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# The Use of Transabdominal Ultrasound in Inflammatory Bowel Disease

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Transabdominal ultrasound (TAUS) is useful in all aspects of lesion screening, monitoring activity, or treating/diagnosing any related complications of inflammatory bowel disease. Its ability to screen or diagnose complications is almost the same as that of other methods, such as CT or MRI. Moreover, its noninvasiveness makes it a first-line examination method. A TAUS image depicting ulcerative colitis will show large intestinal wall thickening that is continuous from the rectum, which is mainly due to mucosal layer thickening, while for Crohn's disease, a TAUS image is characterized by a diversity in the areas affected, distribution, and layer structure. Indicators of activity monitoring include wall thickness, wall structure, and vascular tests that use Doppler ultrasound or contrast agents. While all of these have been reported to be useful, at this time, no single parameter has been established as superior to others; therefore, a comprehensive evaluation of these parameters is justified. In addition, evaluating the elasticity of lesions using elastography is particularly useful for distinguishing between fibrous and inflammatory stenoses. However, the lack of objectivity is the biggest drawback of using ultrasound. Standardizing and popularizing the ultrasound process will be necessary, including scanning methods, equipment settings, and image analysis.
**Keywords:** *Crohn's disease; Ulcerative colitis; Ultrasound; Monitoring; Diagnosis*

## INTRODUCTION

Inflammatory bowel disease (IBD) is a global disease of the 21st century, and the number of patients is increasing rapidly, including in Asian countries [1-4]. To date, there is not much disagreement between endoscopy and endoscopic mucosal healing as the basis of morphological diagnosis for IBD [5]. However, in addition to the invasiveness of this procedure, including pretreatment, as well as the inability to observe the distal side of stenosis and obtain information outside the wall, such as fistulas, the importance of transmural healing has also been emphasized, especially with regard to Crohn's disease (CD) [6,7]. Furthermore, since this disease frequently occurs in relatively young people and requires long-term, almost lifelong, medical care, simpler and less invasive screening and medical follow-up procedures are required. In recent years, tomographic diagnostic methods, such as CT, MRI, and transabdominal ultrasound (TAUS), have gained attention [8-10]. In particular, TAUS has many advantages, such as not requiring any pretreatment or exposure to radiation, simplicity of the technique, relatively inexpensive equipment, and widespread use. Thus, its usefulness in the diagnosis and treatment of this disease is gaining attention [11-13]. Moreover, compared to other methods, such as MRI or endoscopy, TAUS has been reported to have higher patient acceptability than when taking a blood sample [14,15]. This study describes the usefulness of TAUS in the medical diagnosis and treatment of IBD.

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## Screening IBD Using TAUS

### TAUS Equipment Used for Gastrointestinal Tract Examination

While devices commonly used for abdominal USs may be adequate, using a high-frequency (7–12 MHz) probe for detailed observation of the lesion alongside a low frequency

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(3–4 MHz) probe for screening is desirable. In addition, a more accurate evaluation is expected if functions, such as color Doppler US, contrast-enhanced US, and elastography, are equipped. In contrast, highly portable devices, such as those used for point-of-care US (POCUS), are inferior to general devices in terms of image quality and functionality; these devices do not produce sufficient evidence to diagnose IBD.

## Gastrointestinal Tract Screening Scanning Method

For the examination, special pretreatment such as colonic lavage or the use of an anticholinergic agent is not required. Performing scans requires an understanding of the gastrointestinal anatomy [16,17]; therefore, to detect gastrointestinal lesions efficiently on US, a scanning method that reliably identifies areas that consistently appear in certain parts of the body, such as the stomach, duodenum, ascending and descending colon, and rectum, and continuously tracks the lumen (which we refer to as systematic scanning of the gastrointestinal tract) is recommended. For example, the ascending colon is located on the far-right side of the abdominal cavity, with the dorsal side fixed to the retroperitoneum. Additionally, the descending colon is bilaterally symmetrical to the ascending colon and is located on the far-left side of the abdominal cavity, with the dorsal side fixed to the retroperitoneum. However, since the small intestine, mainly the jejunum, is located on the ventral side, unlike the ascending colon, it is necessary to ensure that it occupies the deepest position in the abdominal cavity when performing a scan. Systematic scanning of the small intestine is difficult, but the jejunum and ileum can be distinguished from each other, in terms of the shape (density and height) of their folds and their location.

The gastrointestinal screening procedure used at our facility is as follows: first, the region from the abdominal esophagus to the duodenal bulb is scanned, followed by a continuous scan from the ascending colon to the rectum. As the practitioner gets used to this technique, it takes between a minute or two to complete the procedure. When there is possibility of small intestinal lesions, light pressure is applied to extend the intestinal tract. Then, a scan is carefully conducted from the upper left abdomen (mainly the jejunum) to the lower abdomen (mainly the ileum), which takes a few minutes. Therefore, the total time required for the screening of the entire gastrointestinal tract is five minutes or less when the operator is experienced in gastrointestinal ultrasonography. Figure 1 shows the affected ileal loop detected during the screening of the small intestine.

There are some tips to successfully screen and evaluate the lesions. The detection of a suspicious lesion starts with the use of a 4-MHz convex probe to visualize the entire abdomen since it permits better penetration of the US beam. Applying adequate pressure to the probe is crucial to minimize artifacts, such as multiple reverberations from the abdominal wall and sidelobe artifacts from the adjacent gastrointestinal tract. Application of pressure such that the examiner can visualize the lesion, at a depth of approximately 4–6 cm with a 4-MHz convex probe and at a depth of approximately 2–3 cm with a 7-MHz linear probe, can be helpful. The convex probe is switched to a 7-MHz linear probe after detecting a suspicious lesion to obtain detailed information regarding the lesion, including the wall stratification. Zooming in on the lesion with a 4-MHz convex probe can be an alternative when the 7-MHz probe cannot provide an image suitable for analysis because of beam attenuation caused by the patient's constitution.

Demonstration of the wall layer structure is key to judging the suitability of an US image. The image is considered suitable to evaluate the lesion if the layer structure of the lesion or the adjacent unaffected bowel segment can be appreciated when the lesion has lost the wall stratification. US can be used as a substitute for frequent CT or MRI examinations if a good quality image can be obtained.

## TAUS Images of a Normal Gastrointestinal Tract

Regardless of the part of the body, a TAUS image of a normal gastrointestinal wall has the following five-layer structure: starting from the luminal side, hyperechoic (interface echo and part of the mucosal layer), hypoechoic (mucosa and muscularis mucosa), hyperechoic (submucosa),

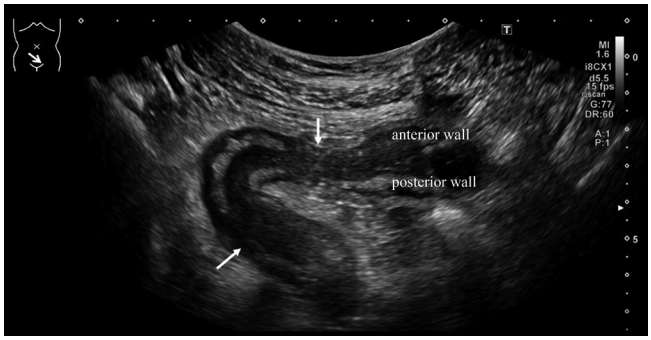


**Fig. 1. Crohn's disease.** An affected ileal loop in the pelvic cavity. There are two bowel segments showing loss of wall stratification (arrows), representing severe transmural inflammation.


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hypoechoic (muscularis propria), and hyperechoic (serous membrane and interface echo) [18,19].

In inflammatory diseases, lesions are depicted as areas with wall thickening, but there are some reports of lesions with normal wall thickness. At the same time, lesions are also affected by factors, such as the degree of the wall stretch or the frequency used. Therefore, setting a strict cutoff value for wall thickness is difficult [20]. Therefore, as a guide, an abnormality in the small or large intestine was suspected when the wall thickness was 4 mm or greater. However, in chronic inflammatory diseases, such as IBD, active lesions may be found endoscopically, even if they are less than 4 mm. Moreover, even if everything is normal, if the lumen is empty, the wall thickness may be 4 mm or greater. Therefore, it is necessary to make a comprehensive judgment that considers other factors, such as how that area compares to other areas, the normal parts of the body, and the layer structure.

## TAUS Images of UC

A typical US image of ulcerative colitis (UC) depicts a distinct wall thickening with a layered structure extending continuously from the rectum to the oral cavity [21-24]. When left untreated, the thickening of the mucosal layer was conspicuous (Fig. 2A-C). It is difficult for shallow ulceration to be depicted, but when an ulcer becomes relatively deep, the first layer, which is the interface echo of the luminal surface, becomes unclear. As it becomes deeper, it becomes identifiable as a missing part of the wall.

## TAUS Images of CD

CD can be characterized by the presence of lesions in all parts of the gastrointestinal tract, and the morphology of the lesions varies from aphthous ulcers to ulcers with a pavement-like appearance. Therefore, it is difficult to conclude what the condition is from a single image. In other words, it can be said that this diversity in body part location and morphology is characteristic of CD. Although there are reports about the thickness and layer structure, these findings are not necessarily CD-specific [25,26]. If there are multiple lesions, skip lesions, which

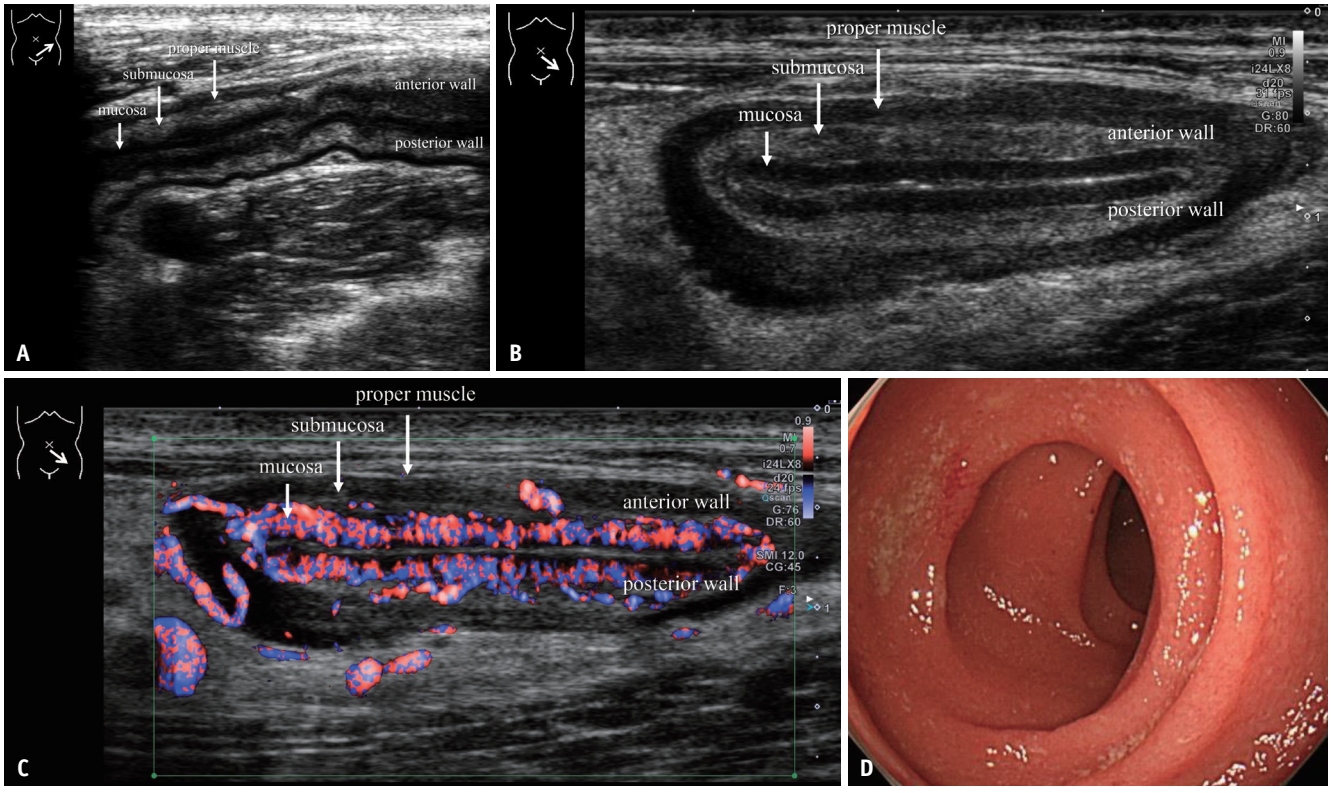


**Fig. 2. Ulcerative colitis.**
**A.** Longitudinal view of the sigmoid colon. The wall layer structure and thickening of the mucosal layer are clearly demonstrated (probe: 7 MHz linear). **B.** Transverse view of the same lesion using a 24-MHz linear probe. Each layer of the lesion is clearly visible. **C.** Blood flow signals using Superb Microvascular Imaging. Increased blood flow signals, mainly in the mucosal layer as the focus of inflammation, are noted (probe: 24 MHz linear). **D.** Endoscopic figure of the same lesion. Endoscopy shows mild inflammation of the mucosa, with an endoscopic Matts score of grade 2.


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are interspersed along a normal gastrointestinal tract, can be found between them, and there are narrow and deep longitudinal ulcers (Fig. 3) that occur on the mesenteric side of the intestine. These are considered characteristic findings of this disease [27].

### IBD Detection and Diagnostic Ability Using TAUS

Although there are some reports on the ability of TAUS to detect and diagnose IBD lesions, they generally show a good diagnostic ability that is almost equivalent to other modalities [28-35]. While normal equipment (not the portable type) was used in these studies, the usefulness of POCUS in IBD diagnosis and treatment in clinics has also been reported [36,37]. Hence, for patients who complain of symptoms that suggest IBD, such as chronic diarrhea and bloody stool, TAUS could be the first-line testing method because of its simple technique and non-invasiveness, despite an associated lack of objectivity.

## Evaluation of IBD Activity Using TAUS

Since IBD is a disease that repeatedly goes through a cycle of remission and exacerbation for more than a year at a time, repeated endoscopy is a heavy burden on patients, as well as the medical staff and the medical economy. The number of endoscopies that must be performed can be significantly reduced by using TAUS to evaluate IBD activity.

The following indicators should be considered when evaluating IBD activity using TAUS. There are many reports on the usefulness of the following: 1) wall thickness, 2) wall layer structure, 3) intramural blood flow measured using Doppler US, 4) intra-intestinal blood flow measured using contrast-enhanced US, and 5) elastography. In extreme cases, when the inflammation becomes severe, the following trends occur: 1) the wall becomes thicker, 2) the submucosal thickening becomes more noticeable, and with extreme inflammation or fibrosis, the layer structure disappears, 3) the color Doppler signal increases (more blood vessels are displayed), and 4) the wall appears enhanced earlier with the contrast US. Although 1) and 2) are indicators that can be compared between different patients, they do not always accurately reflect the patient's condition as the lesions are modified by fibrosis or other factors in the process of chronic inflammation. In contrast, intra-intestinal blood flow measured using Doppler US and intra-intestinal blood flow measured using contrast-enhanced US are relatively sensitive indicators that reflect the degree of inflammation. However, since the measurement of intramural blood flow using Doppler US or contrast US is also affected by other factors such as the

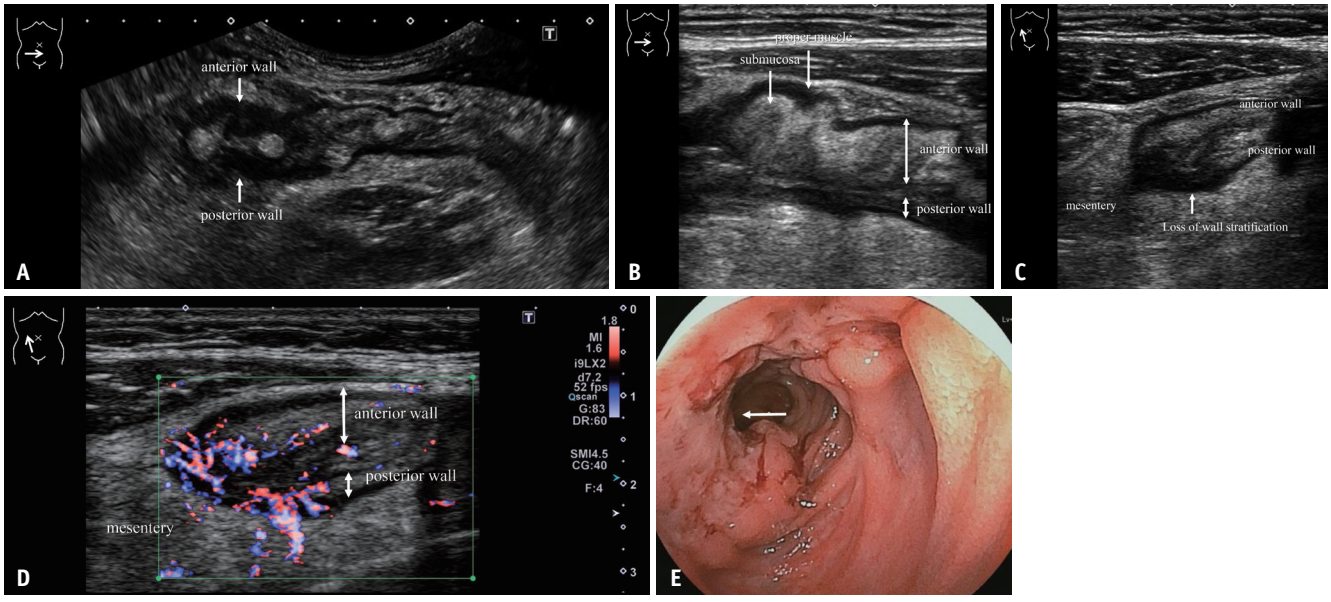


**Fig. 3. Crohn's disease.**
**A.** Super-wide view of the terminal ileum in a patient with Crohn's disease. The wall thickness, as well as the wall stratification, varies according to the location (probe: 4 MHz convex). **B.** Close-up view of the lesion using a 7-MHz linear probe. The loss of wall stratification of the posterior wall is demonstrated. **C.** Transverse view of the same lesion. The focal loss of wall stratification on the side of the mesentery represents longitudinal ulcer (probe: 7 MHz linear). **D.** Transverse view of the same lesion using Superb Microvascular Imaging. Increased blood flow signals are prominent on the mesenteric side. **E.** Endoscopic figure of the same lesion. A longitudinal ulcer is demonstrated (arrow). Loss of wall stratification on the mesenteric side is one of the specific findings of Crohn's disease.


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device performance, the patient's physique, and the location of the lesion in the body, these measurements should, in principle, be used for follow-up examinations of the same part of the body in the same patient.

### Wall Thickness

Wall thickening and the degree to which it has thickened are the simplest and most reproducible among examiners [38], and the measured values are not significantly affected by influences such as the patient's condition or device performance, making them suitable for use as a global standard. As previously mentioned, it has been reported that there is a relatively good correlation between the wall thickness and the degree of inflammation in both CD and UC [39-44]. However, the following points should be noted: in CD, it takes time to improve the wall thickness with treatment, and the proportion of the wall that reduces in thickness is not high [45,46]. In addition, since the mucous membrane is the main cause of inflammation in UC, the wall is not as thick as that of CD. Therefore, it is not always easy to judge the therapeutic effect by only looking at the wall thickness [47]. Figure 4 shows an example of this phenomenon. With a wall thickness of approximately 3 mm, it is not necessarily pathological, but the layer structure makes it unclear. In addition, abundant blood flow signals were observed using Superb Microvascular Imaging (SMI), suggesting high activity, which was confirmed by endoscopy.

### Layer Structure

The layered structure reflects the histopathological changes of all layers and is an important piece of information that cannot be obtained by endoscopy. Loss of this layered structure in both CD and UC suggests a more severe and poor prognosis [48-52]. The disappearance of the local layered structure in CD also indicates a deep

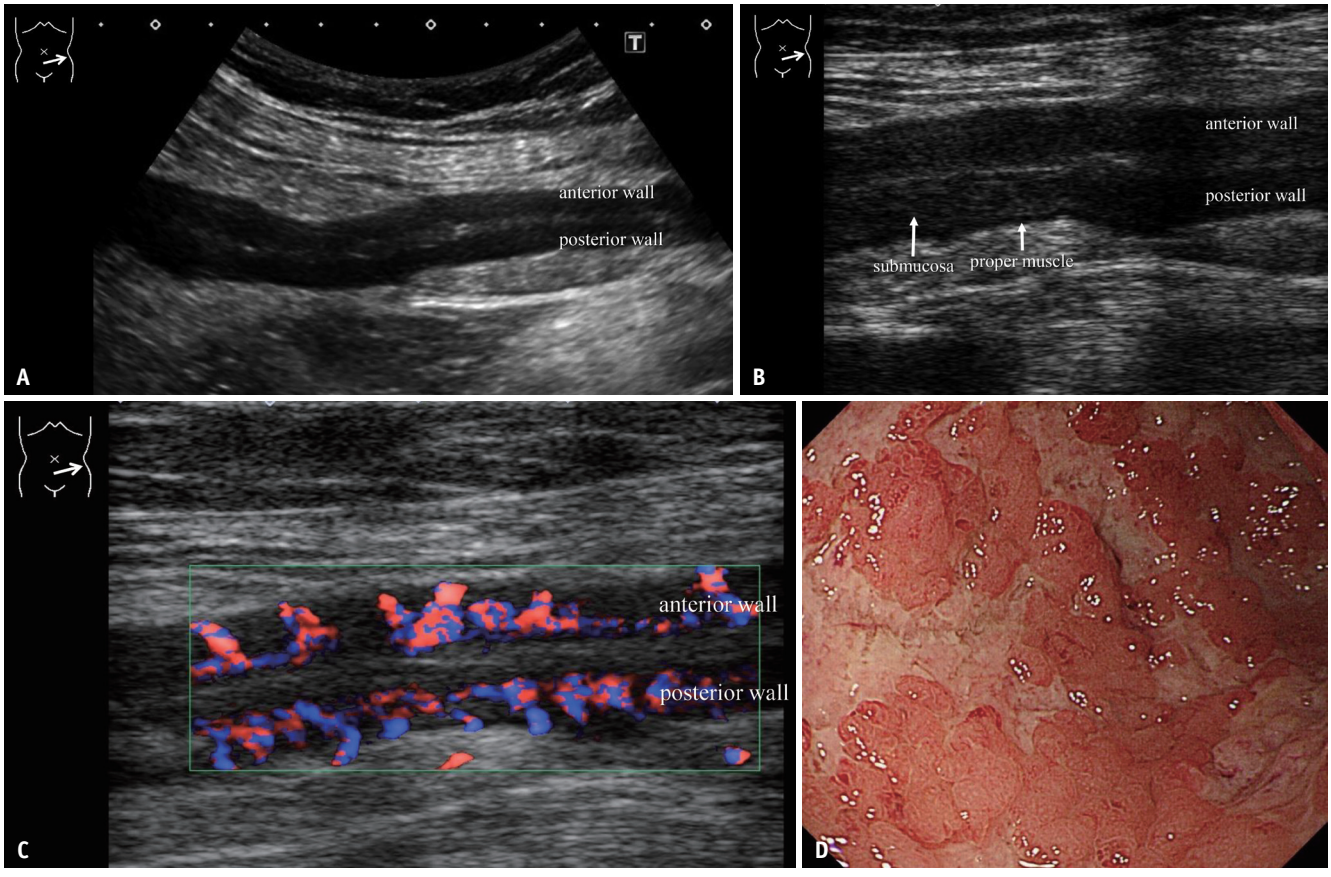


**Fig. 4. Ulcerative colitis.**
**A.** Longitudinal view of the sigmoid colon in a patient with ulcerative colitis. Although the wall thickening is mild (3 mm), the wall layer structure is blurred (probe: 4 MHz convex). **B.** Close-up view of the lesion using a 7 MHz linear probe. Thickening of the submucosal layer is demonstrated, while the mucosal layer is not clearly recognized. **C.** Evaluation of blood flow using Superb Microvascular Imaging of the same lesion. Increased blood flow, especially on the side of the lumen, is demonstrated (probe: 7 MHz linear). **D.** Endoscopic view of the same lesion. Although the wall thickness observed with ultrasound is mild, endoscopy shows severe inflammation, classified as Matts grade 4.


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longitudinal ulcer [27,53]. Meanwhile, some disadvantages of considering the layered structure as a parameter are that it may be affected by factors such as the frequency of the probe being used, the physical condition of the patient, and the fact that this evaluation metric cannot be quantified and lacks objectivity. Therefore, these obstacles need to be overcome to standardize the utilization of this parameter.

### Doppler US

It has long been known that inflammation increases blood flow, and it is reasonable to consider that blood flow evaluation using Doppler US is likely to be useful for IBD. As the use of Doppler US has become widespread, there have been reports on the evaluation of blood flow in the superior mesenteric artery and/or vein, but contradictory results have been reported [54-57]. Theoretically, blood flow in these vessels depends more on physiological conditions than on inflammation in certain parts of the intestinal tract. Moreover, measurement errors between examiners cannot be ignored [58,59]. Accordingly, it would be reasonable to consider it unsuitable as a parameter for assessing lesion activity. Meanwhile, evaluating the degree of local inflammation mainly from the amount of blood flow signals using a color Doppler US seems to be a more appropriate method; its usefulness has been reported for both CD and UC [38,60-65]. However, from the perspective of ultrasonic engineering, Doppler US sensitivity is affected by various factors such as the frequency used, display flow velocity range (folded frequency), and brightness of the background B-mode image. It also depends greatly on the path (acoustic pathway) leading to the target organ. Therefore, it should be kept in mind that although these conditions are offset by comparing groups with large numbers of patients and certain tendencies can be observed, the results obtained for a lesion in one patient are not theoretically valid for comparison with lesions in other patients or even in the same patient at different sites. In addition, in the evaluation of intra-intestinal blood flow, the recently developed SMI has superior sensitivity, especially for a slower blood flow compared to the conventional color Doppler US [66-68]; although it is expected to be useful in assessing the activity of this disease, no clear evidence has been reported about its superiority over the conventional color or power Doppler US. Figure 5 shows an image of a patient follow-up that was conducted using SMI that looked at the same part of the body. It can be seen that the blood flow signal is reduced, reflecting an improvement in the pathological condition of the patient with treatment.

### Contrast-Enhanced US

Various indicators such as maximum peak intensity, area under the curve, and time until the enhancement reaches the maximum value (time to peak) when the time-course of contrast enhancement of the wall is displayed as a time-intensity curve (TIC), are used as parameters for evaluating activity when using contrast-enhanced US. For these parameters, compatibility between patients is not necessarily guaranteed. This is because if the ultrasonic wave is strongly attenuated by the time it reaches the target organ, parameters such as maximum peak intensity and area under the curve, will naturally be affected by this

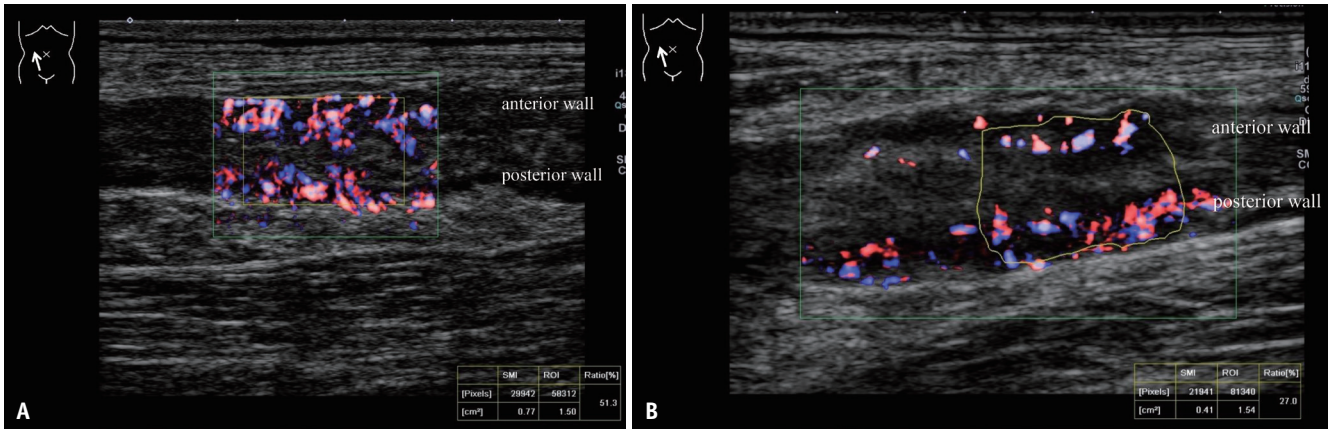


**Fig. 5. Crohn's disease.**
**A.** SMI image of a lesion in a patient with Crohn's disease before treatment. Transmural increase of blood flow is demonstrated, and the ratio of the pixel counts of the colored area to those of the range of interest is 51.3% (probe: 7 MHz linear). **B.** SMI image of the lesion after successful treatment. The blood flow signals decrease as the ratio decreases to 27.0% (probe: 7 MHz linear). SMI = Superb Microvascular Imaging


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and decrease as a result; the time to peak may also be shortened if the time when the shading starts to appear on the US (zero point) is delayed. Therefore, the slope of the line connecting the peak from the zero point (coefficient of the enhancement wash-in slope) is theoretically considered to be the most compatible indicator. However, meta-analyses and systematic reviews have reported that contrast-enhanced US exhibits high sensitivity and specificity in the evaluation of CD activity [69,70]; hence, it is possible that it may be useful. Figure 6 shows the TIC of the contrast-enhanced US of CD. On the other hand, there are few reports on the usefulness of contrast-enhanced US for UC [71,72], and there is currently little evidence at the meta-analysis or systematic review level, regarding its usefulness.

Contrast-enhanced US is more cost-effective than other scanning methods such as CT or MRI [73]; however, these reports were for masses found in the liver. In addition to other factors such as a longer examination time, the invasiveness of the procedure due to the use of an intravenous contrasting agent on the patient as well as the increased financial burden, a drawback of this method is that it requires equipment that can handle contrast-enhanced US and its TIC analysis. In addition, since the strongest enhancement of the lesion is observed only during the early vascular phase, it is difficult to evaluate multiple lesions at a time using contrast US. Therefore, we must decide the lesion of interest that is the most affected bowel segment, before performing contrast US. Thus, there is uncertainty as to whether this method will become widespread as a global standard.

Hence, at present, it is considered more realistic to comprehensively judge wall thickness, layer structure, and Doppler US findings and, if necessary, perform contrast-enhanced US [44,46,74]. While we have previously published a report outlining a scoring system for CD activity using wall thickness and layer structure [49], it unfortunately never became widespread due to its complexity. In the future, the development of a simpler and more useful scoring system is desirable.

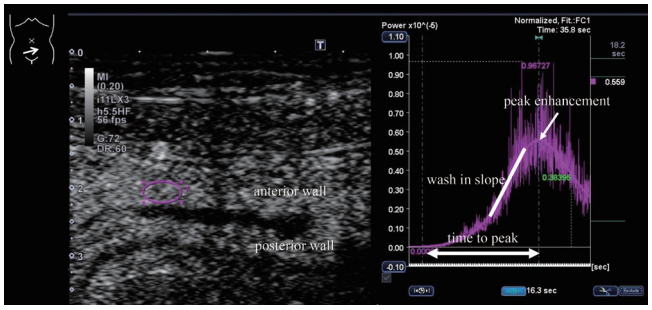


**Fig. 6. Contrast ultrasound of a lesion of Crohn's disease.**
Contrast ultrasound images using Sonazoid™ and the time-intensity curve of the enhancement with some parameters are shown on the right (probe: 7 MHz linear).

## Diagnosis of Complications

It is not always easy to use an endoscope to diagnose complications related to IBD, but the usefulness of US, which is a tomographic diagnostic method, is promising. Stenosis is a complication often encountered in CD that

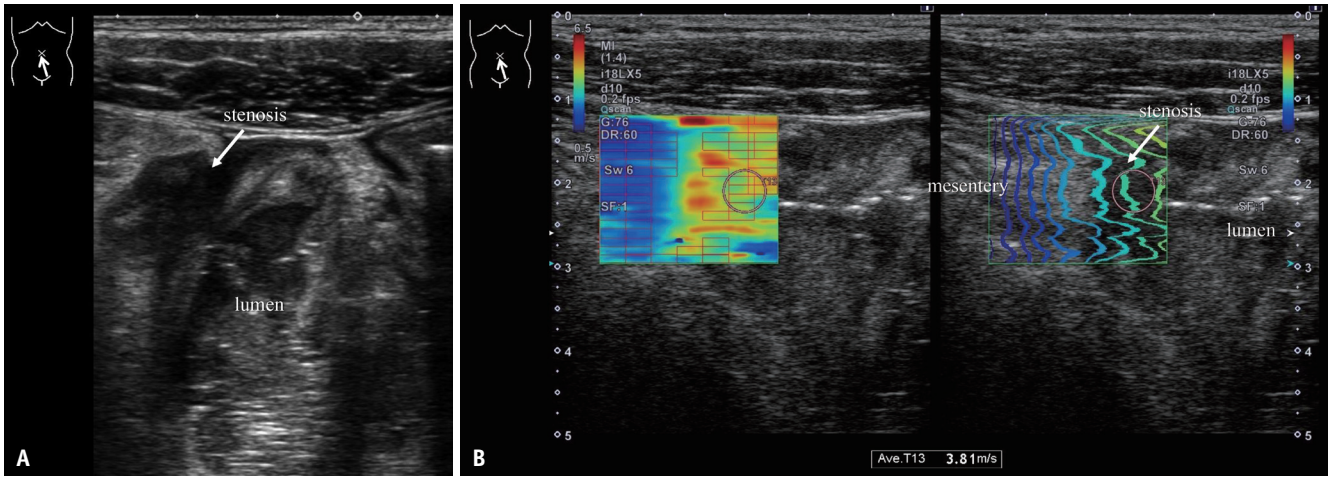


**Fig. 7. Bowel stenosis is seen in a patient with Crohn's disease.**
**A.** Marked luminal narrowing with dilatation of the oral side. The wall stratification of the stenotic segments is lost (probe: 7 MHz linear).
**B.** Shear-wave elastography of the stenotic lesions. The stenotic area is orange-colored, while the adjacent mesentery is blue, which indicates that the lesion has higher elasticity. The shear wave speed is as high as 3.81 m/s (probe: 7 MHz linear).


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requires surgical or endoscopic interventions [75]. US stenosis is defined as luminal narrowing (< 10 mm) with oral dilation (> 25–30 mm) [76,77]; however, it may not always be accompanied by pathological thickening of the stenotic site. Although only one end of the stenotic site can be evaluated with an endoscope, it is possible for the US to evaluate the length of the stenosis and the properties of

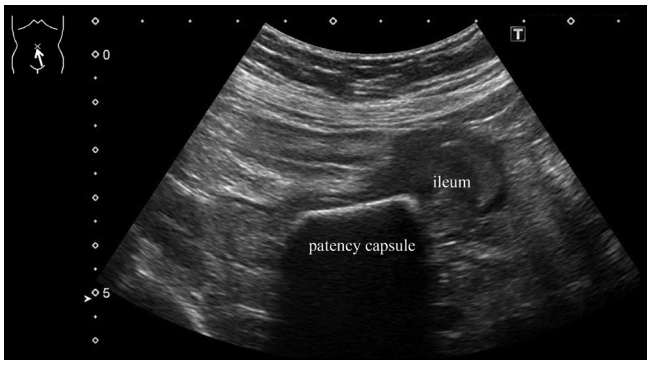


**Fig. 8. Retention of a patency capsule in a patient with Crohn's disease.** The patency capsule demonstrated as a linear, strong echo accompanied by an acoustic window is trapped at the oral side of the stenotic lesion (probe: 4 MHz convex).

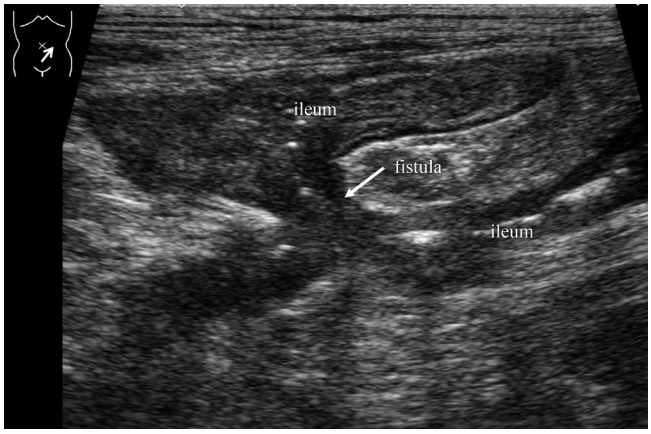


**Fig. 9. Ileo-ileal fistula in a patient with Crohn's disease.** The fistula between the two bowel segments is demonstrated as a hypoechoic band with small air bubbles inside (probe: 7 MHz linear).

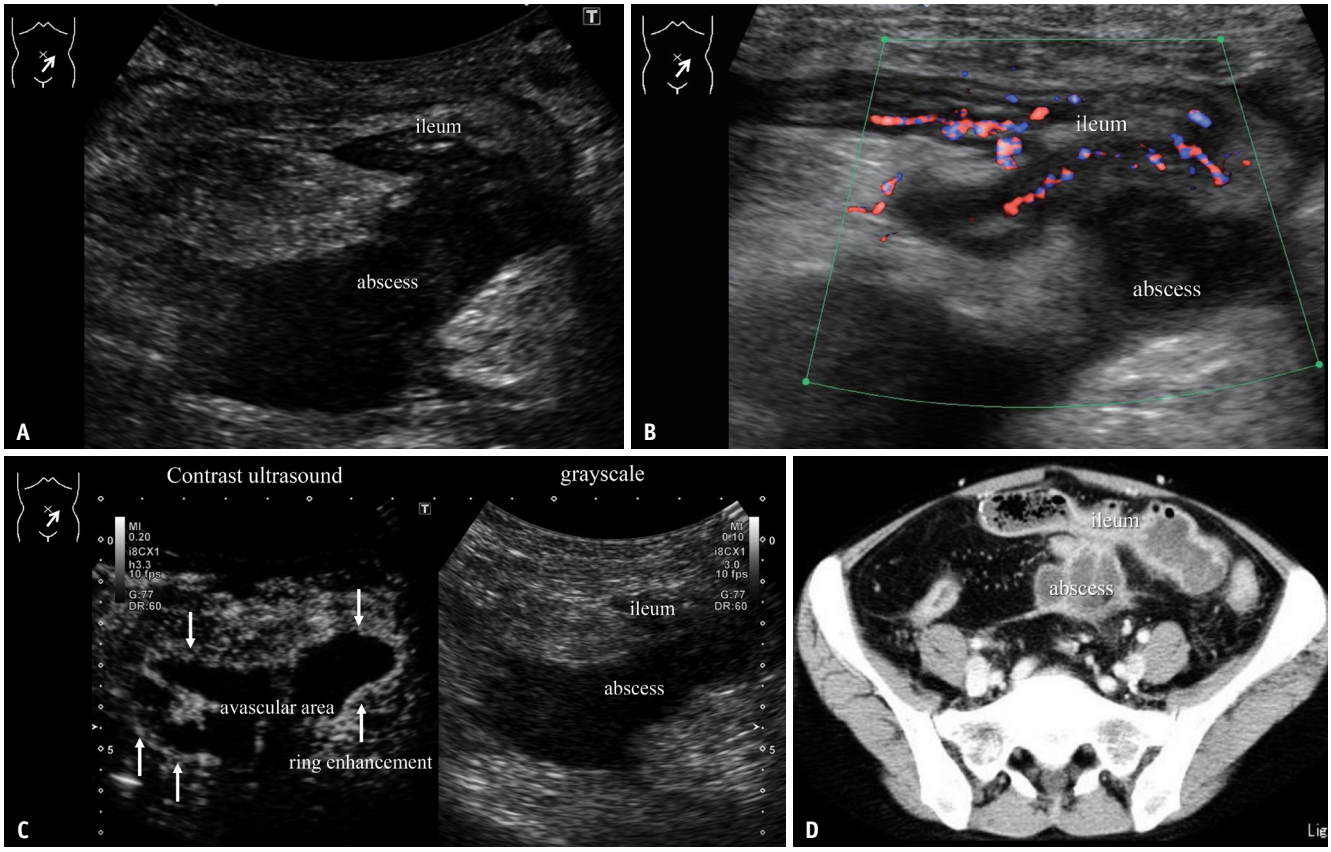


**Fig. 10. Abscess in a patient with Crohn's disease.**
**A.** An abscess is identified as a hypoechoic area attached to the bowel lesion. Fluctuations in the contents can be noticed by real-time observation (probe: 4 MHz convex). **B.** Superb Microvascular Imaging image of the same lesion. The abscess is identified as an avascular area (probe: 7 MHz linear). **C.** Contrast ultrasound of the same lesion. The image on the right shows the contrast ultrasound image and the image on the left shows the monitoring grayscale image. The abscess shows no contrast enhancement, while the surrounding area shows increased enhancement, which is known as ring enhancement (arrows) (probe: 4 MHz convex). **D.** Contrast-enhanced computed tomography image. The abscess is identified as an area without enhancement.


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the wall, including its relationship with surrounding tissues. The mechanism of stenosis is complicated, including hyperplasia of smooth muscle that is associated with chronic inflammation as well as the compression of adipose tissue outside the wall due to wall thickening. However, it is generally necessary to determine whether the stenosis is predominantly due to inflammation or fibrosis, as the former is likely to improve with conservative treatment, while the latter requires surgical treatment or endoscopic dilatation [78]. Regarding the differentiation between inflammation and fibrosis using TAUS, there are reports that, in B-mode, the hypoechoic pattern is more typical in inflammatory stenosis, while the stratified or nonhomogeneous echo pattern indicates fibrosis [79,80]. At the same time, it is important to note that factors such as the appearance and uniformity of the layered structure differ depending on the frequency used or the patient's condition. Additionally, reports using color Doppler and contrast-enhanced US indicated more blood flow with inflammatory stenosis compared to fibrous stenosis, and the finding is believed to be useful in differentiating between inflammatory and fibrous stenosis [81-85]. Recently, it has been reported that evaluation of lesion hardness using methods such as strain elastography or shear-wave elastography (SWE) is useful for diagnosing fibrosis [86-90]. In particular, SWE is expected to be used as an objective and quantitative indicator as well as for lesion activity evaluation in the future. Figure 7 shows stenotic lesions in CD. Clear stenosis of the upper lumen and dilation of the oral intestinal tract were observed in B-mode. When SWE was used, the lesion appeared hard, suggesting that the stenosis was accompanied by a high degree of fibrosis. TAUS can also be used to diagnose areas

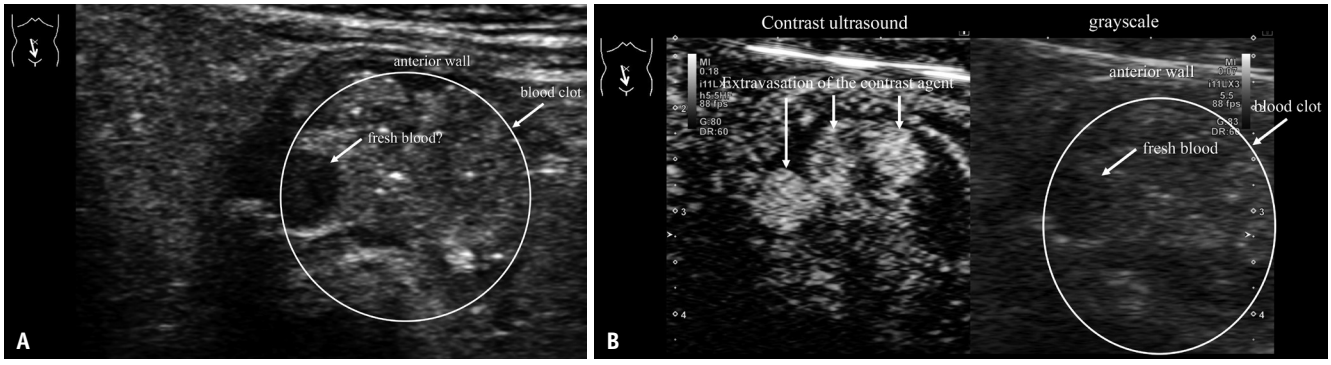


**Fig. 11. BBowel hemorrhage seen in a patient with Crohn's disease.**
**A.** An echogenic mass in the ileal lumen with a small, rounded, hypoechoic area inside is detected. The echogenic mass (circled area) might represent a blood clot, and the hypoechoic area may represent fresh blood (probe: 7 MHz linear). **B.** Contrast ultrasound of the same lesion. The image on the right shows the contrast ultrasound image and the image on the left shows the monitoring grayscale image. Extravasation of the contrast agent into the hypoechoic area (arrows) is immediately demonstrated, and the contrast agent gradually spreads into the mass, which represents the blood clot (circled area) (probe: 7 MHz linear).

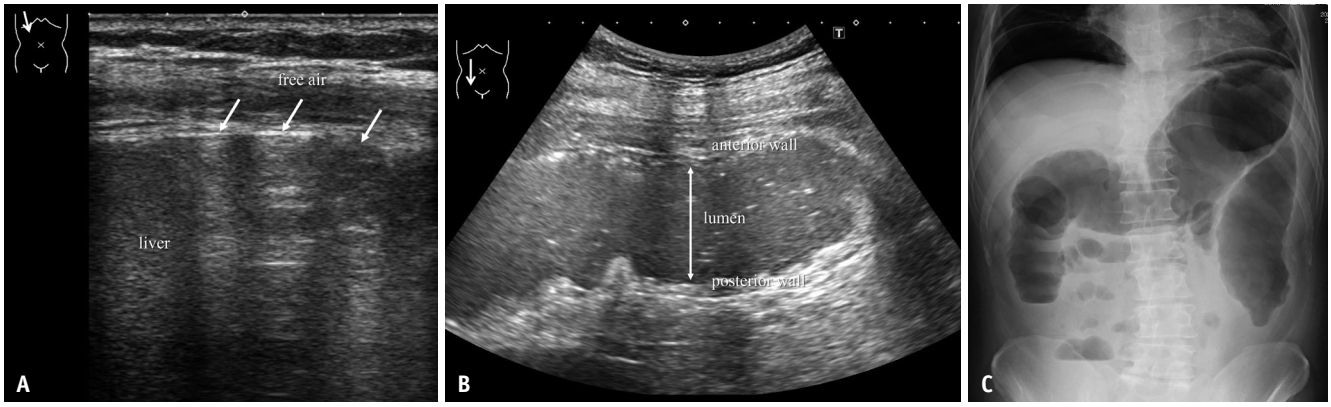


**Fig. 12. Colonic perforation seen in a patient with ulcerative colitis.**
**A.** Free air is demonstrated as hyperechoic bands accompanied by multiple echoes beneath the parietal peritoneum (probe: 7 MHz linear). **B.** Longitudinal view of the ascending colon. The wall thickness is thin, and dilatation of the colonic lumen filled with watery stool is demonstrated, which indicates toxic megacolon (probe: 4 MHz convex). **C.** Abdominal X-ray. Colonic dilatation, suggesting toxic megacolon, as well as free air, is demonstrated.


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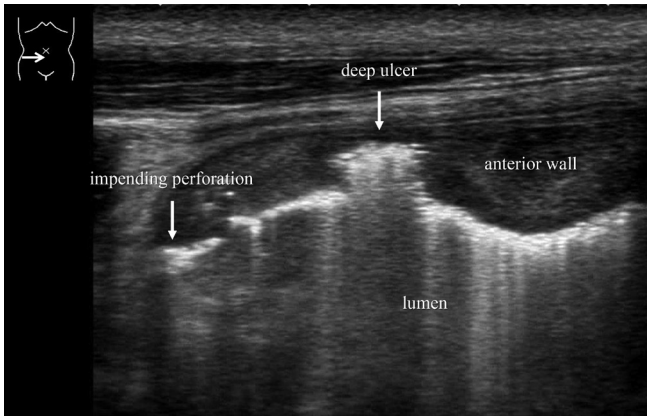


**Fig. 13. Impending perforation of the cecum in a patient with ulcerative colitis.** Deep ulcers are demonstrated, and an ulcer is as deep as the subserosa, indicating a high risk of perforation (probe: 7 MHz linear).

of stasis for capsule endoscopy and patency capsules [91]. Figure 8 shows an image of a patency capsule retained in the ileum in the case of CD.

The sinus and fistula are depicted as linear or band-shaped hypoechoic lesions, continuing from the superior intestinal lesions of the TAUS; air may also be observed inside (Fig. 9) [92,93]. Abscesses are also considered to be low to non-echoic regions with liquid components and sometimes aeration (Fig. 10) [94]. Since it has been reported that the diagnostic abilities of TAUS are almost the same as those of other methods such as CT and MRI scans [95], this method should be tried first.

Meanwhile, it is not easy to diagnose bleeding with B-mode (black and white images) or color Doppler; hence, we have reported a method for showing extravasation of a contrast agent using a contrast-enhanced US and making a diagnosis [96]. However, no IBD-specific papers have been found, and this method is not commonly used, as yet. Figure 11 shows a case of CD in which evidence of active bleeding was found using contrast-enhanced US.

Toxic megacolon is a serious intestinal complication that can occur in a case of UC, but there are very few reports on this complication, in which TAUS was used. In these cases, the large intestine was dilated (> 6 cm), the wall was thinned (< 2 mm), and the lumen was filled with watery stool (Fig. 12) [97]. Evidently, perforation is determined by detecting free air on US. In addition, TAUS can determine the perforation site and the risk of perforation; however, there are no reports on this. Figure 13 shows a case of UC in which a perforation occurred 12 hours after the examination, and deep subserosal ulcers in the cecum and turbid ascites in the surrounding area, signifying imminent perforation.

## CONCLUSION

TAUS is considered to be extremely useful in the diagnosis and treatment of IBD as a non-invasive and simple tomographic diagnostic method. It is an indispensable examination method at our facility for the diagnosis of IBD and several other gastrointestinal diseases, such as acute inflammatory diseases and neoplasm. Since TAUS is non-invasive and does not require any special preparation, it can be easily performed and repeated at any time, whenever necessary. In addition, TAUS can provide detailed information regarding the transmural changes of the lesion, extramural complications, and even minute blood flow changes of the lesion, with its high special and temporal resolution. Therefore, we believe that TAUS has great potential to be the first-line morphological examination method in the diagnostic strategy of gastrointestinal diseases. However, there are some issues that need to be resolved related to the universalization and standardization, as for such a technique, the biggest drawback could be regarding equipment selection and settings, parameters used for evaluation, and lack of objectivity. In the future, discussions between facilities, academic societies, and nations would be necessary.

### Availability of Data and Material

The datasets generated or analyzed during the study are available from the corresponding author on reasonable request.

### Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

### Author Contributions

Conceptualization: Jiro Hata. Resources: Jiro Hata. Supervision: Hiroshi Imamura. Validation: Jiro Hata. Writing—original draft: Jiro Hata. Writing—review & editing: Jiro Hata.

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