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Multiparametric Intestinal Ultrasound (IUS) in Inflammatory Bowel Diseases (IBD)

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Introduction

Background

Multiparametric intestinal ultrasound (IUS) has emerged as a valuable, non-invasive tool for the diagnosis, monitoring, and phenotyping of inflammatory bowel diseases (IBD), offering real-time assessment of bowel wall structure, vascularity, and stiffness [1-2].

The white paper discusses the latest advancements in intestinal ultrasound as below.

- Bowel wall structurer assessment: Conventional versus AI-based bowel wall thickness (BWT) measurement and segmentation
- Bowel vascularity assessment: Using color Doppler, microvascular imaging, contrast-enhanced ultrasound (CEUS)
- Bowel wall stiffness assessment: Using strain elastography, point and 2D shear wave elastography

System Requirements

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Figure 1. (A) Samsung R20 machine and (B) recommended probes LA2-9S, LA2-14A, CA3-10A, and CA1-7S to perform IUS for IBD management.

A high-end ultrasound machine (Samsung R20) with low to mid frequency linear and convex probes (LA2-9S, LA2-14A, CA3-10A, CA1-7S) are recommended for the diagnosis and the management of Crohn's Diseases (CD) and Ulcerative Colitis (UC).

Expert Opinion

Assessment of bowel wall structure

Conventional method

Conventional assessment of bowel wall thickening in IBD relies on at least two measurements in the longitudinal plane, taken 1 cm apart, and two in the transversal scan, taken in two different quadrants, as shown in Figure 2A and Figure 2B respectively. Measurements should be taken at the site of maximum thickening, where both external and internal margins are clearly visible. Calipers should be placed carefully, avoiding folds, wall irregularities, and regions where thickening may be influenced by an oblique scan.

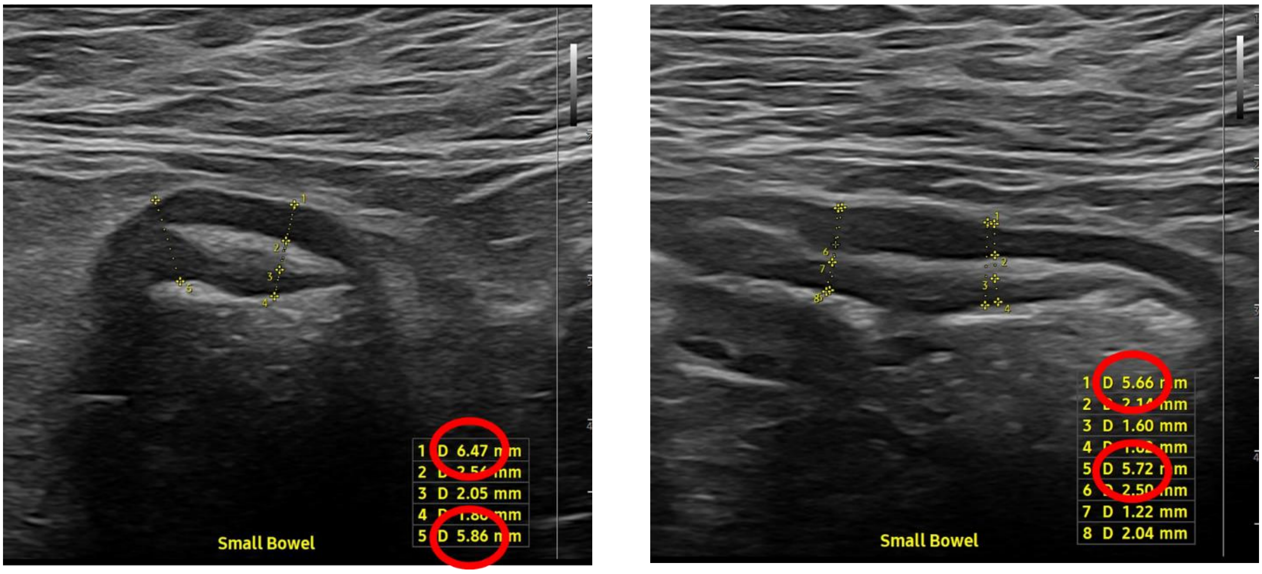

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Figure 2. Conventional measurement of bowel wall thickness (BWT) and its layers in the small bowel, using (A) transverse scan – showing maximum BWTs of 6.47 mm and 5.86 mm – and (B) longitudinal scan, with maximum BWTs of 5.66mm and 5.72 mm.

There may be noticeable variability between BWT measurements along the same bowel segment, leading to considerable intra- and inter-observer variability.

In fact, the bowel wall thickening in both Crohn's disease (CD) and ulcerative colitis (UC), may be not homogenous. As a result, measurement also taken appropriately in close proximity can show significant differences. Therefore, a single measurement may not accurately represent the true extent of bowel wall thickening or allow assessment of bowel damage compared to multiple or serial measurements of the same segments. However, this approach is time-consuming and impractical in routine clinical practice. In this context, artificial intelligence can help overcome the limitation by providing an average BWT measurement within a defined region of interest (ROI) box.

BowelAssist – An AI-based BWT measurement

BowelAssist is an AI-assisted tool designed to measure bowel wall thickness (BWT) both in longitudinal and transverse scan. During the scan, the area of inflammation is identified and an image is captured at the location where BWT measurement is desired. On the captured image, an ROI box is drawn over the inflamed or diseased area y selecting the BowelAssist button on the touch panel. The tool then performs automatic segmentation of the bowel wall and its distinct layers such muscularis propria, sub-mucosa, and mucosa. Following segmentation, BowelAssist also determined whether bowel wall stratification is preserved or has been lost.

- Case1 - Stratification Preserved: BowelAssist will measure the average values of BWT, muscularis propria thickness (MPT), sub-mucosa thickness (SMT), and mucosa thickness (MT) within the ROI box as shown in Figure 3A.
- Case 2 - Stratification Lost: BowelAssist will measure only the average values of BWT within the ROI box. The result will be displayed on the image, as shown in Figure 3B.

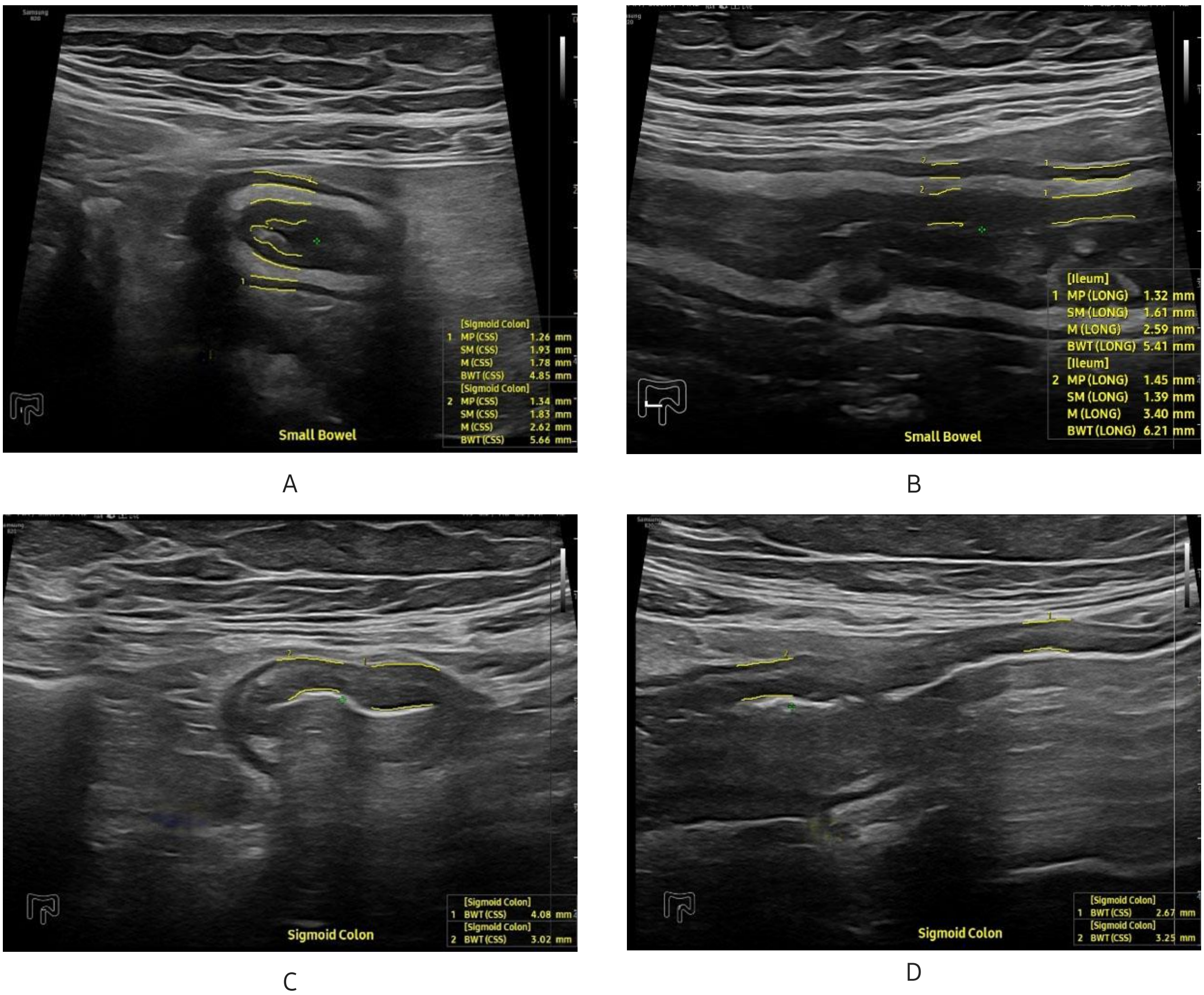

Figure 3. Single BowelAssist-based cross-sectional measurement of the small bowel in transverse (A) and longitudinal (B) scans. BWT, MPT, SMT, and MT have been measured in a segment with preserved stratification. BowelAssist measurements of sigmoid colon segments with lost stratification are shown in transverse (C) and longitudinal (D) scans.

Result will be displayed on the image. The user has the flexibility to confirm and assign the values to bowel report or repeat the measurement. These measurements represents average values calculated from multiple points within the ROI box, resulting in significantly lower intra-observer and inter-observer variability compared to conventional methods. BowelAssist can also estimate bowel wall thickening in case of extensively inflammation, offering a reproducible and accurate approach to assessing the bowel damage.

Assessment of bowel vascularity

The bowel vascularization is a key parameter for assessing the activity in both CD and UC. Active bowel wall inflammation in IBD is strongly associated with hypervascularization and neoangiogenesis. Traditionally, bowel vascularization is assessed using color Doppler ultrasound. However, color Doppler can detect only arterioles, and small vessel with a diameter > 0.1 mm, and with flow velocities of 10-20 cm /sec, as shown in Figure 4.
More recently, advanced ultra-sensitive ultrasound techniques for microvascular imaging have been developed. These enable improve detection of vessels as small as 50 microns and offers enhanced spatial and temporal resolution, allowing better separation of blood flow signals from tissue motion artifacts and background noise.
In addition, contrast-enhanced ultrasound (CEUS) provides a comprehensive evaluation of bowel wall perfusion and significantly improves the detection of vessels smaller than 50 microns, both in the surrounding tissue and within the diseased bowel walls itself.

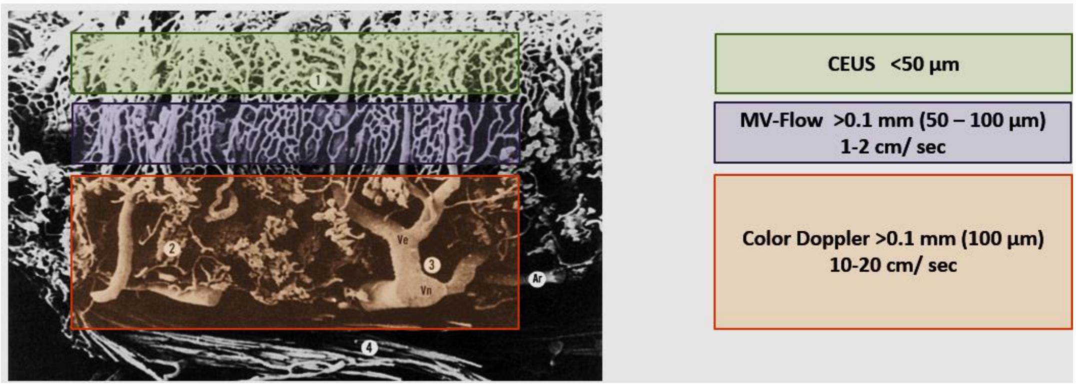

Figure 4. Visualization of bowel wall vascularization at different vessel levels.

Color Doppler Vs. MV-Flow

MV-Flow can detect significantly more blood flow signals than color Doppler within the bowel wall in patients with CD. The R20 and other high-end Samsung systems are equipped with this tool, along with software that calculates the number of vascular pixels within a defined ROI in the bowel wall, providing a perfusion index (vascularity index). This enhances the assessment of bowel wall vascularization in a reproducible manner, also for conventional methods such as Limberg score (Figure 5 and 6)

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Figure 5. Blood flow using (A) Color Doppler and (B) MV-Flow for Small Bowel in longitudinal view for CD.

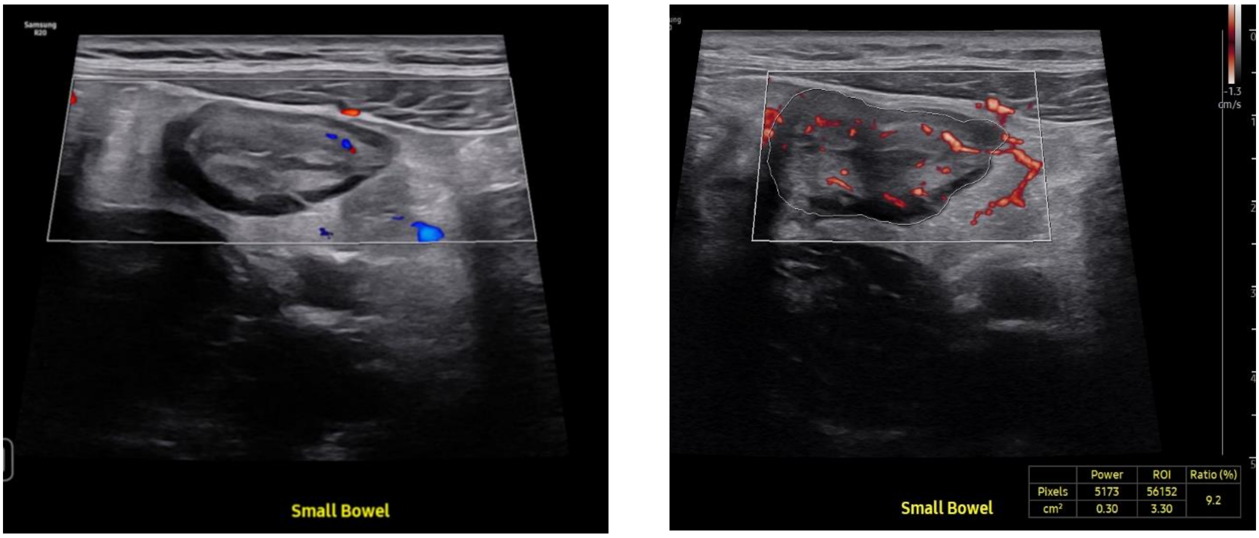

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Figure 6. Blood flow using (A) Color Doppler and (B) MV-Flow for Small Bowel in transverse view for CD.

We can see similar improvement for the MV-Flow over color doppler for patient with UC.

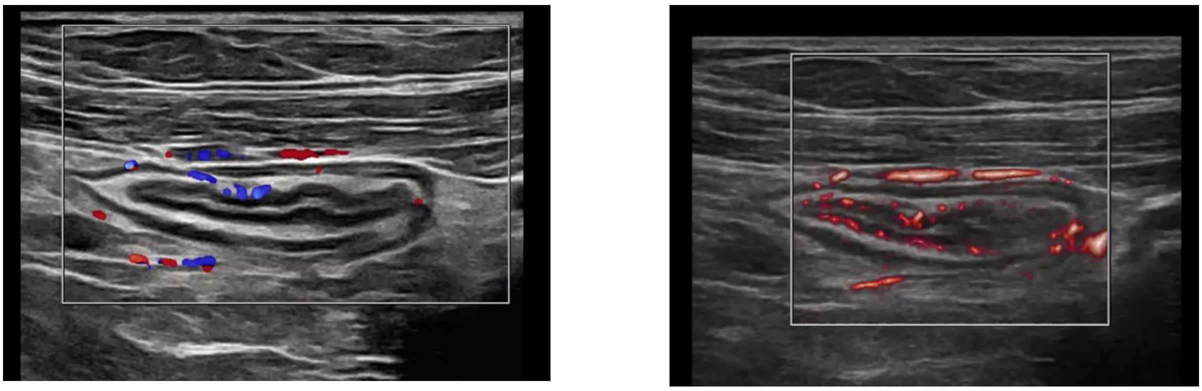

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Figure 7. Blood flow using (A) Color Doppler and (B) MV-Flow in a patient with UC.

Contrast Enhanced Ultrasound (CEUS+)

The current guidelines recommend contrast-enhanced ultrasound (CEUS) for the evaluation of abdominal inflammatory masses complicating CD, particularly to differentiate between abscess, phlegmons, and inflammatory masses. This tool can also be used in combination with transperineal approach to assess septic perianal lesions, enabling the detection of perianal fluid collections in complex perianal disease.

For this indication, CEUS+ is a practical and easy-to-use and examination that provides an accurate evaluation of vascularity within the lesion - especially when combined with microvascular flow imaging, which offers a detailed visualization of the capillary bed and neovascularization, better than conventional transperineal ultrasound.

This approach can help avoid unnecessary – or even risky - attempt at drainage of suspected collection, and may reduce both the cost and diagnostic delay associated with pelvic MRI, thereby accelerating diagnosis and optimizing therapeutic management (Figure 8).

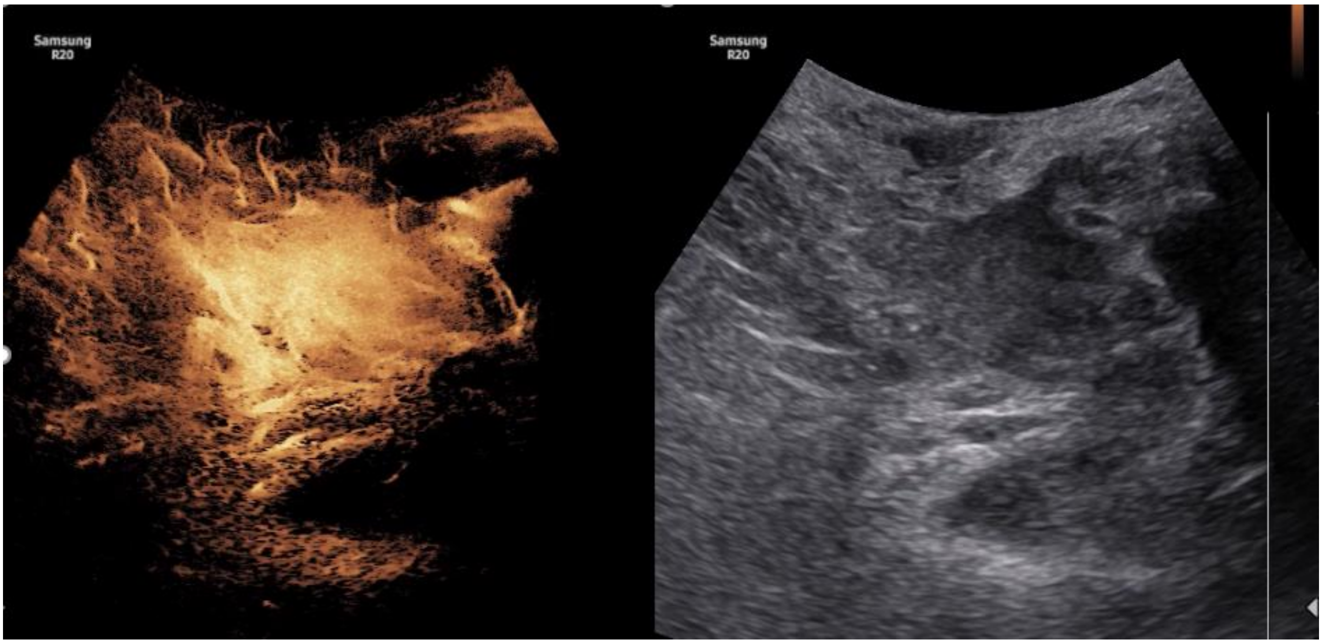

Figure 8. CEUS+ confirming a 4cm perianal inflammatory mass. The images show transperineal CEUS+ (left panel) and a conventional TPUS (right panel) of a 23 year-old male patient with CD, admitted for fever and abdominal and perianal pain, TPUS revealed a large perianal lesion (4cm), extending beyond levator any muscle, rising suspicion of a large perianal abscess. However, CEUS+ showed that the lesion was fully vascularized excluding the presence of any fluid collection.

Assessment of bowel stiffness

The accuracy of the sonographic evaluation of bowel walls elasticity in CD, and more recently also in ulcerative colitis, particularly for the non-invasive assessment of fibrosis using elastography, has been the focus scientific research in the past decade. Currently there are two main types of elastography: strain elastography and shear wave elastography (including point share wave and 2D-shear wave imaging) [3].

Strain Elastography

Strain Elastography offers a semi-quantitative estimation of stiffness by applying repetitive pulse pressures with probe over the bowel loop. The resulting tissue displacement is tracked between pairs of echo frames, and strain is calculated from the gradient of this displacement. Since the exact amount of stress applied is unknown, the absolute elasticity values cannot be measured. Instead, stiffness is reported as ratio between the stiffness of the bowel loop and that of the surrounding softer tissue. A ratio greater than 2 is highly suggestive of stiff, likely fibrotic tissue, as shown in Figure 9.

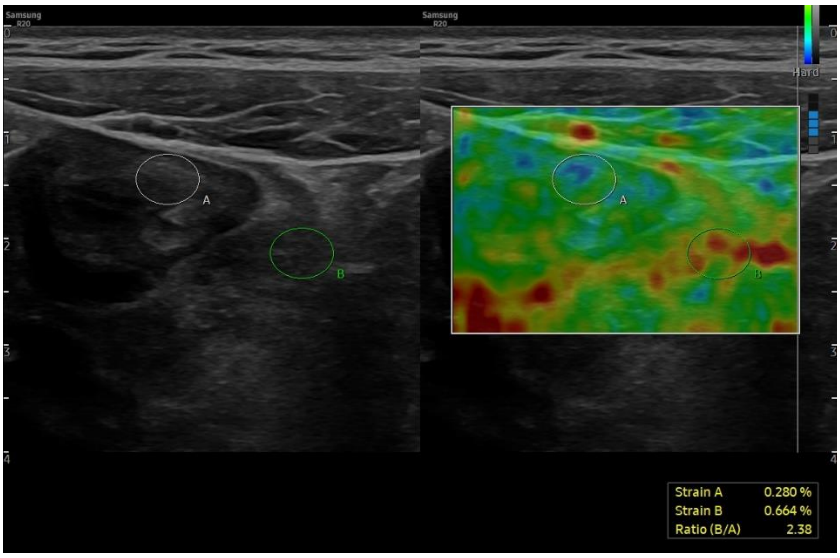

Figure 9. Strain elastography examination for a CD patient, where ratio is >2 suggesting a fibrotic tissue.

Shearwave Elastography (SWE)

SWE has shown strong potential in assessing bowel wall stiffness as a marker of fibrosis in IBD, providing in real-time, quantitative data that correlates with histopathology.

There are 2 variants of SWE: point SWE (p-SWE) and two-dimensional SWE (2D-SWE). The former measures shear wave velocity in a small, and single region of interest (ROI), while the latter generates a color-coded map of tissue elasticity over a wider area, along with a color-coded reliability map, indicating the confidence of each measurement.

R20's 2D SWE Imaging produces a color-coded reliability map, where green indicates the highest confidence, and guides the user in selecting the optimal ROI placement for accurate measurement of the absolute tissue stiffness in kilopascals (kPa). On the corresponding elasticity map (right panel) tissue stiffness is visualized – typically, blue indicates harder tissue.

Although standardization is still lacking, due to variability in stiffness measurements, it is recommended to perform evaluation in multiple ROIs of the bowel wall, in both longitudinal and transversal scan, as shown in Figure 10.

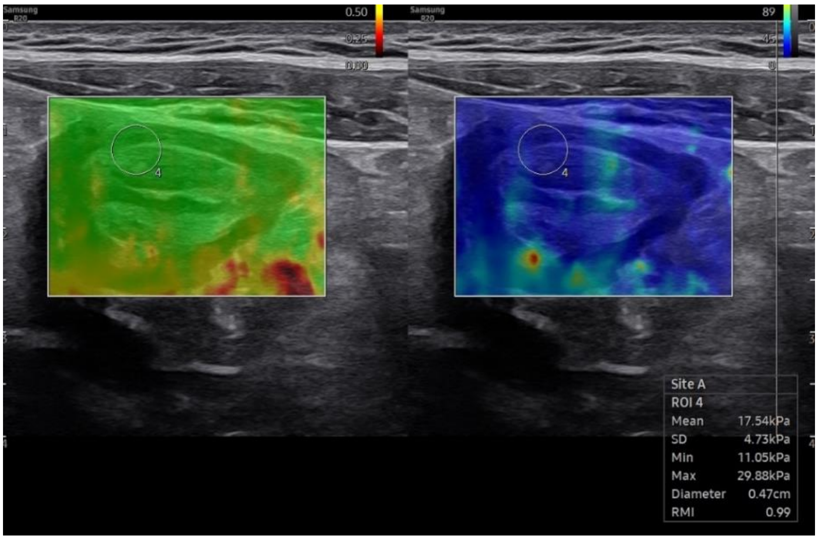

Figure 10. R20's 2D-shearwave Imaging. The system generates a color-coded reliability map indicating the confidence of each measurement- where green represents the highest reliability – and an elasticity map (right panel) where the user can place the ROI to accurately and reliably measure the absolute tissue stiffness in kilopascals (kPa).

Conclusion

Multiparametric sonographic evaluation provides additional and valuable diagnostic information in the assessment of patients with IBD. BowelAssist- an AI-based automated BWT measurement and segmentation - enables easy, accurate and reproducible assessment of bowel wall structure.

This can be seamlessly integrated with vascularity assessment using CEUS+ and/or MV-Flow, as well as with the evaluation of tissue elasticity and stiffness through 2D-shearwave elastography. Together, these tools allow for a precise estimation of bowel inflammation and fibrosis, which can be support personalize therapy, monitor disease progression and help predict therapeutic outcomes in IBD patients.

References

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