Pushing the Envelope in Doppler Imaging

Philips MicroFlow Imaging

Flow sensitivity and spatial/temporal resolution of current Doppler imaging modalities still do not meet the needs of clinicians, that is until Philips' MicroFlow Imaging (MFI).

Doppler ultrasound techniques, first introduced into medicine during the late 1950s, have increased in importance and are now well established as indispensable tools in many diagnostic situations. From spectral Doppler (SD) to Power Doppler Imaging (PDI) to Color Doppler Imaging (CDI), ultrasonic Doppler imaging has become an integral component of ultrasound systems and is used in many clinical situations including diagnosis and treatment planning. As clinical diagnosis using ultrasound continues to improve, there is clinical desire for ever-improving Doppler imaging modalities with increased flow sensitivity and spatial / temporal resolution. As such, current conventional CDI and PDI techniques are reaching their limit in ability to detect and visualize micro-vessel networks. This may explain why in certain clinical cases contrast enhanced ultrasound (CEUS), computerized tomography (CT), and magnetic resonance imaging (MRI) are used to visualize blood flow. However, these techniques do come with their own limitations, such as the use restrictions regarding contrast agents, radiation dosage, and cost and time burden.

It is therefore desirable to image microvascular networks, which are typically characterized by small blood vessels with slow blood flow, without the need for contrast agents or resorting to other imaging modalities. To accomplish this, Philips has developed MicroFlow Imaging (MFI), a new proprietary Doppler mode designed to detect very low-velocity micro-vessel anatomy in tissue. MFI overcomes many of the barriers associated with conventional CDI and PDI methods to detect small vessel flow with high resolution and minimal artifacts. MFI is available on Philips' EPIQ and Affiniti ultrasound systems.

The Pillars of MFI

MFI is a novel technology utilizing principles of Power Doppler and additional processing algorithms to improve flow sensitivity and improve spatial resolution. In order to achieve this MFI relies on three pillars:

1) MFI operates on very low velocity scales
2) MFI utilizes advanced clutter suppression
3) MFI utilizes vessel enhancement algorithms

Microvasculature consists of small blood vessels that typically exhibit blood hemodynamics at very low velocity ranges. MFI operates at these low velocity scales to better detect these weak signals with low Doppler shifts. This allows the wall filter to operate more effectively relative to the normalized Doppler shifts of the blood flow.

In order to obtain maximum low flow sensitivity, the wall filter cutoff is then set low to preserve the small Doppler frequency shifts associated with such vessels. However, at such a low wall filter setting, Doppler shifts from tissue motion are often not readily filtered out and thus appear as a flash artifact.

The current techniques to remove flash artifacts arising from tissue motion generally rely on setting the wall filter aggressively enough to limit the unwanted signal. The reason for this is that the strong tissue signal typically has a low Doppler velocity component. However, when imaging

slow-flow vessels, the Doppler frequency components often fall within the same Doppler ranges as tissue. As such, when the wall filter is set such that tissue motion artifact flashes are removed, the underlying slow flow microvasculature is also lost. Conversely, if the wall filter is set such that the slow blood flow is preserved, then tissue artifacts are not suppressed adequately. MFI addresses this issue by incorporating a novel spatial-temporal filter, which analyzes Doppler signal to separate tissue clutter from slow micro-vessels with slow flow states.

Since tissue signal behaves in a different manner than the microvascular blood flow, MFI will analyze the Doppler data to evaluate the signal characteristics from both a spatial and temporal dimension in order to distinguish between the wanted flow signals from the unwanted tissue clutter signals (Fig. 1). In this manner, MFI can detect the lowest velocity blood flow, which microvascular vessels typically exhibit, and remove unwanted tissue clutter.

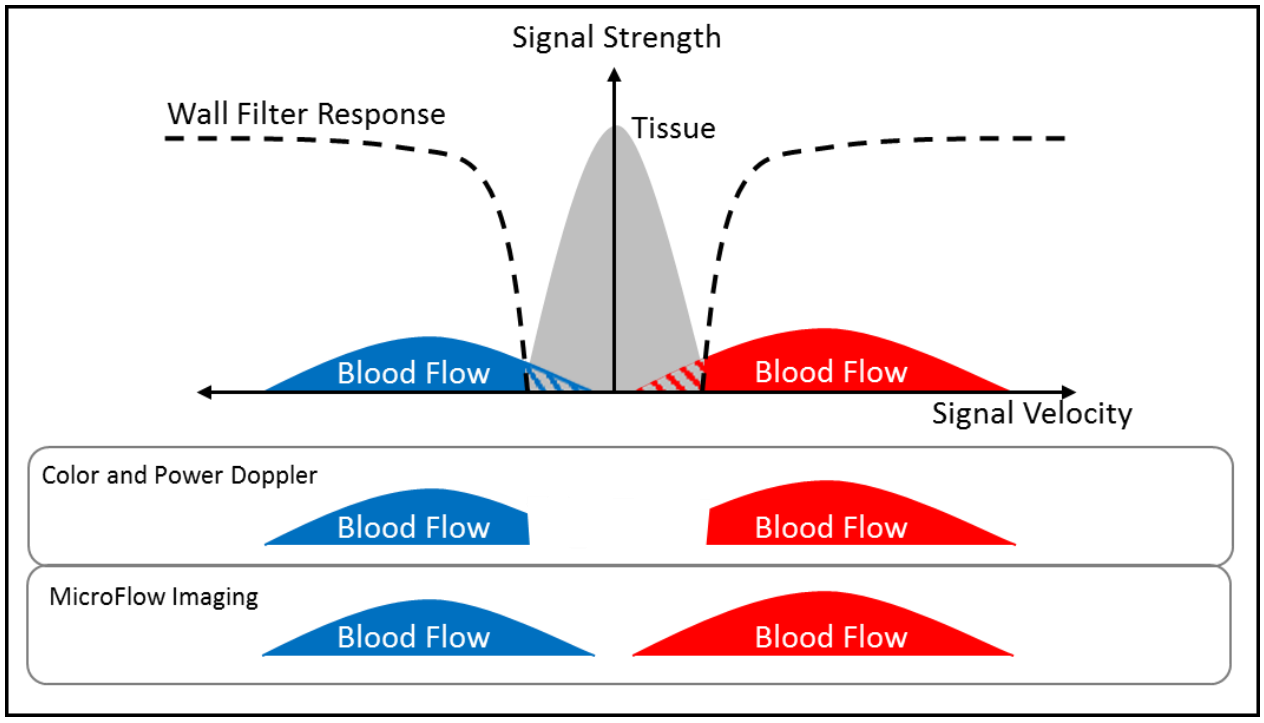

Figure 1: Doppler Signals. In conventional CDI and PDI, the lowest blood flow velocities are removed due to interference from tissue motion. In MFI, a spatial-temporal clutter filter is applied to separate the lowest blood flow velocities from that of tissue. MFI therefore preserves all blood flow signal including those from vessels with very slow flow states.

An example of MFI's clutter rejection algorithm is shown in Figure 2. A novel spatial-temporal clutter filter is applied which continuously analyzes the Doppler data. By analyzing the behavior of the signal in both the spatial and temporal dimension, MFI is able to further separate between low-flow states often seen in microvasculature and the surrounding tissue clutter. Therefore, after the spatial-temporal clutter filtering, the unwanted tissue motion artifacts are suppressed to reveal the underlying vascular network. This process is continuously repeated as new Doppler signals are acquired in real time by the ultrasound system.

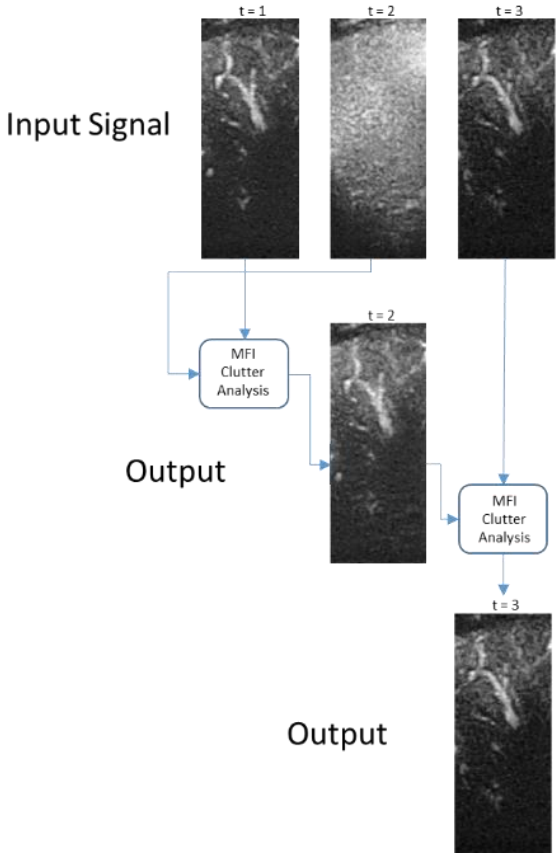

Figure 2: MFI's spatial-temporal clutter filtering analyzes Doppler signal to removed unwanted tissue signal and reveal micro-vessel structure. In this manner, MFI is capable of visualizing low flow blood vessels that would normally be hidden by tissue signal

Similar to how grayscale echo often employs algorithms to reduce tissue speckle and enhance tissue boundaries, MFI utilizes signal-processing algorithm to enhance detected vessels and reduce noise. This allows vessels to be enhanced naturally without introducing blurring often seen with more traditional image processing techniques (Fig. 3). Thus, in addition to acoustic transmits designed to optimize flow sensitivity at spatial resolution, MFI will enhance vessels to improve visualization with high spatial resolution.

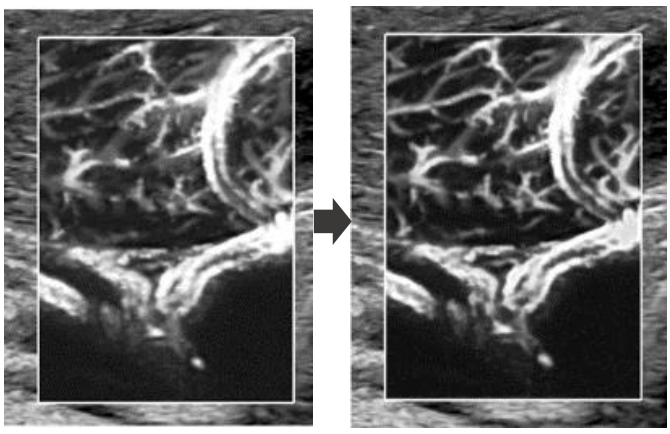

Figure 3: MFI vessel enhancement algorithm off (left) and on (right). MFI utilizes a novel vessel enhancement algorithm to improve spatial resolution, enhance vessel visualization, and reduce noise.

Display modes in MFI

MFI has four display modes, which are a combination of:

- Tissue Subtraction on/off
- Echo-flow Compare on/off

The possible combinations are shown in Figure 4. When tissue subtraction is on, MFI is focuses on displaying only the flow information, and therefore this provides the most sensitive display method. When tissue subtraction is off, MFI utilizes a new tissue-flow arbitration algorithm to seamlessly blend flow with tissue information in a smooth and natural manner, therefore providing anatomical context to the visualized flow. It has the additional benefit of further tissue artifact suppression. As shown in Figure 5, a thyroid carcinoma can be visualized with tissue subtraction on and off. When the tissue is suppressed, all flow information can be seen providing maximum sensitivity. When tissue is blended into the flow signal, the flow is naturally overlaid and blended with the tissue anatomy.

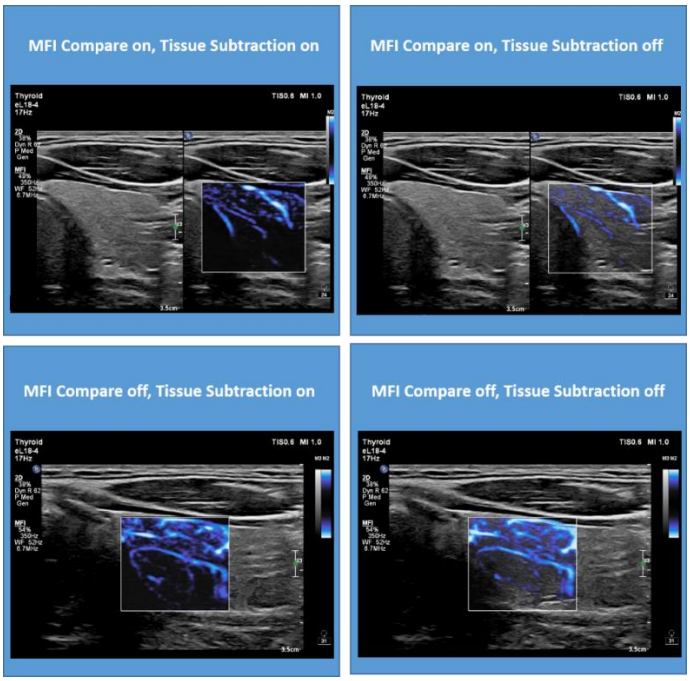

Figure 4: The four display options in MFI. Top left: MFI Compare is on, whereby a side-by-side of grayscale and flow data is displayed, and Tissue Subtraction is on to provide the most sensitive MFI visualization. Top right: MFI Compare is on, and Tissue Subtraction is turned off to blend flow with tissue. Bottom left: MFI Compare is off, and Tissue Subtraction is on. Bottom right: MFI Compare is off, and Tissue Subtraction is off.

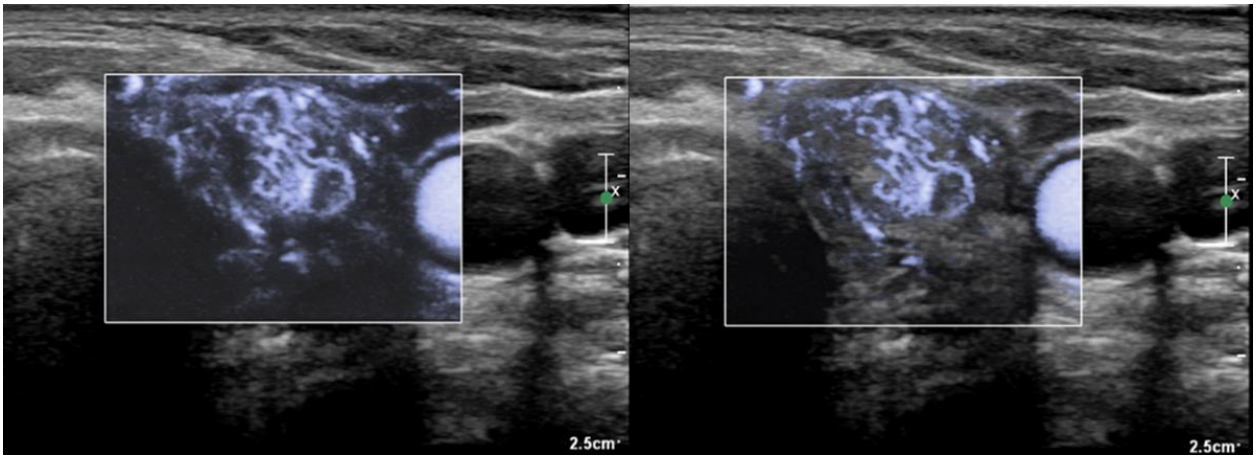

Figure 5: Thyroid carcinoma displayed with Tissue Subtraction on (left) and off (right). When Tissue Subtraction is on, all signals detected as flow are displayed without additional manipulations, providing the most sensitive visualization method. When Tissue Subtraction is off, the flow info is blended seamlessly with the tissue anatomy offering additional anatomical context.

MFI in the Clinic

Hepatocellular Carcinoma

Figure 6 showcases a case of Hepatocellular Carcinoma with liquidation of the center. A suspicious lesion is seen in the grayscale. PDI of the tumor does not show strong vascular perfusion. However, MFI reveals a network of microvasculature within the mass and an absence of vascularity in the center. This was confirmed with CEUS.

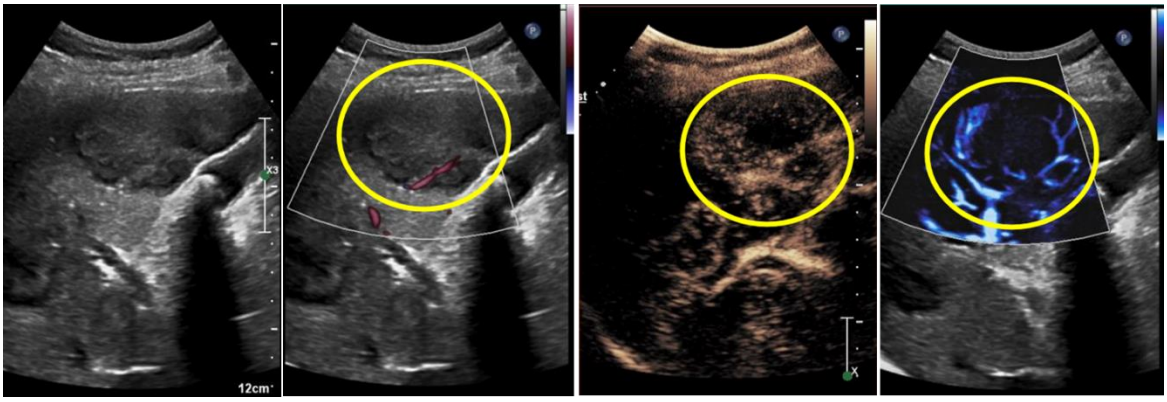

Figure 6: Hepatocellular Carcinoma (HCC) with liquidation in the center. Left most: echo grayscale. Left center: PDI of the tumor mass showing very little perfusion. Right center: CEUS showing perfusion of the mass with a center region void of contrast indicating liquidation. Right most: MFI showing vascular perfusion of the tumor mass and absence of vascularity in the center, in agreement with CEUS. Images courtesy of Dr. Wenping Wang (Department of Ultrasound, Zhongshan Hospital of Fudan University)

Focal nodular hyperplasia

MFI showcases a spoke wheel vascular pattern in a focal nodular hyperplasia lesion. Compared to conventional PDI, MFI better visualizes the vascular network and is confirmed in the CEUS image.

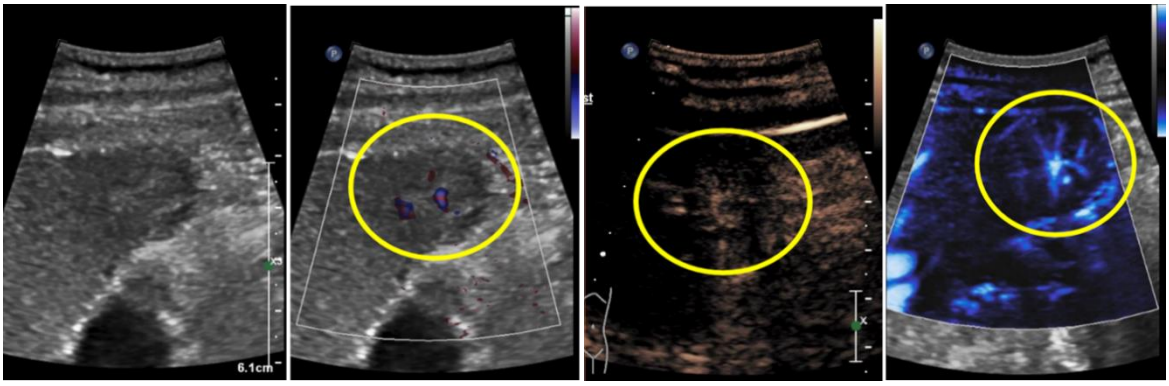

Figure 7: Focal nodular hyperplasia (FNH). Left most: echo grayscale. Left center: PDI of the mass showing little perfusion. Right center: CEUS showing perfusion of the mass and a vascular network. Right most: MFI showing vascular perfusion with a wheel-like appearance better than CEUS. Images courtesy of Dr. Wenping Wang (Department of Ultrasound, Zhongshan Hospital of Fudan University)

Pyloric Stenosis

A case of pyloric stenosis with echo grayscale showing thickened pylorus (Fig 8). MFI is used to visualize the vasculature as well as the restricted gastric flow.

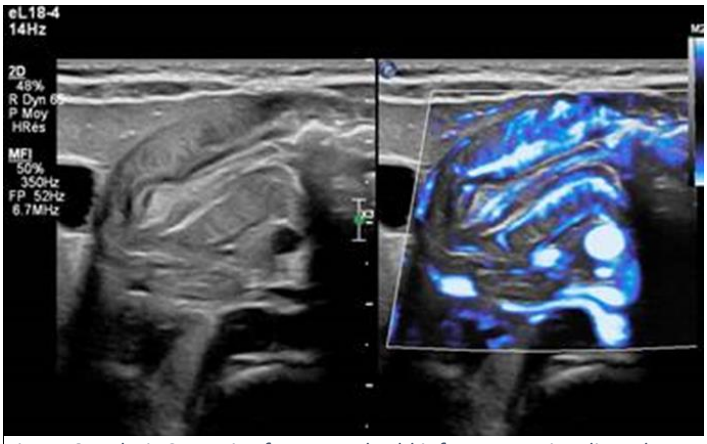

Figure 8: Pyloric Stenosis of a 4-month-old infant. MFI visualizes the bowel vasculature as well as the restriction in the passage of gastric contents

Renal cortical infarctions

MFI is used to interrogate the renal cortex on a transplant patient. MFI demonstrated normal perfusion in the poles, but clear areas of cortical infarction between the equatorial region and the upper pole (Fig 9). Full organ perfusion is mapped using CEUS which confirmed the findings from MFI (Fig 10).

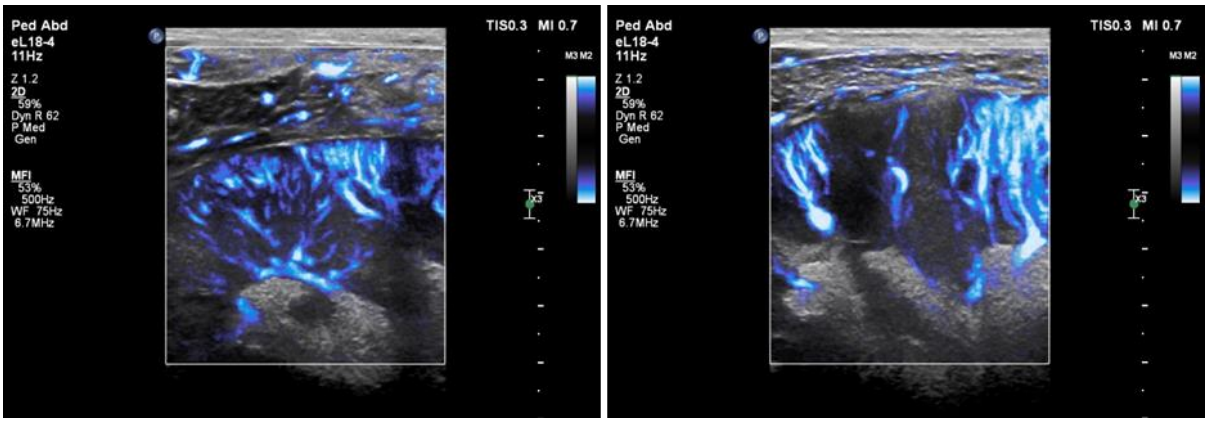

Figure 9: Renal transplant. Left: MFI indicating normal perfusion in the upper pole, while Right: same kidney, but MFI indicating cortical infarction between the equatorial region and the upper pole. Images courtesy of Dr. Ben Stenberg and Dr. Andrew McNeill (Newcastle upon Tyne).

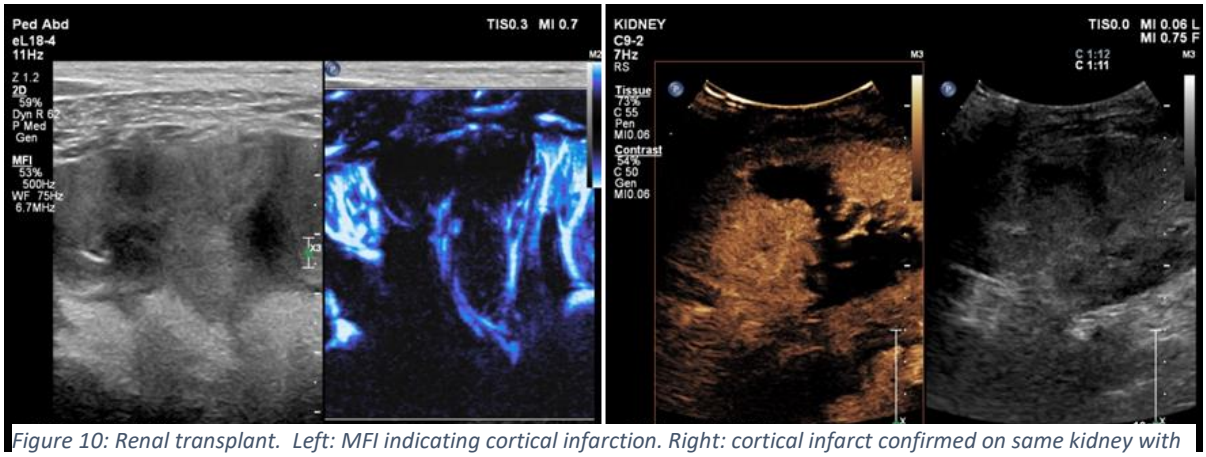

Figure 10: Renal transplant. Left: MFI indicating cortical infarction. Right: cortical infarct confirmed on same kidney with CEUS. Images courtesy of Dr. Ben Stenberg and Dr. Andrew McNeill (Newcastle upon Tyne).

Arterial-venous fistula

In addition to imaging microvasculature, MFI can be used in vascular applications to better visualize complex hemodynamics and to help fill vascular arteries and veins. A case of an arterial-venous fistula aneurysm is seen in MFI (Fig 11).

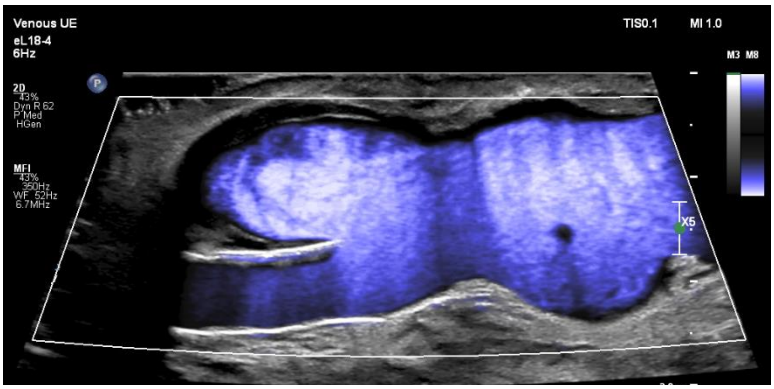

Figure 11: Arterial-venous fistula aneurysm.

Vascular plaque

MFI's high sensitivity and high spatial resolution is used to outline a carotid plaque body at the carotid bifurcation (Fig 12). MFI does not override the plaque body and can be used to help characterize the stenosis.

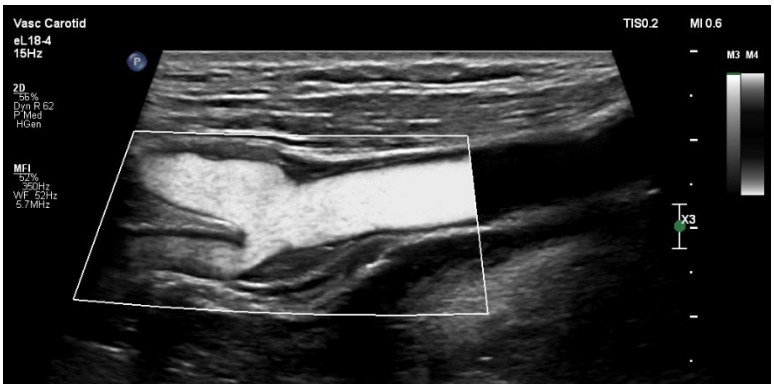

Figure 12: highlighting presence of carotid plaque at the carotid bifurcation.

Conclusion

Philips continues to bring meaningful innovation in order to better diagnosis and improve clinical outcome. Philips' MFI reveals previously undetected microvasculature by extending beyond the conventional boundaries of flow detection sensitivity and imaging resolution. By pushing the envelope in Doppler imaging, MFI demonstrates itself as a new indispensable tool in many clinical applications and it will surely raise the bar in Doppler ultrasound.