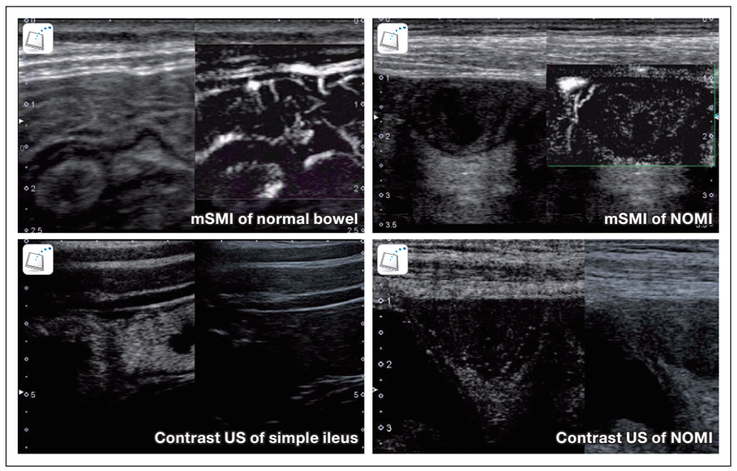

Figure 22. NOMI (non-occlusive mesenteric ischemia)

in patients with cancer, tumors, rheumatoid arthritis, and many other medical conditions. In studies performed with a contrast medium, the use of SMI can further increase sensitivity and improve diagnostic accuracy.

Conclusion

Without doubt, SMI is an extremely useful tool providing valuable information about minute vessels which we have previously not been able to evaluate, especially during physiological change and even without contrast agents. In the near future, SMI will be an essential tool for the diagnosis and the assessment of various diseases, regardless of the affected organ.

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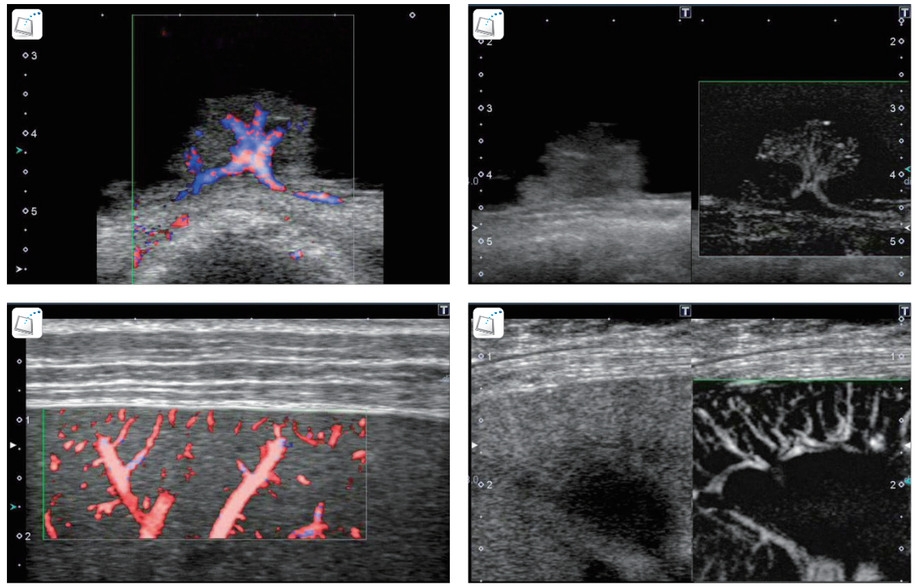
Leading Innovation

Medical Review

Seeing the Unseen
New Techniques in Vascular Imaging

Superb Micro-Vascular Imaging



Seeing the Unseen
New Techniques in Vascular Imaging

Superb Micro-Vascular Imaging

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Ultrasound is a readily available, non-invasive imaging technology that is frequently used as a first-line diagnostic exam, providing clinicians with a rapid procedure to diagnose disease and quickly develop treatment plans. This is especially true in vascular Imaging where clear and precise hemodynamic data is presented in visual and trace form. Clinically significant challenges exist in detecting small or microflow states without the use of contrast media.

Toshiba's Aplio™ 500 ultrasound system provides a full suite of tools for evaluating vessels and hemodynamics, including color Doppler Imaging, power Doppler, Advanced Dynamic Flow™ and pulsed wave Doppler. Combined with the contrast capability of the system, this provides an outstanding tool-kit for vascular diagnosis. To expand the range of visible flow in ultrasound, Toshiba's Aplio 500 is now equipped with a new technology, specifically for imaging very low flow states.

This new feature called Superb Micro-Vascular Imaging (SMI) is an innovative ultrasound Doppler technique. SMI is a unique ultrasound Doppler technique employing a unique algorithm that allows visualization of minute vessels with slow velocity but without having to use a contrast agent. The advantages of SMI are:

1. Low velocity flow visualization
2. High resolution
3. Minimal motion artefact
4. High frame rates

SMI has demonstrated its value in clinical situations encountered in daily practice. The evaluation of the density and shape of tumor vessels with SMI facilitates the diagnosis and differentiation of lesions. SMI could also be used to assess the therapeutic effect of chemotherapy and evaluate the disease activity in inflammatory disorders, such as ulcerative colitis and Crohn's disease.

In addition, SMI provides a more sensitive view of minute vessels in contrast-enhanced ultrasound (CEUS) helping to obtain sustained dynamic images of microflow after the first pass of the contrast agent.

Background

Diagnostic ultrasound, a non-invasive, radiation-free technique, is widely used in all stages of medical care from initial diagnosis to follow-up. In recent years, ultrasound has become the frontline imaging modality for definitive diagnosis, treatment planning and therapy evaluation of patients with malignant and benign lesions. Diagnostic imaging studies must be able to detect malignancy in its early stages in order to achieve the best possible therapy outcomes. Nevertheless, conventional color Doppler technique suffers from technical limitations with regard to visualizing fine vessels and low-velocity blood flow. While contrast-enhanced ultrasound (CEUS) increases the detectability of blood flow and thus is able to overcomes some of these limitations, it does have a number of drawbacks: CEUS is not readily available everywhere, it is subject to certain restrictions regarding contrast agent use and it places an additional cost burden on the patient.

To address these issues and allow clinicians to see the unseen, Toshiba developed Superb Micro-Vascular Imaging (SMI), an innovative vascular imaging technique that can visualize smaller vessels and lower-velocity blood flows without the use of contrast medium. SMI is available on the Aplio 500, Toshiba's premium ultrasound system, and on other Toshiba systems.

Throughout the decades, Toshiba has been improving vascular visualization, providing better resolution and detecting a wider velocity range. In 2001, Toshiba introduced a the high-resolution Doppler imaging technique, Advanced Dynamic Flow (ADF), which displays small blood vessels and complex blood flow with amazing accuracy. Despite its excellent performance, ADF has frame rate and flash limitations for slower velocity ranges. In order to overcome these limitations, Toshiba developed Superb Micro-Vascular Imaging (SMI) by utilizing its unique Doppler technologies (including ADF), High-Density Beamformer Architecture, and real-time Application platform available on the Aplio series. With SMI, Toshiba has redefined Doppler technology by allowing detection of low-velocity blood flow with high frame rates, less motion artefact, and high resolution.

The Principle behind SMI

The principle underlying SMI is a powerful and intelligent algorithm that effectively separates flow signals from overlaying tissue motion artefacts, preserving even the subtlest low-flow components with unmatched detail and definition.

1. Doppler signals

Both blood flow and tissue motion (clutter) produce ultrasonic Doppler signals. The strong clutter signals overlap the low-velocity blood flow components (Fig. 1).

2. Conventional Doppler imaging & SMI

Conventional Doppler imaging applies a wall filter to remove clutter and motion artefacts, resulting in a loss of low-flow components (Fig. 2).

SMI analyzes clutter motion and uses a new adaptive algorithm to identify and remove tissue motion and reveal true blood flow.

Conventional Doppler techniques were developed with the primary goal of visualizing blood flows at higher resolution. Moving beyond this goal, SMI is able to visualize lower-velocity blood flows as well (Fig. 3).

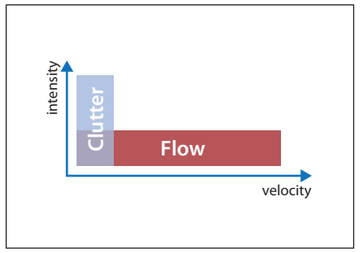

Figure 1. Doppler signals

The most significant problem in the detection of low-velocity blood flow is the presence of extraneous Doppler signals (motion artefacts) arising from nearby structures. Conventional techniques are unable to distinguish these motion artefacts from actual blood flow. With SMI, we analyzed the characteristics of such motion artefacts and successfully extracted only the clinically relevant information (Fig. 4, 5, 6).

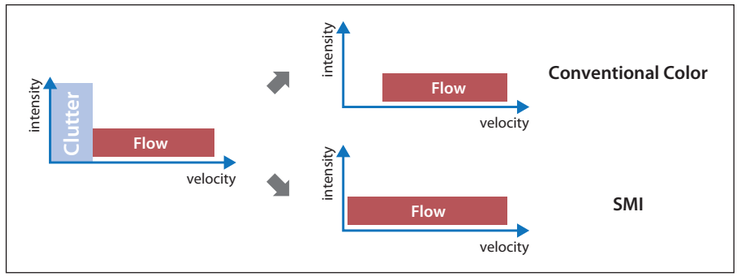

Figure 2. Conventional Doppler imaging & SMI

Modes of SMI

SMI is available in two modes: monochrome (grayscale) and color.

- The color mode (cSMI) demonstrates B-mode and color information simultaneously.
- The grayscale mode (mSMI) focuses only on the vasculature, improving sensitivity, by subtracting the background information.

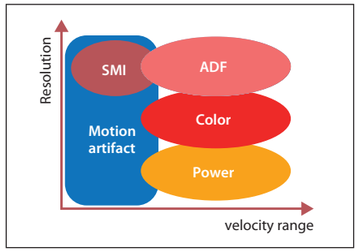

Figure 3. Conventional techniques and SMI

Potential clinical applications

There are several clinical applications of SMI that we will discuss, including neoplastic diseases and inflammatory disease.

Neoplasms

SMI has demonstrated significant clinical value in the evaluation of the density and shape of tumor vessels. Additional information can be gained by combining CEUS and SMI.

Hepatocellular carcinoma

In the case of hepatocellular carcinoma, the grayscale mode shows a suspicious lesion near the surface of the liver. With conventional ADF at a velocity range of 9 cm/s some vessels can be recognized but the pattern of the tumor vessels cannot be determined. When we lower

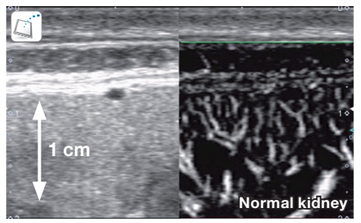

Figure 4. Abundant blood flow in the cortex of a normal kidney is visualized within 1cm, even with patient breathing freely.

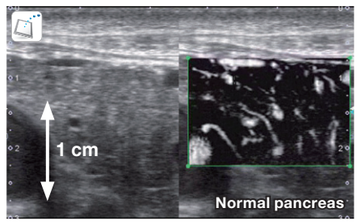

Figure 5. While conventional color Doppler poorly visualizes vasculature in a normal pancreas, SMI shows even fine vascular structure.

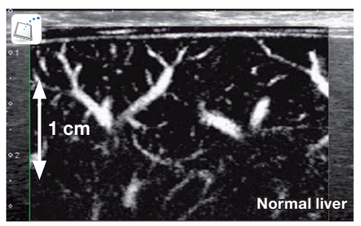

Figure 6. In normal liver, we can see a tiny vessels just beneath the surface of the liver.

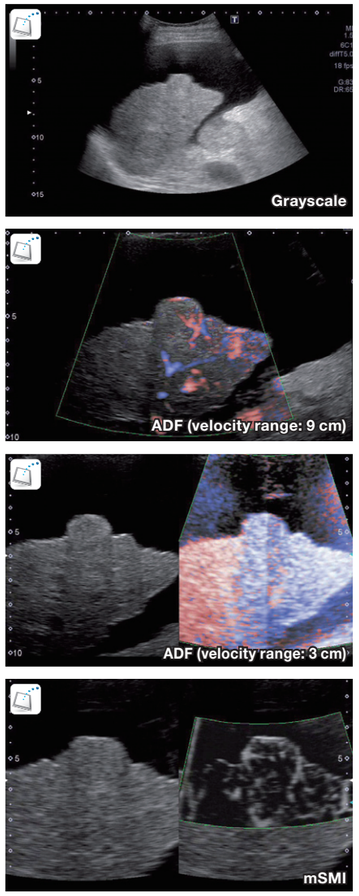

Figure 7. Hepatocellular carcinoma

the velocity range to 3 cm/s, the image is badly distorted by the clutter. Once we activate mSMI, we can see the internal tumor vessels whose basket shape strongly indicates HCC (Fig. 7).

Liver metastasis originating from a jejunal gastrointestinal stromal tumor (GIST)

With conventional color Doppler we can see some tumor vessels with a higher velocity and higher caliber. cSMI and mSMI both visualize the finer vessels within the tumor in more detail, thus providing us with a better understanding of the vascular structure and vascular density of these tumors than conventional color Doppler (Fig. 8).

Using contrast enhanced ultrasound (CEUS), we can see the fine vessels permeating the tumor but the enhancement effects dwindle as time goes by. cSMI further enhances the effect and shows many more vessels. Even at a higher frequency, we can see more detail of the finer vessels inside the tumor.

Bladder carcinoma

These grayscale and 3D images clearly show two small tumors and one diverticulum. By using cSMI and mSMI with a high frequency probe, we can find the branch-like structures inside the tumor without the use of CEUS (Fig. 9).

Gastric cancer

This scirrhous gastric cancer is relatively hypoechoic with a few color signals. By using SMI to enhance the CEUS, we can see the new blood vessels and flow patterns. Since blood flow in the body is dynamic and changes every moment SMI can delineate these changes of the blood flow even within a scirrhous tumor, clearly demonstrating sensitive tracking of blood flow during contraction and relaxation (Fig. 10).

Cervical lymph nodes (malignant lymphoma)

Visualization of blood flow within superficial lesions is an excellent application of SMI.

In the case of this malignant lymph node, SMI shows abundant blood flow inside the tumor. We can determine that the normal blood vessel structure in this lymph node has been destroyed because the blood flow is not coming from the lymph node hilum.

In this case, mSMI is more sensitive than cSMI and shows more of the finer vessels (Fig. 11).

Skin lesions

Malignant melanoma

Superficial skin lesions are one of the best applications for SMI.

This is a 5 mm malignant melanoma on the tip of a finger. Even in the tiny tumor, abundant tumor vessels can be displayed using cSMI (Fig. 12).

Squamous cell carcinoma

Using mSMI and a high frequency transducer, abundant tiny tumor vessels can be displayed in a squamous cell carcinoma on the face (Fig. 13).

Gastrointestinal Stromal Tumor of the ileum

SMI gives us additional options to visualize tiny vessels within tumors that may have been difficult or impossible to image with conventional CDI. mSMI shows fine vessels and combined with CEUS, the perfusion of the tumor blood vessels is visible. After the CEUS, cSMI shows the real-time image of new, previously unseen vessels (Fig. 14).

Inflammation

SMI with its microflow detection and depiction is particularly useful for assessment of disease activity in many body regions.

Rheumatoid arthritis (radio-carpal joint)

With conventional power Doppler, we can see several vessels inside the thickened synovial membrane in this

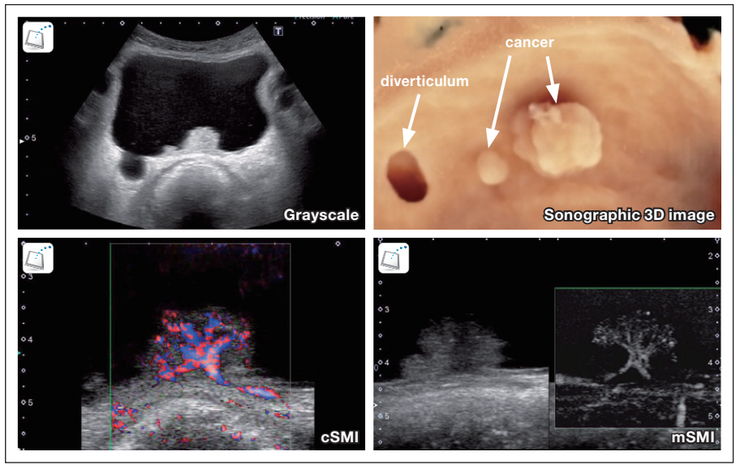

Figure 9. Bladder carcinoma

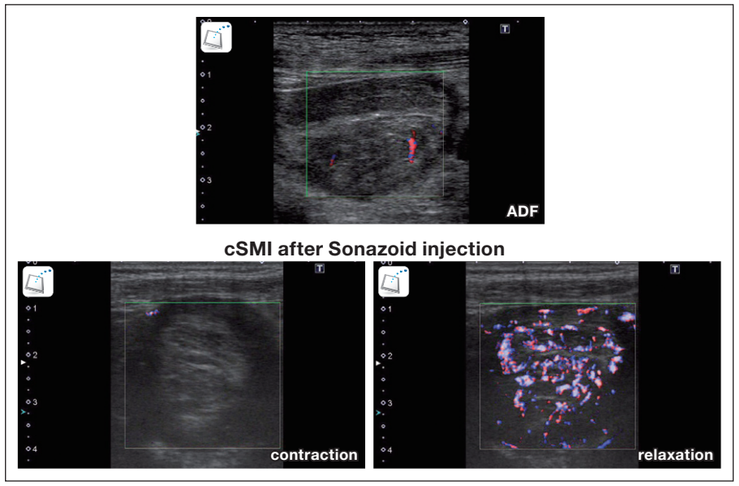

Figure 10. Gastric cancer

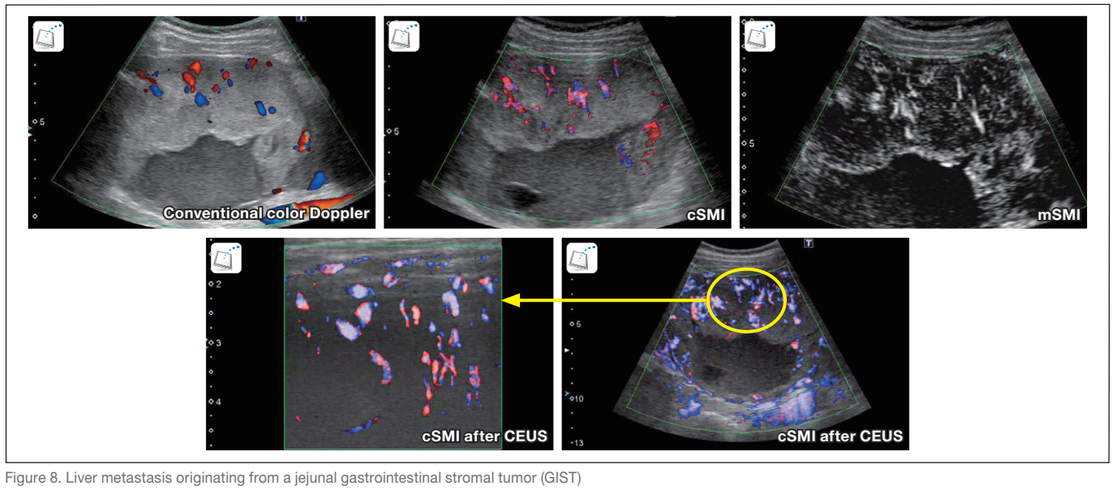

Figure 8. Liver metastasis originating from a jejunal gastrointestinal stromal tumor (GIST)

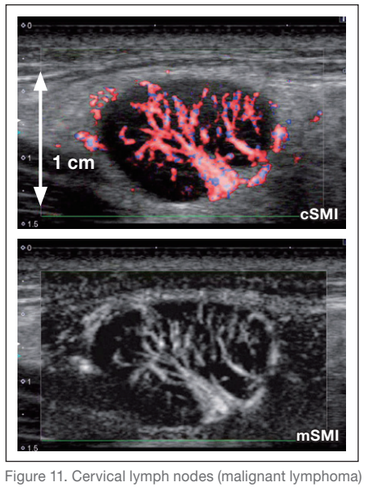

Figure 11. Cervical lymph nodes (malignant lymphoma)

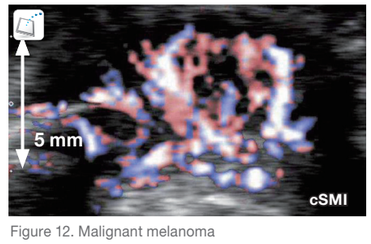

Figure 12. Malignant melanoma

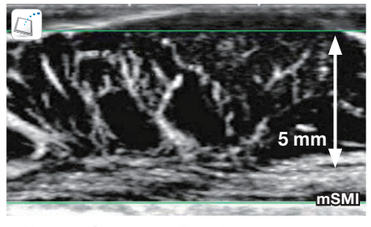

Figure 13. Squamous cell carcinoma

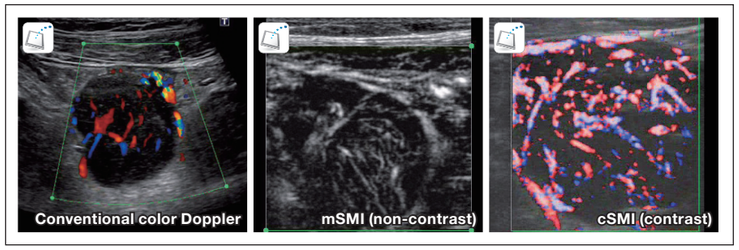

Figure 14. Gastrointestinal stromal tumor of the lieum

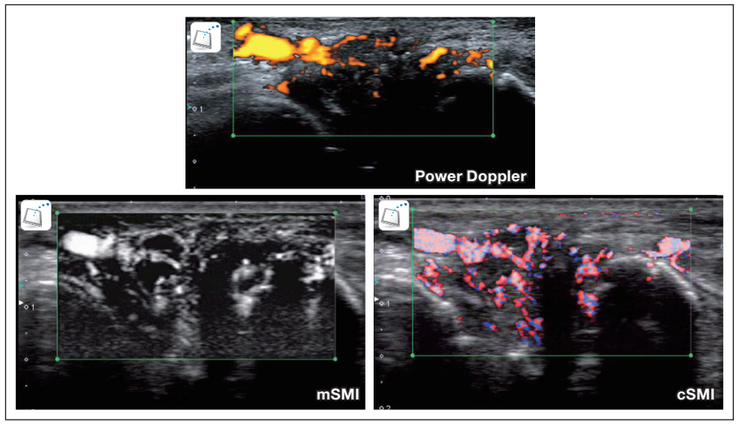

Figure 15. Rheumatoid arthritis (radio-carpal joint)

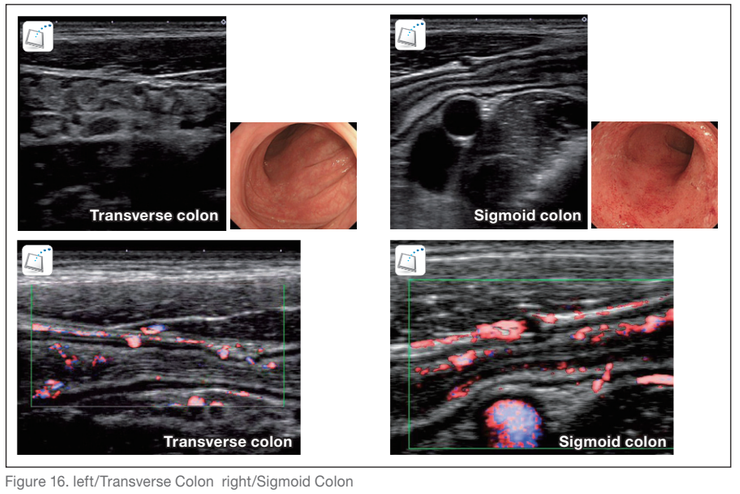

Figure 16. left/Transverse Colon right/Sigmoid Colon

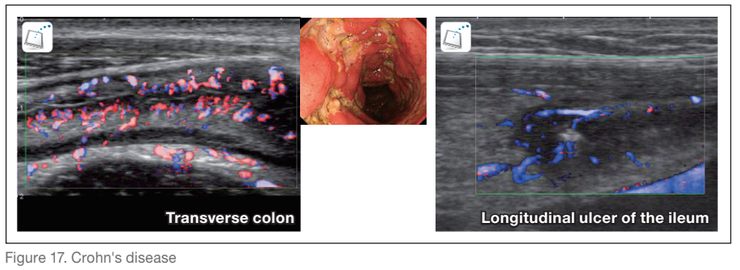

Figure 17. Crohn's disease

case of rheumatoid arthritis. Both cSMI and mSMI show significantly more vessels, a typical vascular pattern of inflammation. SMI is clearly superior to traditional PDI and has the potential to change the criteria for evaluation of disease activity in RA (Fig. 15).

Ulcerative colitis

The gastrointestinal tract is another good clinical application for SMI. Since on the grayscale image the wall segments appear to be similar in thickness, it is difficult to ascertain which segment is more active.

SMI visualizes the sparse vascular structure in the transverse colon wall but there is a dense and rich vascular structure (which represents hyperemia even in the mucosal layer, the hypoechoic layer) in the sigmoid colon wall. Abundant blood flow in the mucosal layer demonstrates the hyper-inflammation in the sigmoid colon in comparison with the transverse colon. Endoscopy images confirm the SMI results severe inflammation in the sigmoid colon (Fig. 16).

Crohn's disease

Transverse views of the ileum show hyperemia (increased blood flow) around the longitudinal ulcer of the ileum. When the inflammation spreads throughout the whole bowel segment, we can see the hyperemia in the total segment of the bowel wall (Fig. 17).

One of the major complications of Crohn's disease is subcutaneous abscesses. Grayscale shows the details inside the abscess cavity and the presence of hypoechoic layers within. With cSMI, we can clearly demonstrate the large quantity of inflammatory vessels surrounding the abscess cavity (Fig. 18).

Other clinical uses

SMI is highly sensitive to lower, slow blood flow has proven to be effective in the diagnosis of ischemia or necrosis.

Necrotizing lymphadenopathy

We can see the branch-like structure of the normal lymph node and detect an avascular area that represents necrosis. Even in tiny lymph nodes of 3 mm in diameter, we can suspect the existence of necrosis with cSMI, and confirm our suspicions using mSMI (Fig. 19).

Laceration of the spleen

This is a case of a 6-year-old boy with a suspected injury to the spleen. On grayscale, we can see a hypoechoic area inside the spleen. mSMI shows that the hypoechoic area is avascular, and composed of both a hematoma and damaged splenic parenchyma (Fig. 20).

Testicular torsion

This is a case of a 6-year-old boy with pain in the left testis. mSMI allows us to visualize straight vascular structures going through the right testis which can be difficult to visualize using conventional color Doppler alone.

There are no visible vessel structures in the left testis, indicating a diagnosis of testicular torsion in the left testis (Fig. 21).

NOMI (non-occlusive mesenteric ischemia)

Diagnosing NOMI is challenging with any modality. Using SMI in this normal bowel segment, we can clearly see rich blood flood in the intestinal wall, thus enabling a diagnosis.

NOMI is clinically difficult to diagnose because it is defined by the absence of blood flow in the affected bowel, which means there is no detectable flow even with CEUS. Despite using mSMI and CEUS together the diagnosis remains challenging, given the optimum visualization of normal bowel structure (Fig. 22).

Summary

SMI has significant advantages in low-flow imaging, including visualization of minute vessels, less motion artefact, increased sensitivity with the use of CEUS, and high frame rates.

SMI ensures vascular imaging with outstanding detectability for low-velocity blood flows, even in studies performed without the use of a contrast medium. This technique is of great value for early diagnosis and treatment planning

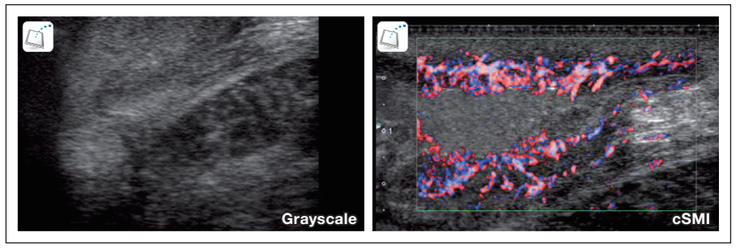

Figure 18. Subcutaneous abscess due to Crohn's disease

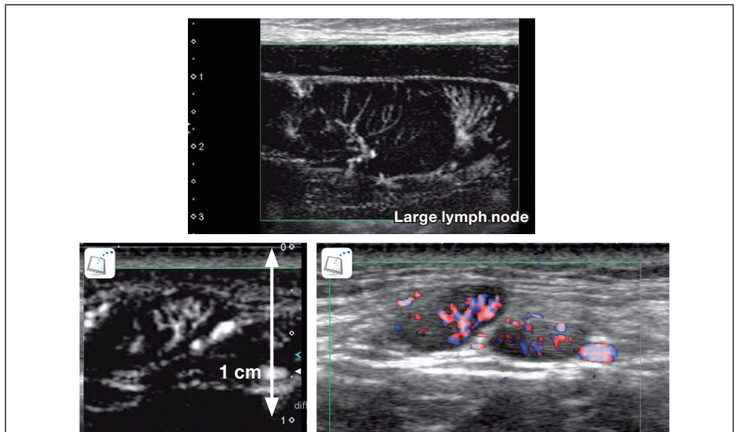

Figure 19. Necrotizing lymphadenopathy

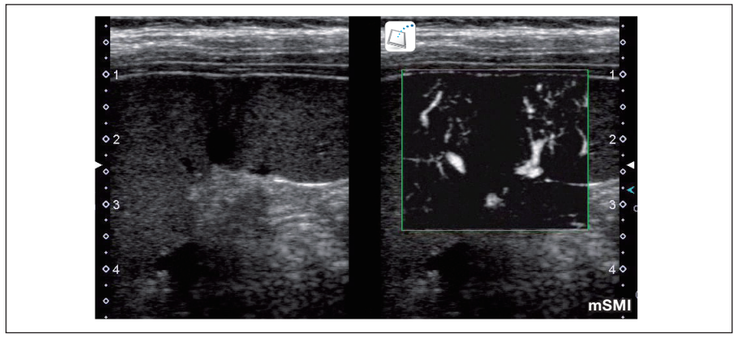

Figure 20. Laceration of the spleen

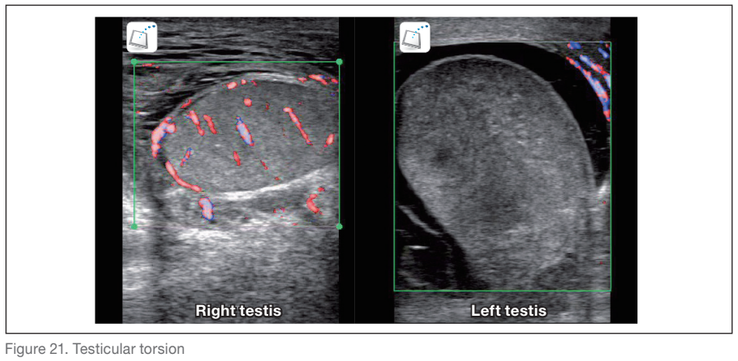

Figure 21. Testicular torsion