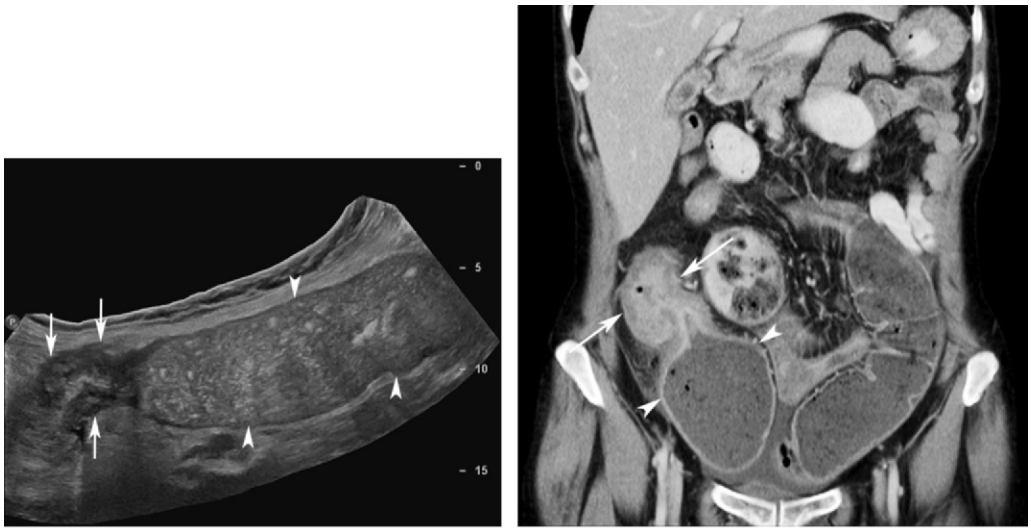
b.

Figure 5. Loss of the gut signature in a 47-year-old woman with Crohn disease. **(a)** Longitudinal US image obtained with a 5- to 12-MHz linear transducer shows a thickened loop of sigmoid colon (arrows) due to active Crohn disease. The bowel wall is diffusely hypoechoic, with loss of the normal bowel layer stratification. **(b)** Axial CT image shows diffuse thickening of the involved loop of sigmoid colon (arrows).

be observed adjacent to these thickened loops of bowel (Fig 3).

In the regions of involvement, there is hypertrophy of the mesenteric adipose tissue, which causes separation of the bowel loops at imaging. This hypertrophy of the mesenteric fat occurs despite overall weight loss in the patient. In addition, ectopic tissue known as "creeping fat" is also identified around the active regions of inflammation; this tissue extends to the antimesenteric surface of the bowel and tends to correlate with the degree of inflammation. The creeping fat appears as an echogenic region around the involved bowel and blends into the adjacent hypertrophied mesenteric fat. In the literature, *creeping fat* is often defined as a proliferation and extension of the mesenteric fat. However, the results of more recent animal studies have suggested that this creeping fat represents inflammatory and fibrous-based tissue and is not an adipose tissue (19) (Fig 4).

US can potentially be used to evaluate the morphology of the bowel wall in patients with Crohn disease. The gut signature is usually preserved in these patients. However, in some patients, there may be loss of the normal gut stratification, which may be difficult to differentiate from malignancy (Fig 5). Hata et al (20) compared in vivo US images of 12 patients with Crohn disease with in vitro images and histopathologic findings from the surgically resected segments of bowel. They showed that loss of the normal gut stratification is more common in active disease and is characterized by inflammatory histologic changes (21). A follow-up study by the same authors showed that the morphologic features of the bowel wall, including mural thickness



a. b.

Figure 6. Luminal narrowing and loss of the normal gut signature in a 58-year-old woman with Crohn disease. **(a)** Longitudinal US image shows focal ileal wall thickening, luminal narrowing, and loss of the normal gut signature (arrows) due to active Crohn disease. The proximal small bowel (arrowheads) is grossly dilated as a result of the small bowel obstruction. **(b)** Coronal CT image shows wall enhancement, thickening, and almost complete collapse of the lumen in the involved segment of ileum (arrows), with dilatation of the proximal small bowel loop (arrowheads).

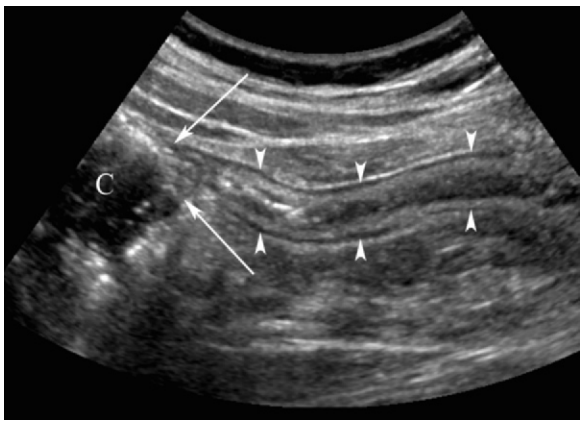


Figure 7. Luminal narrowing with preservation of the normal gut signature in a 36-year-old man with Crohn disease who underwent distal ileal resection and ileocolic anastomosis and experienced an acute recurrence. Longitudinal US image shows continuous thickening and luminal narrowing of a long segment of the neoterminal ileum (arrowheads), which extends to the ileocolic anastomosis (arrows) and causes a partial small bowel obstruction. *C* = colon.

and wall signature, correlated strongly with endoscopic findings but only weakly with clinical and biologic indices of inflammation (22). Therefore, loss of the normal gut signature is suggestive of active inflammatory histologic changes but may not correlate with the clinical presentation of the patient. In addition, there is no evidence in the literature to suggest that loss of bowel signature is of prognostic value with regard to predicting patient outcome or treatment response.

Luminal narrowing can occur in Crohn disease because of gross inflammatory thickening of the bowel wall or because of fibrotic strictures. At imaging and clinical assessment, it often is challenging to differentiate inflammatory strictures from fibrotic strictures. It has been suggested that loss of normal bowel wall stratification is compatible with an inflammatory stricture with a low degree of fibrosis, while a maintained gut signature is more consistent with a fibrotic stricture (Figs 6, 7; Movie 2). The bowel wall in fibrotic strictures shows a preserved signature, often with a prominent echogenic submucosal layer that is sometimes thicker than in the normal bowel, secondary to collagen deposition in that layer. With inflammatory strictures, the bowel wall shows loss of the normal signature and appears hypoechoic secondary to mural hyperemia and neovascularization (23).

Several authors have investigated the prospect of using power or color Doppler US to evaluate mural vascularity within loops of bowel that appear abnormal to quantify disease activity. Correlation has generally been found between power Doppler US demonstration of increased wall vascularity and endoscopic or histologic evidence of activity; however, there is weak correlation with clinical or biochemical indicators of active disease (21,24,25).

In patients who have completed medical treatment of an exacerbation of Crohn disease, demonstration of bowel wall hyperemia at color Doppler US has been associated with an increased risk of relapse (26). Although Doppler US of the bowel may contribute to overall assessment of disease

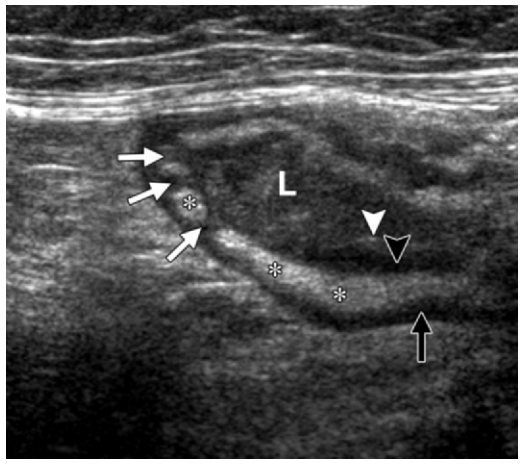
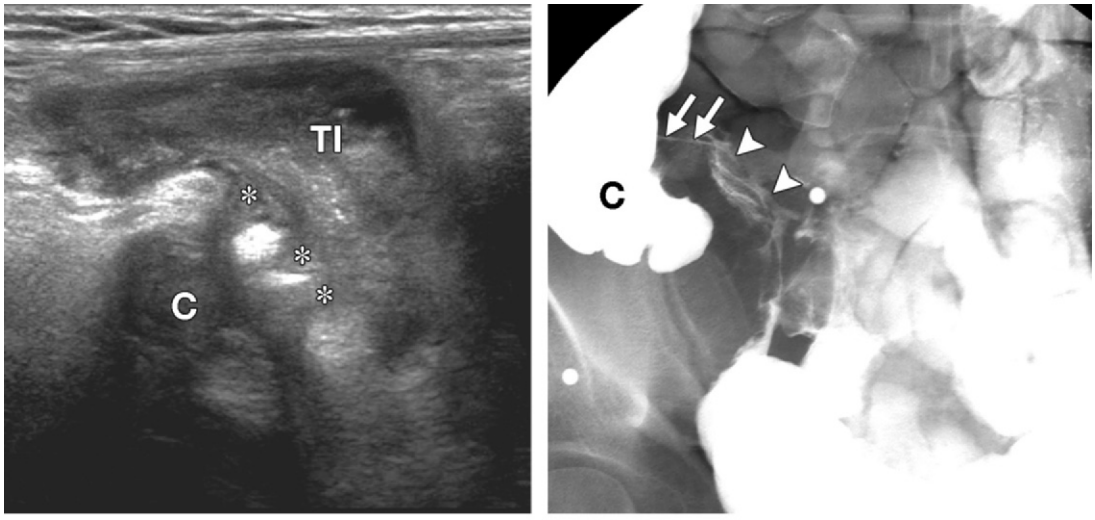


Figure 8. Intramural ulcers in a 54-year-old woman with Crohn disease. Oblique US image shows linear hypoechoic bands (white arrows) in a segment of ileum, which represent intramural ulcers that traverse through the echogenic submucosa (*) . Black arrow = muscularis propria, black arrowhead = muscularis mucosa, white arrowhead = mucosal interface, *L* = lumen.



a. **b.**

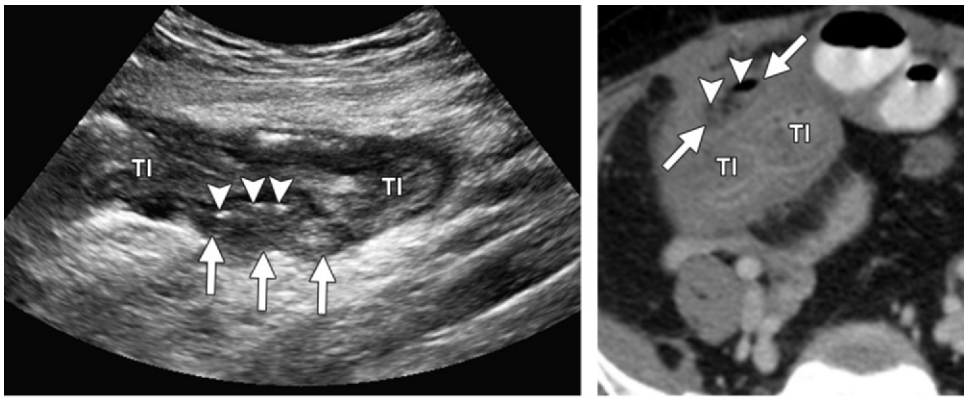
Figure 9. Enteroenteric fistula in a 24-year-old woman with Crohn disease. *C* = cecum. **(a)** Longitudinal US image shows a thickened terminal ileum *(TI)* due to Crohn disease, with three fistulas (*) extending to the cecum. **(b)** Image from a small bowel barium study shows the thickened terminal ileum (arrowheads), with a thin track of contrast material (arrows) that represents a fistula connecting to the cecum. A single fistula was seen at the barium study.

activity, these findings should be evaluated in conjunction with findings on gray-scale US images. The use of US contrast agents can increase the sensitivity of Doppler US to flow within the bowel wall. However, the role of Doppler US, with or without intravenous contrast agents, in diagnosis and monitoring of the gut for active inflammatory bowel disease should be further examined (12).

Occasionally, intramural ulcerations or abscesses may be identified traversing through the different layers of the wall (Fig 8). Deep ulcer formation in Crohn disease may lead to transmural inflammation, sinus tract formation, and in some cases, fistula formation. At US examination, detection of bowel fistulas is usually challenging and requires meticulous imaging. Enteric fistulas appear as linear bands of variable echogenicity that extend from a loop of thickened bowel to an adjacent segment of gut or to surrounding structures such as the bladder, vagina, or skin (Fig 9).

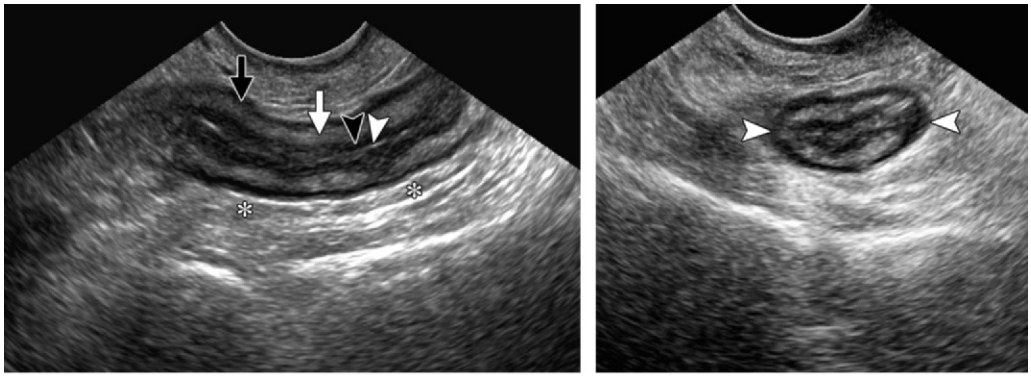
Transmural inflammation may also result in perienteric inflammation and infection. In the phlegmonous stage, a poorly defined hypoechoic area without fluid content may be observed adjacent to the involved segment of bowel. Abscess formation may occur, with development of a complex fluid collection that may or may not contain intracavity gas (Fig 10).

Segments of bowel involved with active Crohn disease show variable gut motility ranging from aperistalsis to a moderate decrease in peristalsis (Movies 3, 4). The pathophysiology of this alteration in bowel motility is uncertain; however, it has been suggested that such changes are caused by the presence of a ganglioneuritis as well as alterations in the interstitial cells of Cajal in these patients. These interstitial cells are viewed as



a. b.

Figure 10. Air-containing abscess in a 39-year-old woman with Crohn disease. *TI* = terminal ileum. **(a)** Longitudinal US image shows a thickened terminal ileum with an associated abscess (arrows). Echogenic foci (arrowheads), which represent tiny bubbles of air, are seen abutting the bowel wall. **(b)** Axial CT image shows the segment of thickened ileum, with the adjacent small abscess (arrows). Multiple bubbles of air (arrowheads) are seen in the abscess.



a. b.

Figure 11. Ulcerative colitis in a 34-year-old woman. Longitudinal **(a)** and transverse **(b)** transvaginal US images of the sigmoid colon (arrowheads in **b**) show preservation of the gut signature. The different layers are labeled in **a** (* = serosa, white arrowhead = mucosal interface, black arrowhead = muscularis mucosa, white arrow = submucosa, black arrow = muscularis propria).

"pacemaker" cells that are vital for normal bowel peristalsis. Ohlsson et al (27) assessed the enteric neuroanatomy of 30 patients with inflammatory bowel disease and detected ganglioneuritis in 11 of 19 patients with Crohn disease and in five of 11 patients with ulcerative colitis. In both groups, changes were also observed in the interstitial cells of Cajal. Therefore, changes in these cells as well as the presence of ganglioneuritis could potentially result in an alteration in normal bowel motility (28).

Ulcerative Colitis

Ulcerative colitis is characterized by mucosal inflammation and affects the colon in a continuous manner from distal to proximal. Limited information is found in the literature with respect to the US appearance of ulcerative colitis. The main abnormalities of the bowel wall include thickening, hyperemia, and loss of haustra coli. Mural stratification is preserved in most patients with ulcerative colitis because of the superficial pattern of inflammation (Fig 11). The presence of toxic megacolon should be suspected when, at US examination, a marked decrease in wall thickness (<2 mm) is found in conjunction with dilatation (>6 cm) of the colon and increased free fluid (21,29).

Acute Conditions

In most diagnostic imaging departments, patients with an acute abdominal condition or severe abdominal pain are evaluated with CT. Nevertheless, there is a role for US in assessing these patients as well as those with undiagnosed abdominal pain. The sonographer should be aware of the different US appearances of abnormal bowel, as this may be detected incidentally in patients in whom bowel disease is not clinically suspected. Although US should not be considered a replacement for CT, there is value in a multimodality imaging approach when assessing and following up patients with acute or subacute abdominal symptoms.

Bowel Obstruction

The typical US appearance of bowel obstruction depends on the time of imaging relative to the onset of the obstruction. In the acute stage, the gut wall is thin, and there is hyperperistalsis of the bowel, with back-and-forth movement of the intraluminal contents (Movie 5). As the obstruction progresses, the bowel becomes aperistaltic and the walls may become thick and edematous. If an obstruction is detected at US, the bowel distal to the obstructing lesion is often smaller in diameter than the more proximal loops (30). However, the caliber of the loops distal to the obstructing lesion is dependent on whether the obstruction is complete or incomplete. Ko et al (31) reported that preoperative US examination showed an accuracy of 89% in diagnosis of small bowel obstruction.

Ileus is a form of bowel obstruction related to adynamic function of the bowel. The bowel lumen is patent, dilated, and fluid filled and demonstrates minimal peristalsis. There often is poor visibility and poor assessment of the bowel because of increased intraluminal gas.

Diverticulosis and Diverticulitis

Diverticulosis continues to rise in prevalence, especially in Western countries, affecting 5%–10% of the population over 45 years of age and approximately 80% of those over 85 years of age (32). A diverticulum of the colon morphologically represents a saccular outpouching caused by herniation of the mucosa and submucosa through a defect in the muscular lining of the colon. At US, an uncomplicated diverticulum appears as a thin-walled round or oval outpouching that contains echogenic material thought to represent air or feces, which often produces distal acoustic shadowing. The perienteric fat around the diverticulum is normal in echogenicity (33). In diverticulosis, the muscularis propria may be thickened because of hypertrophy (34). However, a solitary finding of a thickened muscularis propria in a region of thickened bowel, without evidence of diverticula at US examination, is not diagnostic of diverticula disease. Pathologic studies have documented hypertrophy of the muscularis propria in other conditions causing bowel wall thickening, such as cystic fibrosis (35). Nevertheless, observation of a prominent muscularis propria in a segment of thickened bowel should prompt the sonographer to meticulously scan for diverticula.

Acute diverticulitis occurs when the apex of a diverticulum is occluded by stool or food particles, resulting in a microperforation of the diverticulum. In patients with diverticulitis, defining the location, severity, and presence of complications is essential to proper management. Verbanck et al (36) reported that the sensitivity and specificity of US in the diagnosis of acute colonic diverticulitis are 85% and 80%, respectively. On US images, the inflamed diverticulum appears as a thick-walled outpouching, with hypoechoic thickening of the adjacent bowel (37). The segments of thickened bowel may show increased mural vascularity at color Doppler US because of inflammation (13,38). The surrounding perienteric fat is almost always echogenic and thickened secondary to inflammation or infection (34) (Fig 12).

Complicated diverticulitis can develop if the inflammatory process results in an abscess, bowel obstruction, free perforation, or fistula formation. Abscesses are differentiated from free peritoneal fluid by their resistance to changes in shape or location with external compression (39). Fistula tracts can occur with ongoing inflammatory change and appear as linear tracts from the colon to the bladder, vagina, or adjacent bowel loops, which have variable echogenicity based on their content.

Bowel Hemorrhage

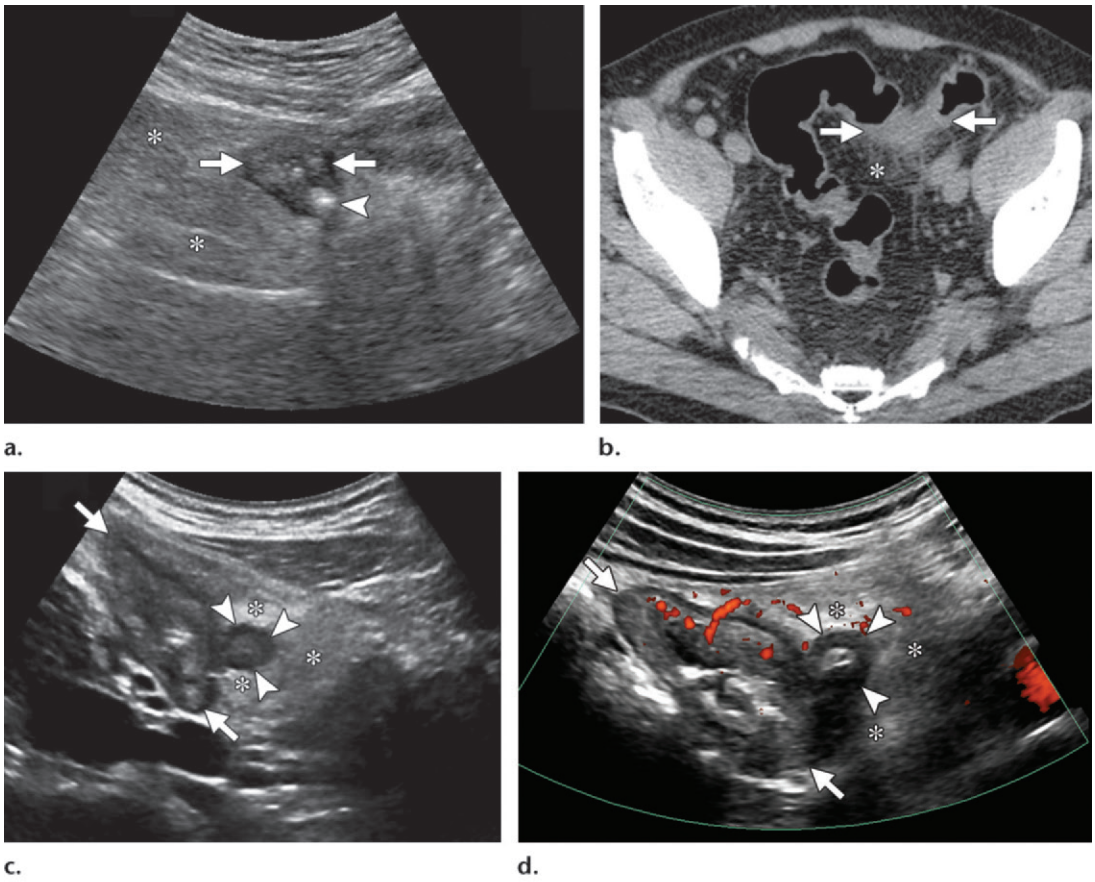
Acute intramural intestinal bleeding typically leads to homogeneous hypoechoic symmetric thickening of a long stretch of the affected bowel segment and marked luminal narrowing (40). Mural stratification may or may not be preserved in the setting of bowel wall hemorrhage (Fig 13). Vascularity within intramural hematomas has been reported as normal, diminished, or absent at Doppler US assessment (41,42). Causes of bowel hemorrhage include anticoagulant therapy, ischemic bowel disease, vasculitis, hemophilia, and coagulation abnormalities.

Ischemic Colitis

Ischemic colitis is caused by a reduction in bowel perfusion due to occlusion of an artery or vein or hypoperfusion secondary to hypovolemia or hypotension. The left side of the colon is involved in 80% of cases of bowel ischemia, with the watershed areas being most susceptible. These areas include the splenic flexure at the junction of the superior mesenteric and inferior mesenteric artery territory and the region of the rectosigmoid junction at the border of the inferior mesenteric and hypogastric artery territory. The distribution is typically segmental, without discontinuity, and the length of the segment involved is commonly 10 cm or more (43).

US typically shows circumferential hypoechoic thickening of the bowel wall, variable loss of mural stratification, and abrupt transition from the ischemic to the normal bowel segment (Fig 14). Color flow is absent or diminished

Figure 12. Acute diverticulitis in two patients. **(a, b)** In a 74-year-old man, transverse US image of the left lower quadrant **(a)** shows a thick-walled segment of sigmoid colon (arrows), with a thick-walled inflamed diverticulum that contains an echogenic fecalith (arrowhead). The surrounding fat (*) is thickened, echogenic, and inflamed. Axial CT scan **(b)** shows the thickened segment of the sigmoid colon (arrows), with increased attenuation of the adjacent fat (*). The inflamed diverticulum was not identified at CT. **(c–e)** In a 26-year-old woman, transverse gray-scale US image of the right lower quadrant **(c)** and corresponding color Doppler US image **(d)** show a thick-walled cecum (arrows) and thick-walled diverticulum (arrowheads) secondary to diverticulitis. Increased vascularity of the cecal wall and adjacent surrounding tissues is seen in **d**. The fat surrounding the diverticulum (*) is echogenic and inflamed. Longitudinal US image obtained after medical treatment 19 days later **(e)** shows a thin-walled cecum (arrows), with normal hypoechoic surrounding fat (*). The diverticulum could not be identified in **e**. The patient's treatment was based on the US findings and clinical examination; a correlative CT scan was not performed.



in the bowel wall in as many as 80% of cases. However, the lack of mural flow at Doppler US is an indicator of the severity of ischemic colitis, with a sensitivity of 82% and a specificity of 92% (44). Blood flow may be detected at Doppler US in some cases of ischemic bowel, as decreased perfusion does not always result in transmural infarction. Furthermore, bowel ischemia can sometimes be reversible, with the detected blood flow at Doppler US representing reperfusion of the gut wall (13). The perienteric fat is often unaltered unless there is severe transmural necrosis (43,45). Ascites, pneumatosis intestinalis, gas within the portal veins of the liver, and luminal distention of the gut are also common associations.

Intussusception

Intussusception is defined as the telescoping of a proximal segment of the gastrointestinal tract, called the intussusceptum, into the lumen of the adjacent distal segment of the gastrointestinal tract, called the intussuscipiens (46). In adults, almost 90% of cases are associated with

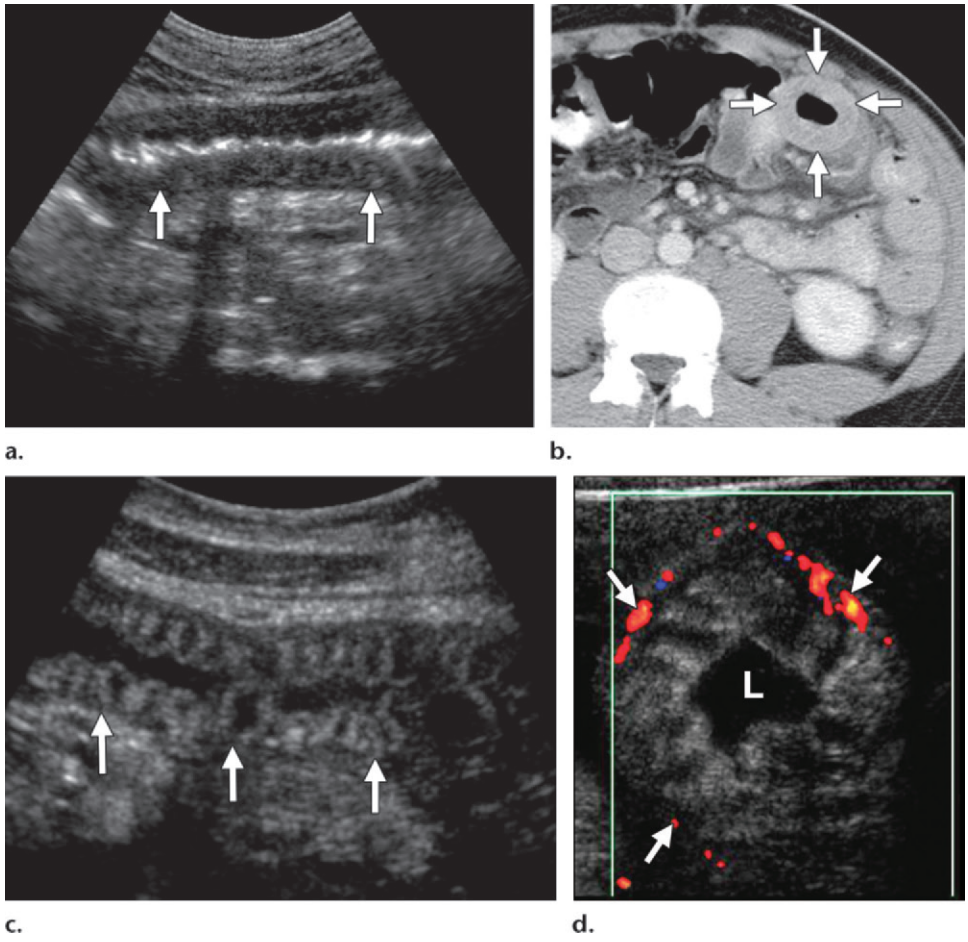


Figure 13. Intramural hemorrhage in two patients. **(a, b)** In a 23-year-old man with hemophilia, longitudinal US image **(a)** shows a thick-walled jejunum (arrows), with loss of the gut signature. Axial contrast-enhanced CT image **(b)** shows concentric thickening of the loop of jejunum (arrows) due to intramural blood. **(c, d)** In a 27-year-old woman with systemic lupus erythematosus, longitudinal US image **(c)** shows a thick-walled jejunum (arrows) due to intramural bleeding, with preservation of the gut signature. Transverse color Doppler US image **(d)** shows preservation of blood flow at the periphery of the thickened loop of jejunum (arrows). *L* = lumen.

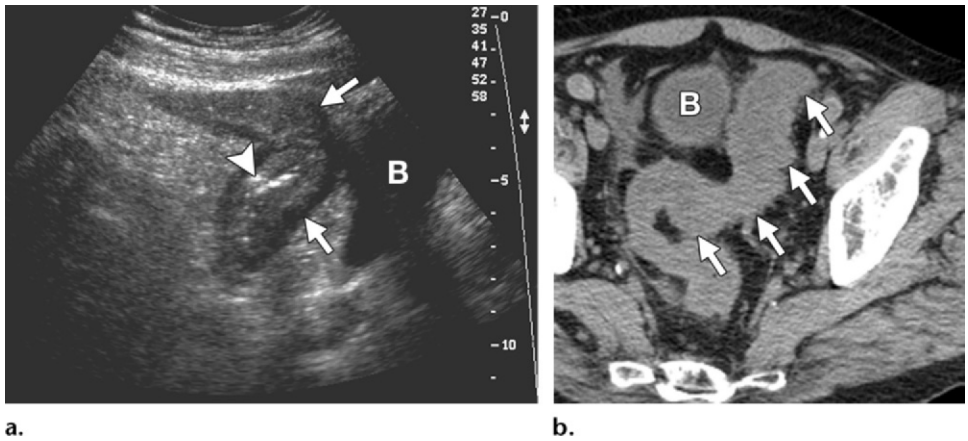
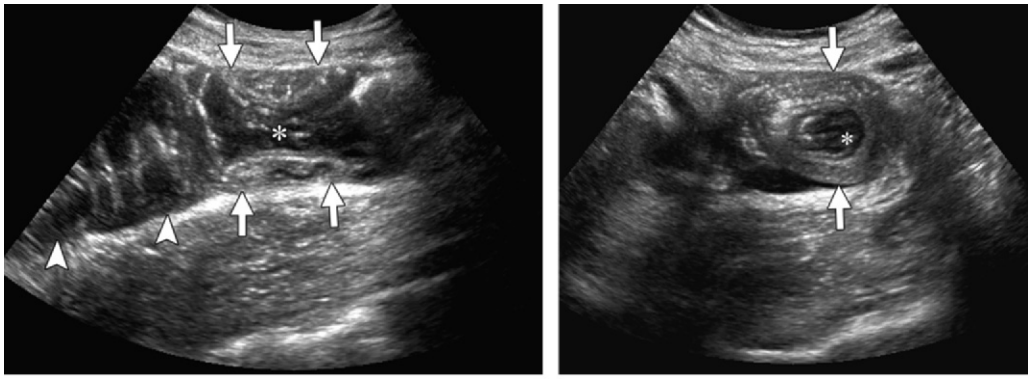


Figure 14. Ischemic colitis from multiple emboli in the sigmoid colon of a 59-year-old man. *B* = bladder. **(a)** Coronal US image shows a thickened portion of sigmoid colon (arrows), with loss of the gut signature and a small bubble of air in the bowel wall (arrowhead) secondary to ischemic colitis. **(b)** Axial CT image shows the thickened loop of sigmoid colon (arrows). The intramural air bubble was not seen at CT.



a. b.

Figure 15. Intussusception in a 48-year-old man secondary to primary bowel lymphoma. **(a)** Longitudinal US image shows intussusception of a segment of ileum secondary to bowel lymphoma. The outer ring of bowel represents the intussuscipiens (arrows), and the inner, hypoechoic, thick-walled bowel represents the intussusceptum (*). The intussusceptum and proximal ileum (arrowheads) are thick-walled secondary to lymphoma, while the thin-walled intussuscipiens does not show lymphoma involvement. **(b)** Transverse US image of the intussusception shows the outer intussuscipiens (arrows) and the central hypoechoic intussusceptum (*).

an underlying identifiable bowel lesion. The lead mass in adults is often a neoplasm, which usually is malignant in large bowel intussusception and benign in small bowel intussusception (47).

At cross-sectional imaging, the classic appearance includes the "target" sign, with an outer ring representing the intussuscipiens and a central area of alternating echogenicity representing the intussusceptum, which is often edematous. In the longitudinal plane, the entire structure is more elongated, resembling a pitchfork, with the three hypoechoic limbs of the trident made up of the central intussusceptum and the outer walls of the intussuscipiens (Fig 15) (48). A varying degree of proximal bowel dilatation can be seen, but complete obstruction is rare.

Pneumoperitoneum

Detection of pneumoperitoneum is of utmost importance as it often indicates an acute underlying abdominal emergency (49). US is not usually the initial imaging modality used to assess free intraperitoneal air, but the sonographer should be familiar with its appearance because US is often used in the workup of patients with undiagnosed abdominal pain. The normal peritoneal stripe is seen as a single or double hyperechoic line deep to the anterior abdominal wall (Fig 16). Pneumoperitoneum produces a specific and reproducible appearance, namely, enhancement of the peritoneal stripe. Associated posterior shadowing or reverberation artifacts may be seen, depending on the amount of free air. Intraluminal bowel gas can be differentiated, as it is associated with a normal overlying peritoneal stripe. This sign can be used by sonographers to identify free intraperitoneal gas and to differentiate it from intraluminal gas (50). A clinical trial in a tertiary care center found that in patients with blunt abdominal trauma, the sensitivity of US for gastrointestinal perforation was 85.7% and the specificity was 99.6% (51).

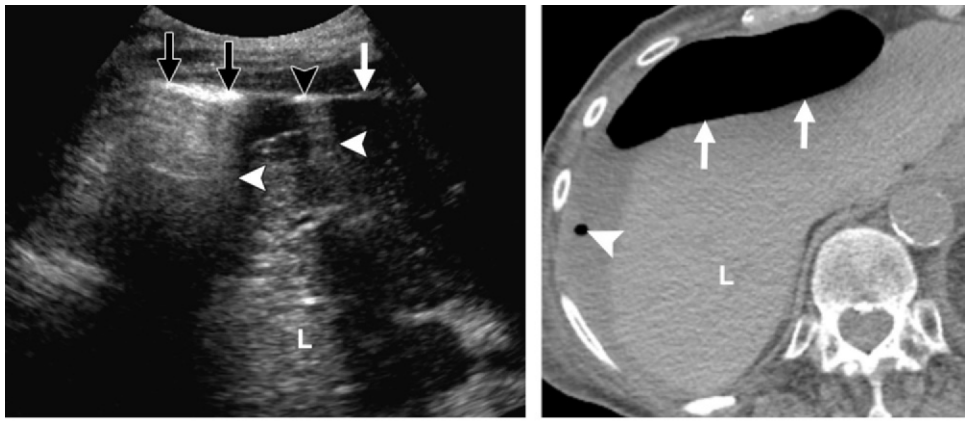
Pneumatosis Intestinalis

Diagnosis of pneumatosis intestinalis at US is challenging and requires documentation of air within the bowel wall. Although this may be observed in benign conditions, in patients with acute abdominal pain, ischemic bowel becomes the diagnosis of exclusion. The disease usually involves the entire wall in a circumferential pattern and may be localized to either a single loop or multiple loops diffusely. False pneumatosis intestinalis, or pseudopneumatosis intestinalis, may occur for a variety of reasons, including foreign bodies within the bowel wall producing a bright specular reflection mimicking air, tiny bubbles of air that are trapped between folds in the wall, and the misregistration of air bubbles that are outside of the scanning field but within the thickness of the ultrasound beam (Fig 17) (52).

Bowel Neoplasms

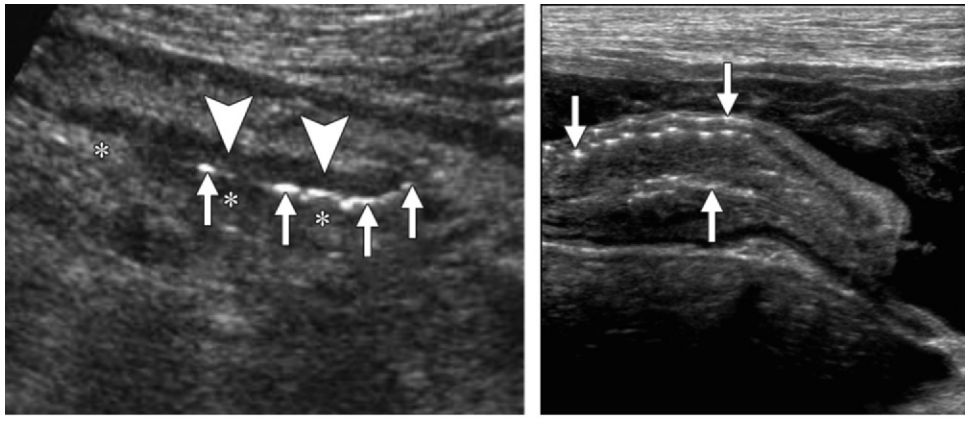
Lymphoma

Although primary gastrointestinal lymphoma is uncommon, it represents the most frequently occurring extranodal lymphoma. It can affect any segment of the gastrointestinal tract and is almost exclusively of the non-Hodgkin type. In the Western world, gut lymphoma most commonly affects the stomach, small intestine, colon, and esophagus, in decreasing order of frequency. Lymphoma originates in the lamina propria and submucosa, as these layers of the bowel wall contain lymphoid elements (53).



a. b.

Figure 16. Pneumoperitoneum in a 92-year-old woman with a perforated duodenal ulcer. *L* = liver. **(a)** Transverse US image shows the normal peritoneal stripe (white arrow) as a thin echogenic line. A small bubble of air (black arrowhead) and large pocket of air (black arrows) produce enhancement and thickening of the peritoneal stripe, findings associated with reverberation artifact (white arrowheads). **(b)** Axial CT image shows a small bubble of air (arrowhead) and adjacent large pocket of air (arrows).



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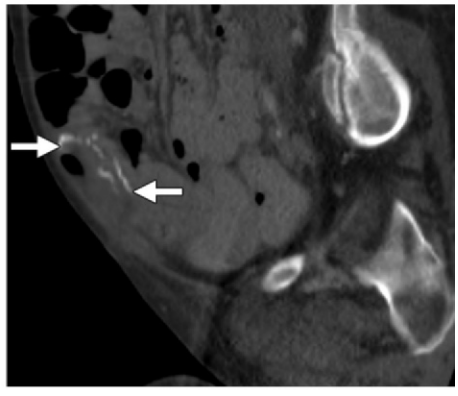

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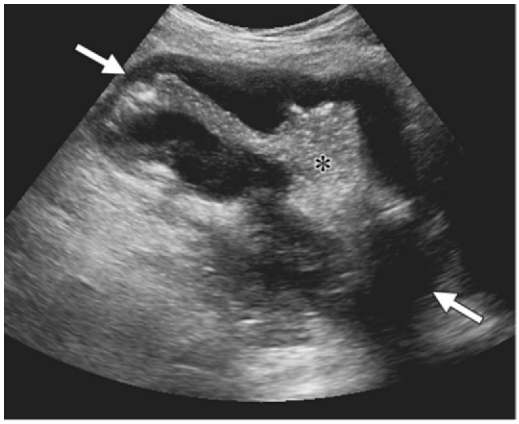
Figure 17. Pneumatosis intestinalis and pseudopneumatosis intestinalis. **(a)** Longitudinal US image in a 27-year-old man with Crohn disease shows true pneumatosis intestinalis. Multiple bright echogenic foci (arrows) representing tiny bubbles of air are identified in the nondependent wall of the gut, situated between the muscularis propria (arrowheads) and the serosa (*). **(b)** Longitudinal US image in a 49-year-old woman with an ileal conduit shows pseudopneumatosis intestinalis. Multiple bright echogenic foci (arrows) are seen in the dependent and nondependent walls of a thickened loop of small bowel. The echogenic foci represent multiple bowel staples in the wall of the patient's ileal conduit. **(c)** Sagittal CT image in the same patient as in **b** shows rows of bowel staples (arrows) in the ileal conduit.

Gastrointestinal lymphoma demonstrates a wide variety of imaging appearances. At US, these tumors are usually hypoechoic to anechoic and are associated with destruction of the gut signature. They can manifest with a number of growth patterns, including segmental circumferential growth, a focal mural-based solitary mass, multifocal bowel wall thickening, and extraluminal tumor spread into the mesentery. Circumferential wall thickening is the most common pattern demonstrated at US. Aneurysmal dilatation of the involved bowel may also be seen because of infiltration of the muscularis propria and destruction of the autonomic nerve plexus by the tumor (Fig 18). Lymphoma rarely results in bowel obstruction because the tumor does not elicit a desmoplastic response. Loss of peristalsis is a late sign of lymphoma (54,55).



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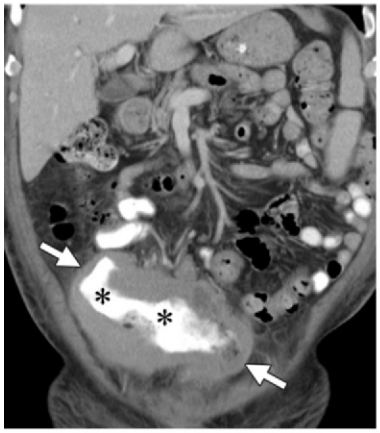

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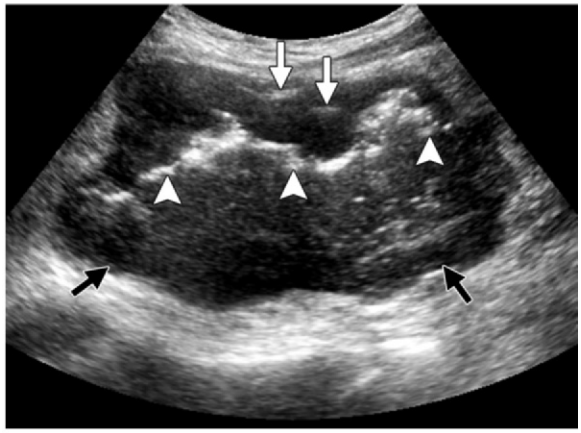


c.

Figure 18. Primary bowel lymphoma in two patients. **(a, b)** Longitudinal US image **(a)** and coronal CT image **(b)** in a 70-year-old man show aneurysmal dilatation and thickening of a loop of ileum (arrows) with distention of the lumen (*) due to lymphoma. **(c)** Transverse US image in a 41-year-old man with lymphoma shows gross thickening of the terminal ileum (black arrows) with loss of the gut signature, collapse of the lumen (arrowheads), and focal wall ulcerations (white arrows).

Adenocarcinoma

Adenocarcinoma is the most common malignancy of the gastrointestinal tract. At US, adenocarcinomas appear similar to other bowel tumors and manifest as hypoechoic masses with loss of the normal mural stratification. Focal tumors may manifest as a short segment of annular wall thickening or a polypoid lesion, which may be associated with superficial ulcerations or bowel obstruction depending on the extent of luminal narrowing (56). In some instances, infiltration of the tumor through or along the bowel wall can lead to diffuse mural thickening and decreased peristalsis (Fig 19, Movie 6).

Carcinoid Tumors

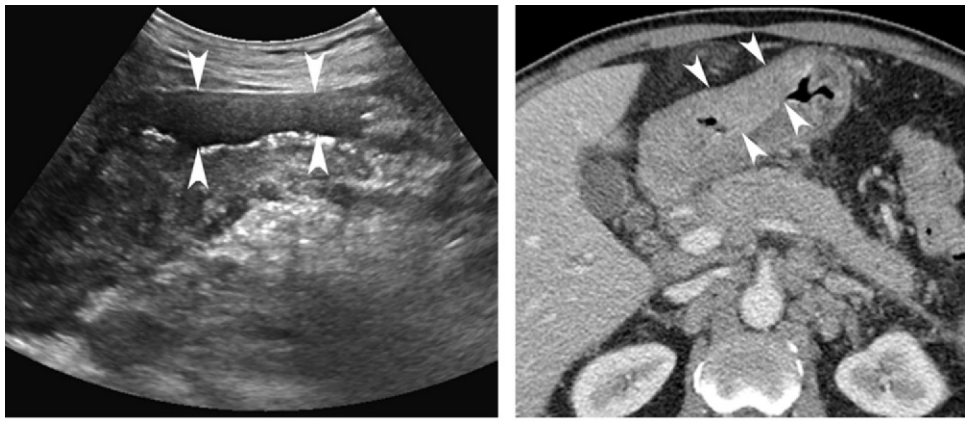
Carcinoid tumors are the most common small bowel malignancy, are most frequently located in the distal ileum, and constitute approximately 2% of all gastrointestinal tumors. In the early stages, these neuroendocrine tumors are small and are confined to the submucosal layer of the bowel wall. As the tumor enlarges, extension outside the involved bowel loop may occur, with infiltration into the mesentery and associated desmoplastic reaction.

At US, small bowel carcinoid tumors may appear as smooth, intraluminal, hypoechoic oval masses interrupting the submucosal layer. Muscularis propria thickening, puckering, wall retraction, serosal invasion, and mesenteric metastatic disease may also be seen (Fig 20). Mesenteric metastases are of similar echogenicity to the primary tumor and can demonstrate calcification (57).

Gastrointestinal Stromal Tumors

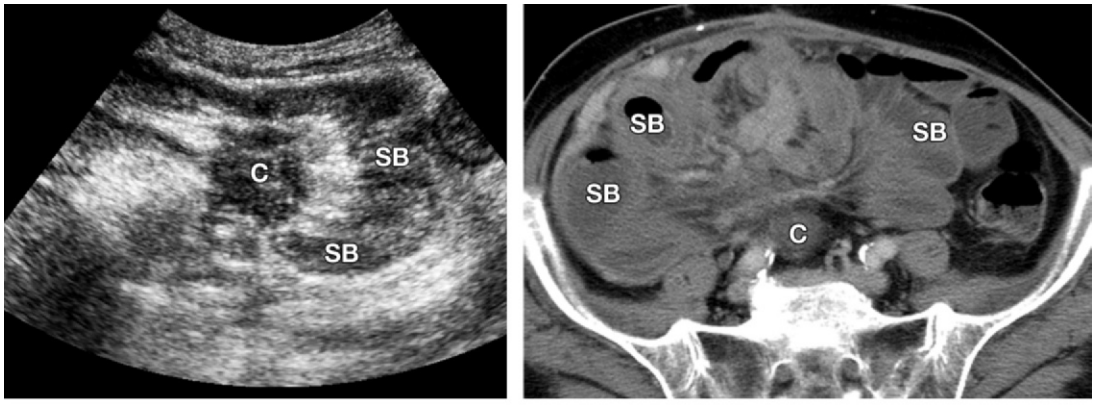
Gastrointestinal stromal tumors (GISTs) are the most common mesenchymal tumors of the gastrointestinal tract and are most frequently located in the stomach, followed by the small bowel. They arise from the interstitial cells of Cajal in the muscularis propria. The interstitial cells of Cajal are intrinsic to the regulation of gut peristalsis at a cellular level by acting as "pacemaker" cells (9). Therefore, it stands to reason that because GISTs arise from these cells, bowel motility will be altered (58).

These tumors may grow into the bowel lumen and manifest as an intraluminal mass, or they may extend through the serosa and manifest as a large exophytic mass. Displacement of adjacent structures is more often seen than direct invasion into the surrounding tissues. At the time of diagnosis, 50% of patients have metastases, which most commonly involve the liver and peritoneum. Lymph node metastases are rare (59).



a. b.

Figure 19. Adenocarcinoma of the stomach in a 63-year-old man. Transverse US image **(a)** and axial CT image **(b)** show thickening of the anterior wall of the stomach body (arrowheads) secondary to poorly differentiated adenocarcinoma. Loss of the normal bowel signature is seen in **a**.



a. b.

Figure 20. Carcinoid tumor in an 81-year-old man. Transverse US image **(a)** and axial CT image **(b)** show a mesenteric-based mass *(C)*, which represents a carcinoid tumor metastasis, surrounded by dilated small bowel loops *(SB)*. The loops of small bowel show tethering on their mesenteric surface due to the desmoplastic reaction associated with the tumor.

The US features of GISTs include a large, often exophytic, well-defined, predominantly solid mass with variable echogenicity. A thick echogenic rim is seen in some cases. Central hypoechoic areas corresponding to regions of necrosis may also be seen (Fig 21, Movie 7) (60). The gut origin is often difficult to determine at US. Preoperative determination of the malignancy potential of GISTs is difficult.

Conclusion

There is a significant focus in the medical imaging community to limit the exposure of patients to ionizing radiation from medical diagnostic tests. The full potential of imaging modalities that do not use ionizing radiation, such as US, should be revisited. The realm of abdominal US needs to move from a modality that focuses predominantly on the solid viscera and vascular system to include the bowel, in order for complete assessment. Although there may be initial skepticism regarding the use of US to diagnose and monitor bowel-related disease, with the development of scanning expertise and an overall appreciation of the different appearances of gut-related pathologic conditions by radiologists and technologists, US can become a routine modality for bowel evaluation.

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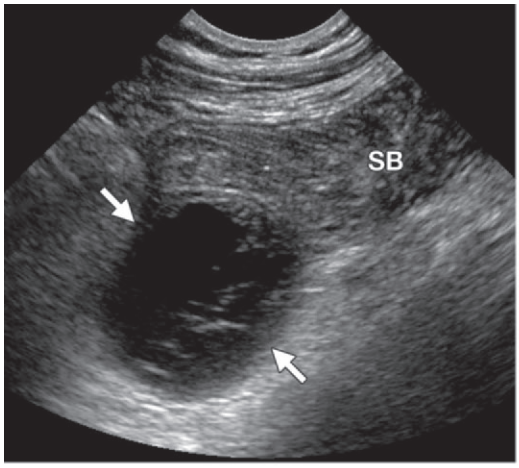

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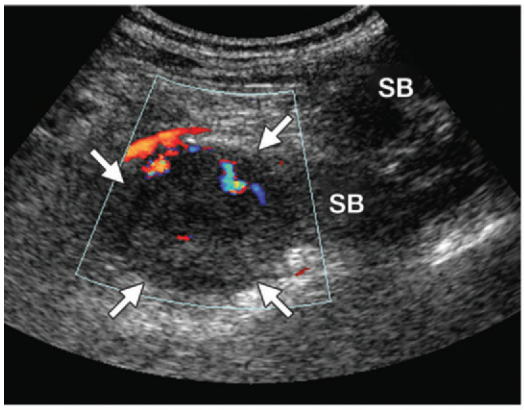

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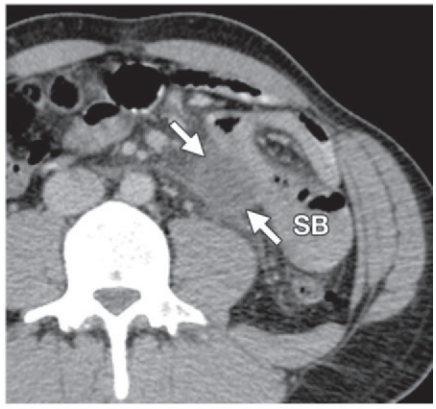

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Figure 21. Cystic degeneration of a GIST in a 36-year-old man. *SB* = small bowel. **(a)** Transverse gray-scale US image shows the cystic component of a GIST (arrows), which contains internal strands due to degeneration. **(b)** Transverse color Doppler US image of the more solid component of the GIST (arrows) shows flow in the wall of the tumor. **(c)** Axial CT image shows the GIST (arrows) as a low-attenuating mass. The tumor is shown to abut the small bowel in **a** and **b**.

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