WHITEPAPER

Flow Imaging

LOGIQ E10 Series

Introduction

Ultrasound can be a highly desirable imaging tool to assess flow hemodynamics due to its lack of ionizing radiation, real-time nature, portability, and economy. To address the wide-ranging clinical needs of various specialties, GE Healthcare has made a variety of flow technologies available on the LOGIQ™ E10 Series ultrasound systems, including:

- Color Flow
- Power Doppler Imaging
- Microvascular Imaging
- Radiant*flow*™
- B-Flow™ Imaging

This paper will review the technical aspects and clinical benefits of each flow technology.

Color Flow

Introduction

The color flow (CF) mode allows the visualization of flow direction and velocity information within the region of interest (ROI), or color box, defined by the operator. The Doppler shifts of returning ultrasound waves within the ROI are color-coded based on average velocity and direction.

How CF Works

Similar to Pulsed Wave (PW) Doppler, CF utilizes intermittent sampling of ultrasound waves, and avoids the range ambiguity of Continuous Wave (CW) Doppler.

Flow is depicted in blue when traveling away from the transducer (negative Doppler shift), while flow traveling toward the transducer (positive Doppler shift) is depicted in red. Lighter shades of each color denote higher velocities. The areas of high flow turbulence are depicted in a third color.

An aliasing artifact appears as flow in the opposite direction of the real flow. This occurs when the Nyquist limit is reached due to a sampling rate that is too slow relative to the speed of the blood.

Figure 1 shows CF (light blue, inside the ROI) and background B-Mode (gray), which are generated by separated transmit (Tx) waveforms and received (Rx) echoes. The entire CF frame is created by overlaying CF information onto the background B-Mode.

A wall motion filter (WMF) is always applied to differentiate true flow and clutter.

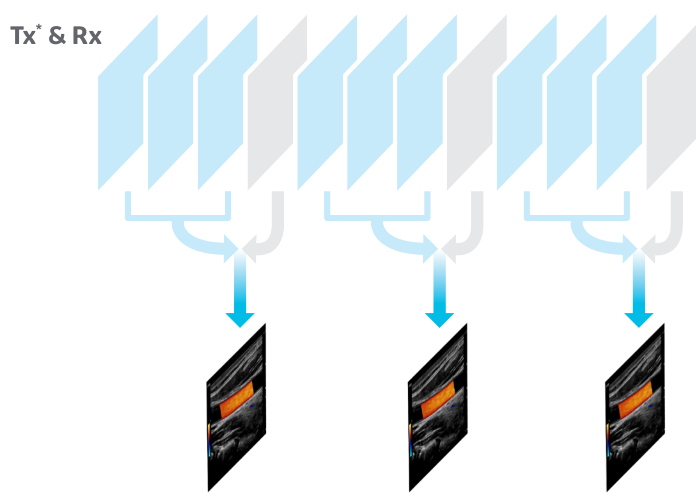


Figure 1. Color flow imaging. (*Tx: Pulse transmission, Rx: Receiving echo signal; Gray: B-Mode Tx & Rx).

Since CF on the LOGIQ E10 Series incorporates proprietary Coded Excitation technology for a new flow processing chain, it helps achieve finer spatial resolution and less flow overwriting at shallow depth, and simultaneously penetrates more at deeper depth.

Color Flow Technical Advantages

Compared with other flow modes, CF imaging has the following advantages:

- Displays flow velocity for both small and large vessels at different depths
- Helps show flow information at deeper depths
- Improves separation of arteries and veins in close proximity

Color Flow Clinical Benefits

Abdominal Imaging

CF may help to improve:

- Hepatic artery and portal vein separation (Figure 2)
- Visualization of renal vessels from origin to the hilum
- Deep aortic imaging

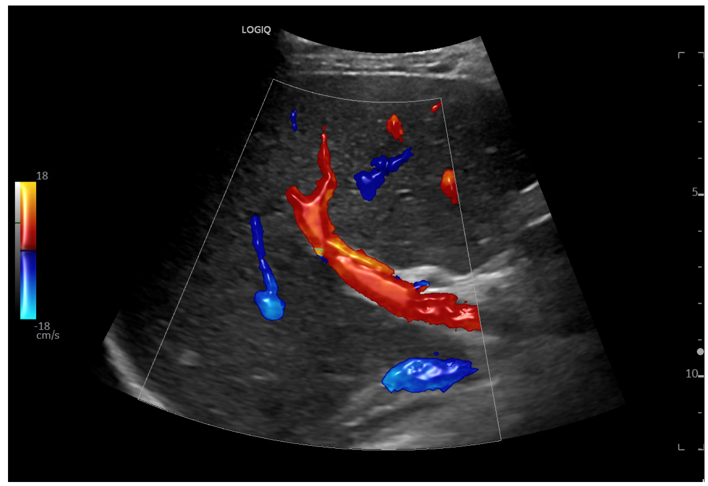


Figure 2. Separation of hepatic artery and portal vein using CF imaging.

Gynecologic Imaging

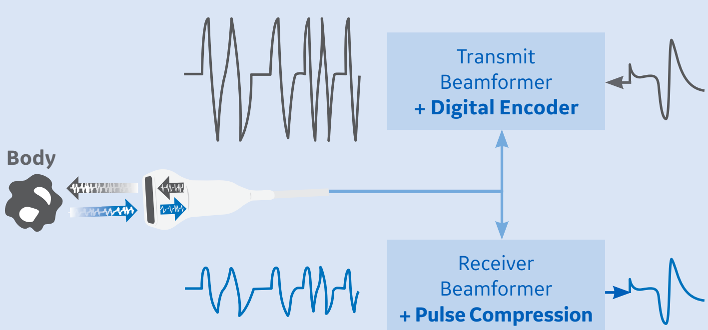
CF may be useful in:

- Evaluation for torsion in deep ovarian vessels
- Assessment of flow in a fibrotic uterus

Figure 3. Color flow imaging in a fibroid using the C2-9 transducer.

CODED EXCITATION

Coded Excitation, a proprietary technology of GE Healthcare, is a key component in many of the ultrasound flow modes referenced in this paper. As shown below, the Coded Excitation process digitally codes a typical wideband signal (short pulse base waveform) to form a long pulse on the transmit side. The echoes from both tissue and blood cells are then on the receiver side, which decodes the long pulse into a pulse similar in length to the original pulse, but with much larger amplitude.



Obstetric Imaging

CF may be useful in:

- Visualization of the chambers of the fetal heart and great vessels
- Visualization of umbilical cord to see separation of the vein and arteries (Figure 4)

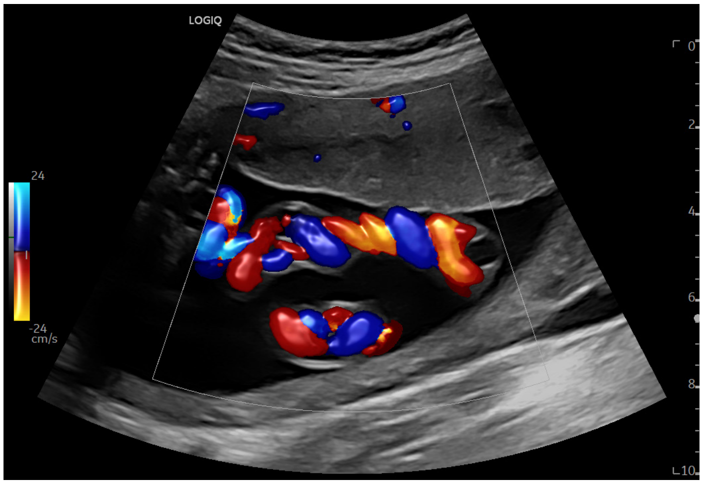


Figure 4. Separation of vein and arteries in umbilical cord.

Vascular Imaging

CF may be useful in:

- Detection of high velocity areas in the carotid or lower extremity arteries (Figure 5)
- Detection of slow flow in deep arteries and veins

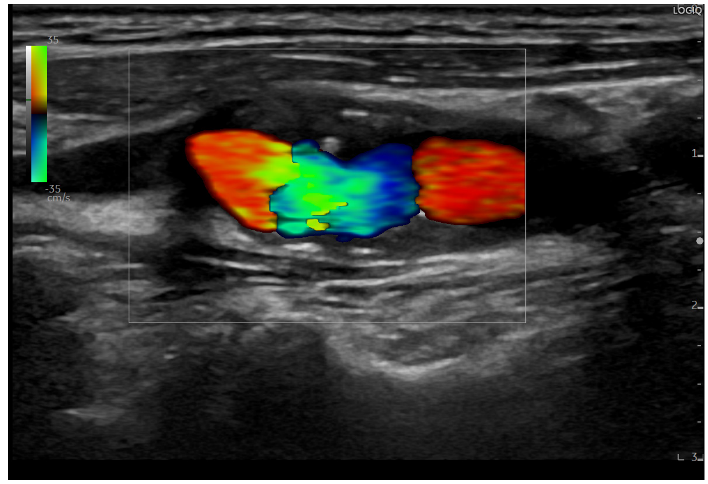


Figure 5. CF imaging in the carotid artery showing high grade stenosis.

Power Doppler Imaging

Introduction

Unlike CF, Power Doppler Imaging (PDI) is independent of velocity and direction of flow, and does not have any signal aliasing issue. Therefore, it allows detection of lower velocities than CF. In general, PDI has higher sensitivity than CF, which makes a trade-off with flash noise artifacts.

How PDI Works

Ultrasound images are formed by the reflected ultrasound echoes. These waves have an amplitude and a frequency, which is equal to the frequency of the emitted wave if the anatomy is static. But frequency shift is generated due to movement (e.g. blood).

Spectral analysis of Doppler signal consists of both frequency and amplitude information of a small sample. In PDI, the brightness of the pixels represents the amplitude of the signal (related to Power Doppler).

PDI works in a similar fashion to color flow. Power Doppler flow (inside the ROI) and background B-Mode (gray) are generated by separated Tx waveforms and Rx echoes, as shown in Figure 6. An entire PDI frame is created by superimposing Power Doppler flow information onto the background B-Mode.

PDI Technical Advantages

Compared with other flow modes, PDI has the following advantages:

- Shows high flow sensitivity, especially for small vessels at shallow depths
- No aliasing as compared with CF
- Displays intensity information and can show directional information with Directional PDI Maps

Clinical Benefits

Abdominal Imaging

PDI may be useful in:

- Assessment of liver lesions
- Assessing inflammation or ischemia in the kidneys (Figure 7)

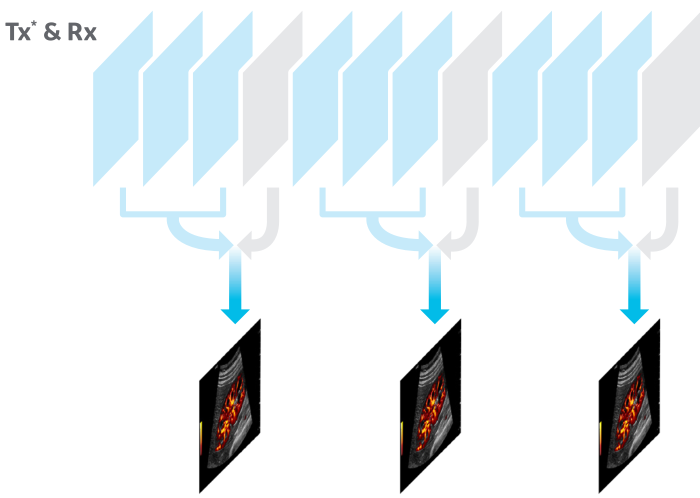


Figure 6. Power Doppler Imaging (PDI). (*Tx: PDI Pulse transmission, Rx: PDI Receiving echo signal; Gray: B-Mode Tx & Rx).

Figure 7. PDI showing renal perfusion.

PDI always uses WMF to differentiate true flow and clutter.

Since PDI on the LOGIQ E10 Series incorporates proprietary Coded Excitation technology for a new flow processing chain, it helps achieve finer spatial resolution and higher sensitivity at shallow depth, and simultaneously has deep penetration.

Small Parts Imaging

PDI may be useful in:

- Evaluation of thyroid nodules to assess vascular patterns (Figure 8)
- Evaluation of testicular torsion or hyperemia in the epididymis

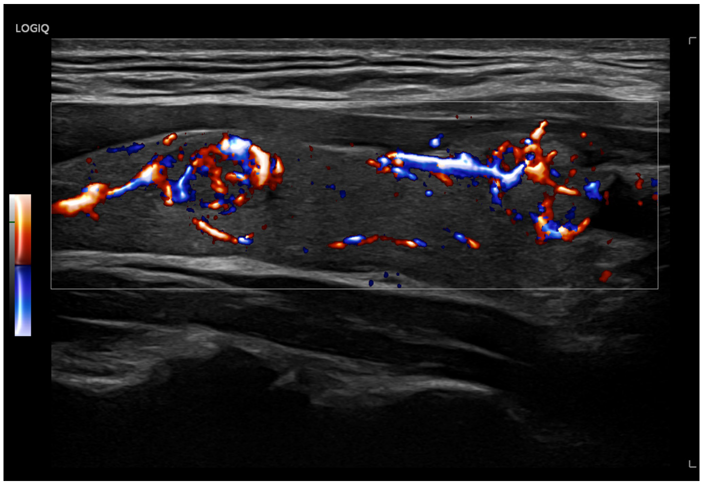


Figure 8. PDI showing vascular patterns within thyroid nodules.

Obstetric Imaging

PDI may be helpful in:

- Visualization of chambers in a fetal heart and great vessels (Figure 9)
- Assessing separation of the vein and arteries in the umbilical cord

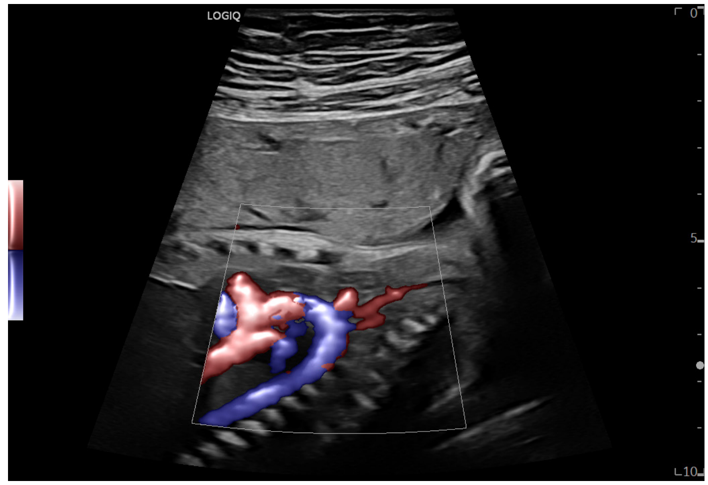


Figure 9. PDI showing aortic arch in a fetus.

Additionally, PDI may be beneficial when assessing neonatal brain perfusion as shown in Figure 10.

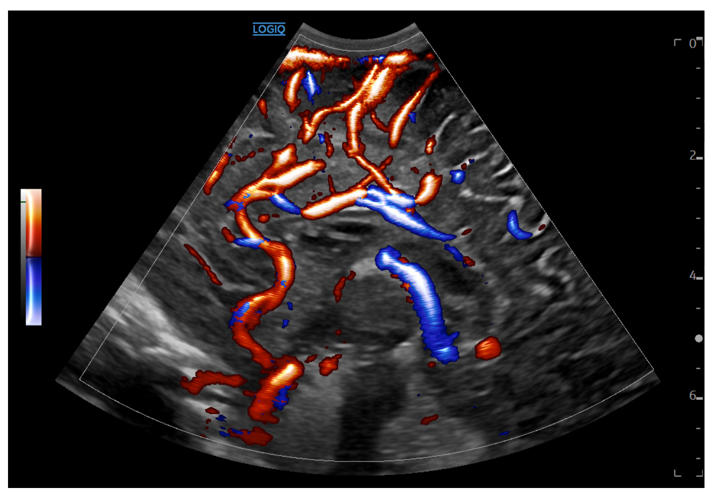


Figure 10. Perfusion through neonatal brain using PDI.

Micro Vascular Imaging

Introduction

There has long been a clinical need for detection of slow flow states especially in areas where assessment of vascularity is crucial to diagnosis and follow-up treatments. Traditional flow modes are limited in detecting very slow flow especially in small vessels. The Micro Vascular Imaging (MVI) technique has the potential to fill this role.

Limitations of Other Flow Imaging Modes

Traditional flow modes, such as CF and PDI, are challenged by clutter signals resulting from stationary and slowly moving tissue, including vessel walls. Removing this motion with conventional WMFs is effective but it also removes slow flow that occupies the same bandwidth on the frequency domain.

Conventional flow techniques acquire a limited number of samples for each point in the flow ROI. The number is dictated by the system or user-specified packet size, which is typically in the range of 10-13 to maintain an adequate frame rate. The relatively small number of samples limits both frequency resolution and the design options for WMFs. As a result, WMFs filter out tissue motion but also some blood flow.

How MVI Works

Continuous Scan Sequence

MVI is designed to continuously acquire samples at each point in the flow ROI. Unlike traditional flow techniques that fire the entire B-Mode image sequentially and then resume the flow transmit events, this continuous MVI scan sequence transmits only parts of the B-Mode image in between individual flow firings.

Figure 11 shows the basic diagram of MVI processing compared with CFM/PDI, illustrating that conventional flow modes have a limited number of packets. MVI's continuous scan sequence, combined with proprietary digitally encoded ultrasound technology, helps to boost weak blood cell echoes and enhance spatial resolution.

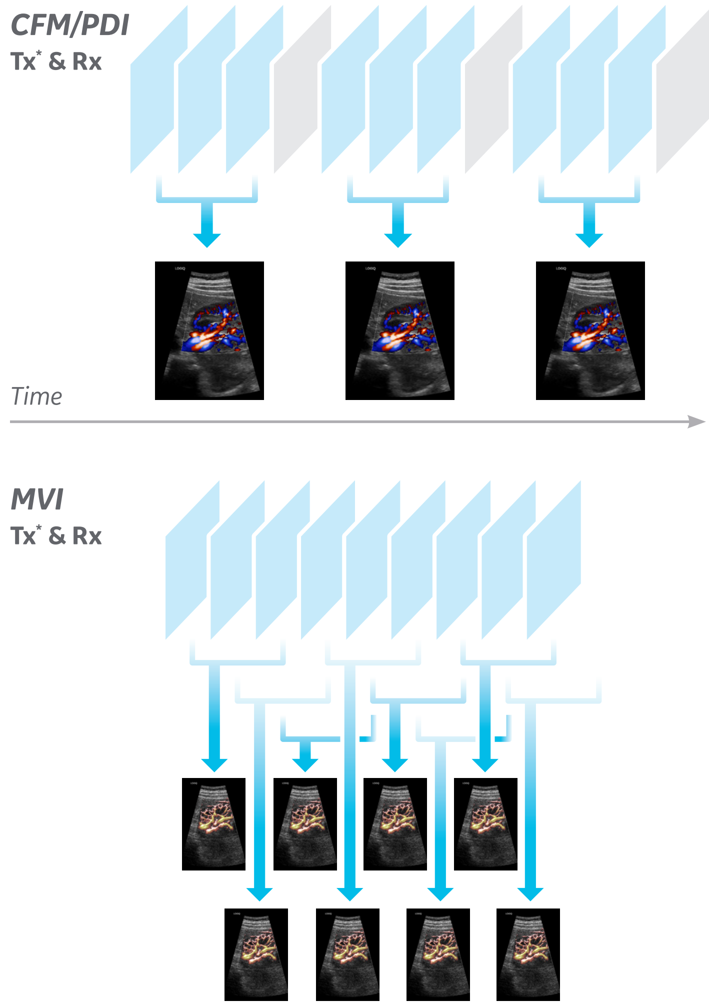


Figure 11. Continuous scan sequence of MVI versus traditional flow mode (PDI). At the top, conventional flow modes need to fire desired packet size of flow and a full frame of background B-Mode (gray in picture). At the bottom, MVI continuously acquires flow frame without interruption due to background B-Mode and theoretically has no limitation on packet.

Advanced Clutter Filter

To make sure these weak blood cell echoes are not lost while removing the clutter signal, a different WMF approach is needed and the access to continuous samples for each point in the flow ROI enables this more advanced approach.

As seen in Figure 12, the advanced clutter filter shifts flow data into a new domain to separate slow flow signal from clutter. In this new domain, clutter is separated from slow flow without the impact of losing sensitivity in real time.

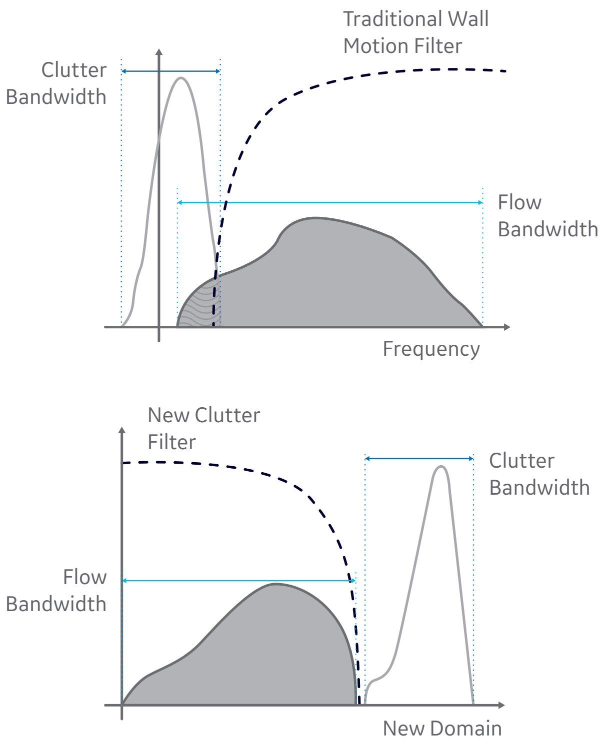


Figure 12. Comparison of a traditional WMF (top) and an advanced clutter filter (bottom). The traditional filter reduces slow flow (wavy stroke) due to overlap with clutter. The advanced clutter filter shifts domain into covariance and effectively removes clutter without losing slow flow.

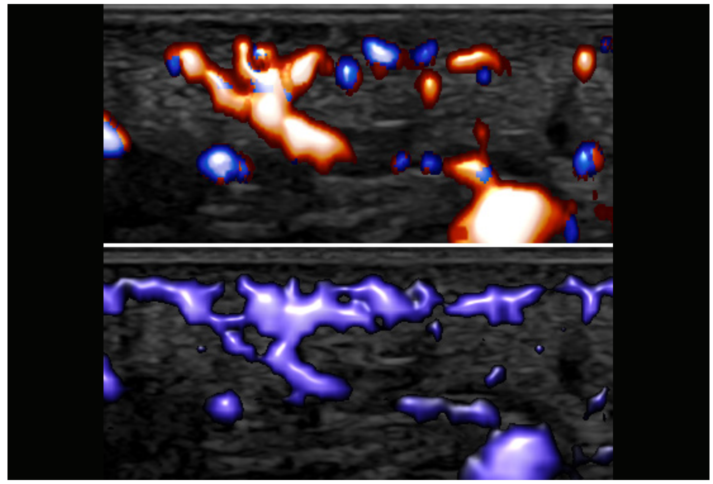


Figure 13. Flow in finger. Comparison of conventional flow presentation with PDI (top) and with MVI (bottom). MVI shows more small branches and slow flow with excellent continuity.

Clinical Benefits

Musculoskeletal and Superficial Imaging

MVI may be useful in:

- Assessing inflammation in wrist and finger (Figure 14)
- Improving visualization of a foreign body

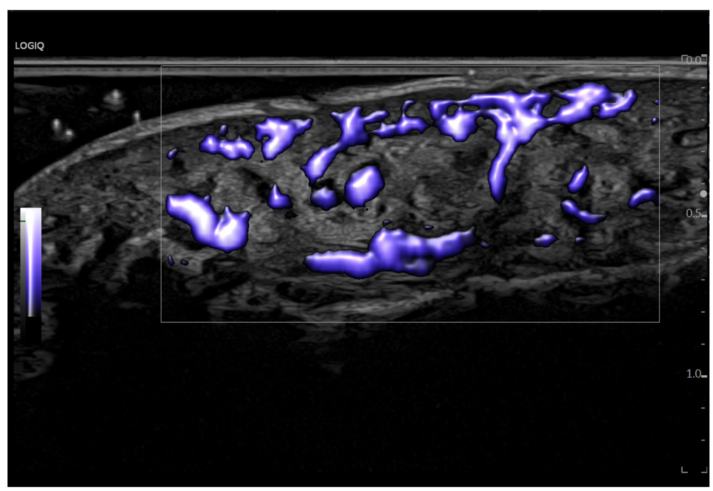


Figure 14. Perfusion through finger with MVI.

Small Parts Imaging

MVI may be useful in:

- Pediatric scrotal imaging to assess inflammation or torsion (Figure 15)
- Evaluating a lymph node or lesion vascularity

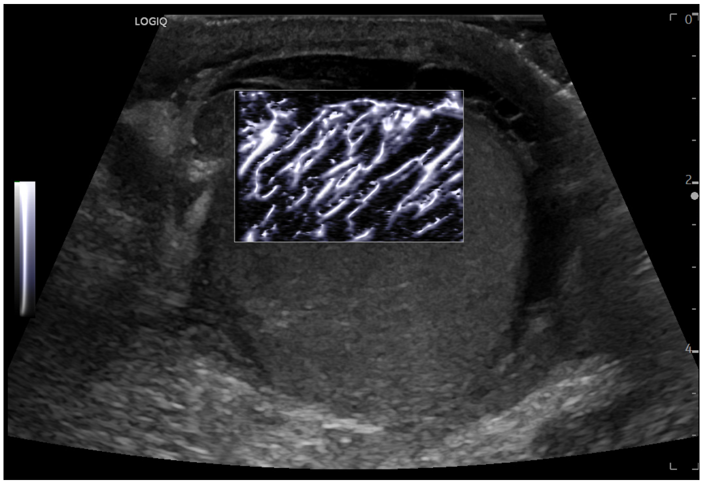


Figure 15. Perfusion through testicle using MVI.

Abdominal Imaging

MVI may be useful in assessing:

- Perfusion through a renal transplant and detecting areas of ischemia
- Vessel patterns in a superficial liver lesion (Figure 16)

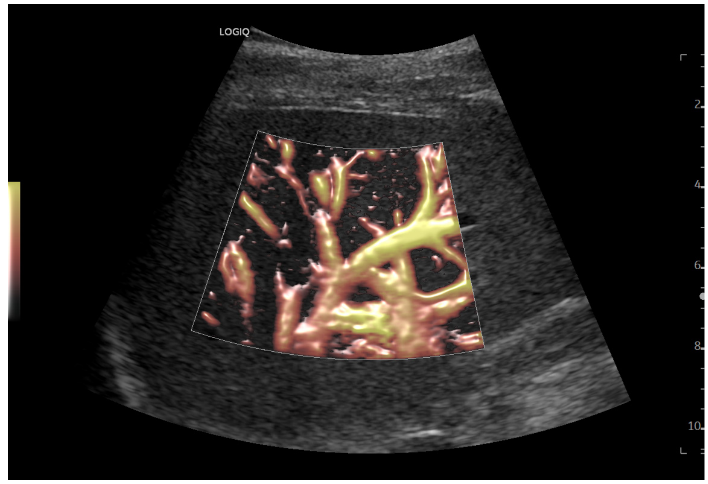


Figure 16. Liver perfusion using MVI with Radiant*flow*.

In addition, MVI may be useful in identifying inflammation in superficial lymph nodes and evaluating flow characteristics in suspicious lumps or bumps (Figure 17).

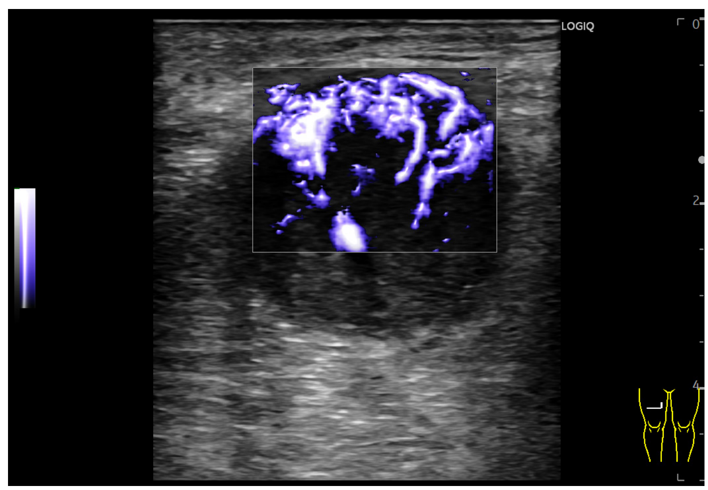


Figure 17. MVI showing slow small vessel flow through a superficial mass.

Radiant*flow*

Introduction

Radiant*flow* is an advanced visualization technology which improves vessel separation and tightness. Radiant*flow* algorithms add height and depth information to CF, PDI or MVI signals to provide a 3D-like appearance. Radiant*flow* provides clearer separation of the signal and background and assists in identifying slow flow in small vessels that at times can be hard to detect with traditional visualization techniques.

How Radiant*flow* Works

Traditional flow images use color to represent components such as velocity, power or variance (turbulence). Radiant*flow* utilizes the power component as elevation data to represent flow as a color textured surface as seen in Figure 18.

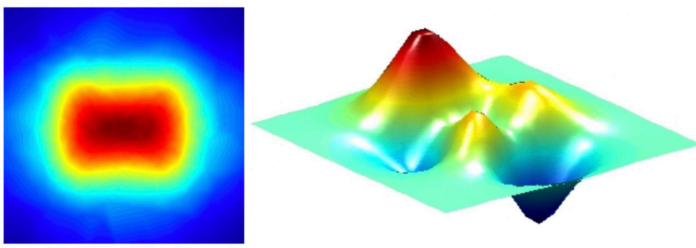


Figure 18. Conventional color flow map of velocity (left) and illustrated 3D converted flow map with Radiant*flow* (right).

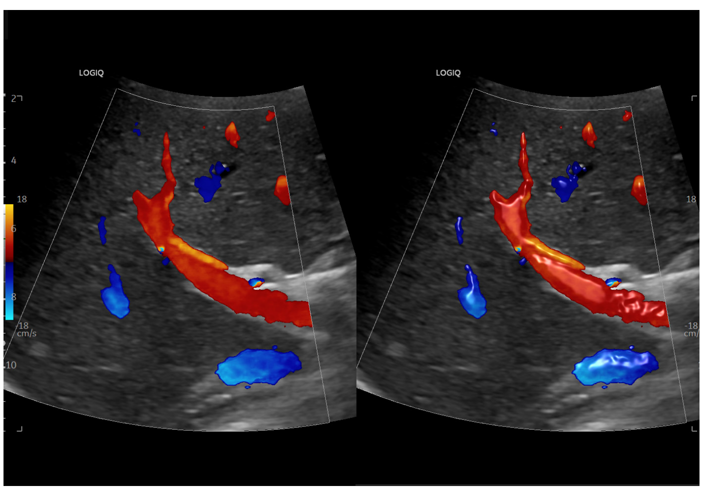


Figure 19. Normal color flow (left) and Radiant*flow* (right).

3D visualization technologies, such as diffuse and specular reflections, are applied in order to enhance Radiant*flow* visualization effect as seen in Figure 19.

Three different presets, MIN-MID-MAX, enable Radiant*flow* imaging to be tailored to various scan conditions, as seen in Figure 20.

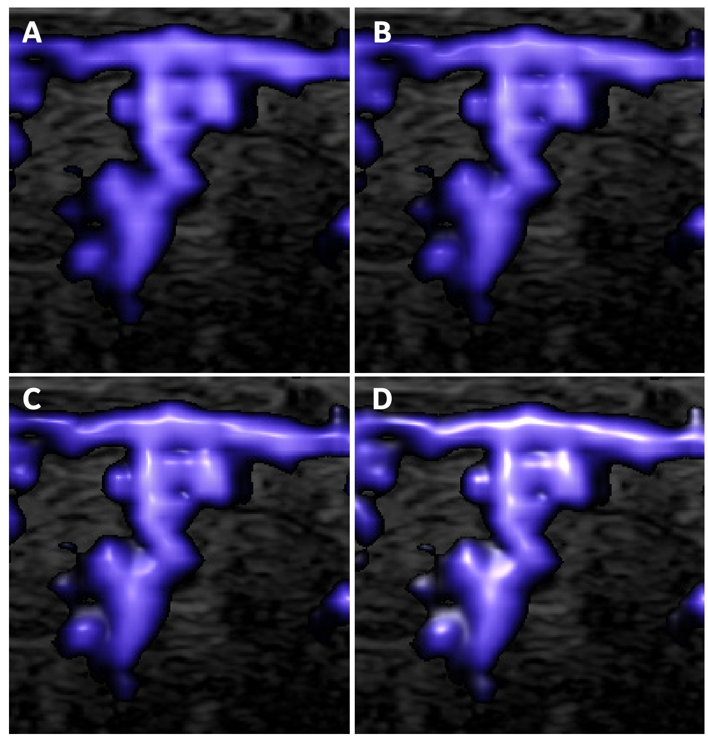


Figure 20. The level of Radiant*flow* at different presets: A. OFF; B. MIN; C. MID; D. MAX (Flow in finger with MVI).

In Summary

Radiant*flow* algorithms add height and depth information to color Doppler signals, providing a 3D-like appearance. When used with CF, PDI and MVI, this advanced visualization technology can help to improve vessel separation and tightness.

B-Flow

Introduction

B-Flow is a unique flow mode that directly images blood reflectors and tissue information simultaneously, providing an accurate morphologic display of the intraluminal blood flow throughout the entire field of view.

How B-Flow Works

B-Flow uses Coded Excitation technology to boost weak blood flow signal. Coded ultrasound pulses are transmitted with long waveforms containing a large amount of energy. In receiving, the digital beam former decodes the long echo waveforms to very sharp and crisp short pulses. This helps achieve deep penetration and tight resolution at the same time.

B-Flow Technical Advantages

B-Flow is a GE technique that displays the small vessel flow signals in gray scale throughout the entire field of view. This non-Doppler technique uses coded excitation to capture the hemodynamics within large vessels and perfusion of smaller vessels through organs. B-Flow is not angle dependent and visualizes real flow without overwriting of vessels. Finally, the user can choose to visualize B-Mode and B-Flow in a dual screen or use Hybrid Visualization which shows the B-Flow overlaid on the B-Mode image, as shown in Figure 21.

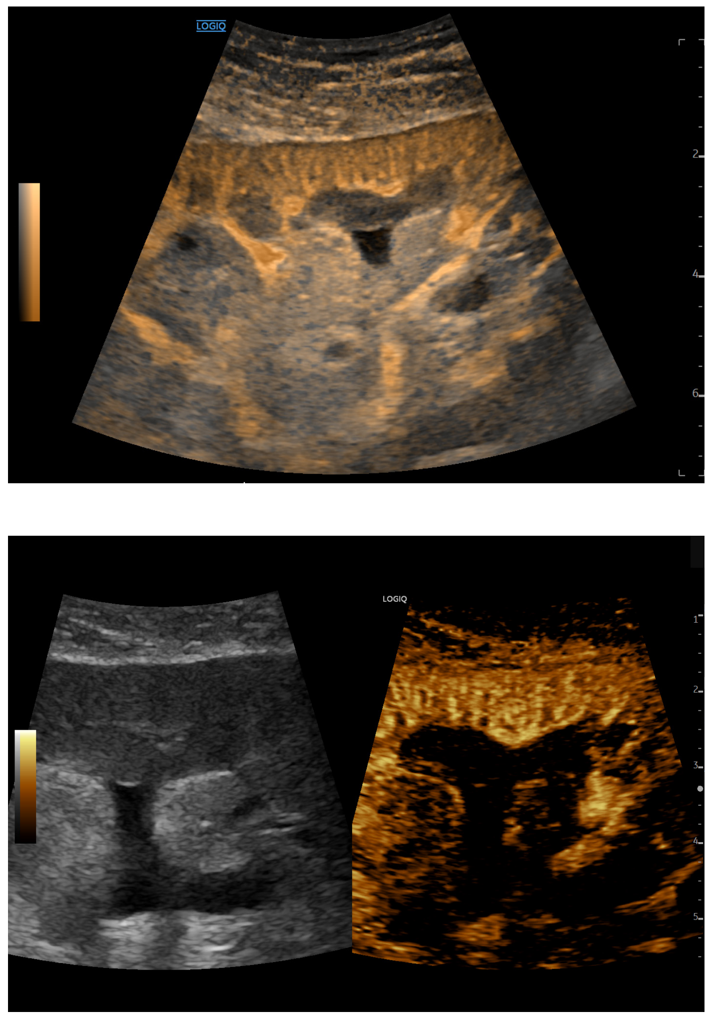


Figure 21. Dual (bottom) and hybrid (top) B-Flow displays. Hybrid provides an overlay of the B-Flow on the reference B-Mode image, enhancing background detail and producing less flash noise in the image.

B-Flow Clinical Benefits

Compared to other flow modes, B-Flow has the following advantages:

- Displays the true vessel diameter
- High spatial resolution to show fine vessel details and flow hemodynamics in larger vessels
- No angle dependency or ROI needed

Vascular Imaging

B-Flow may be useful in:

- Assessing high grade stenosis in arteries (Figure 22)
- Visualizing flow around an area of soft plaque

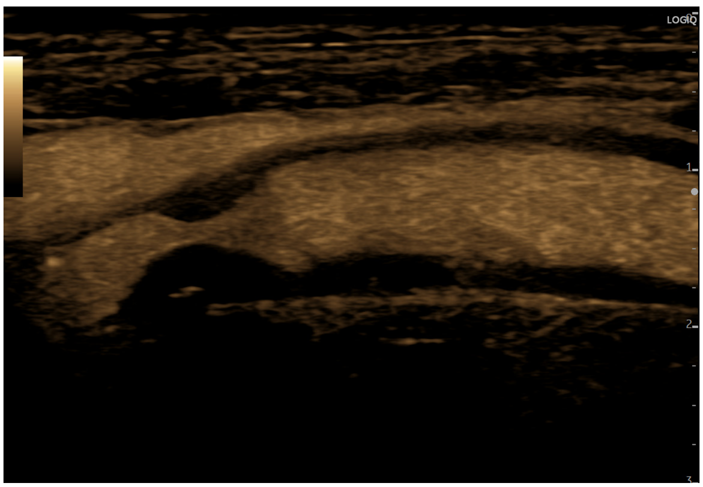


Figure 22. Distal common carotid artery with B-Flow allowing a clear delineation of the wall defect caused by plaque.

Abdominal Imaging

B-Flow may be useful in:

- Evaluating liver surface for tortuosity of vessels (Figure 23)
- Assessing organ perfusion through a kidney transplant
- Confirming vessel patterns in liver lesions

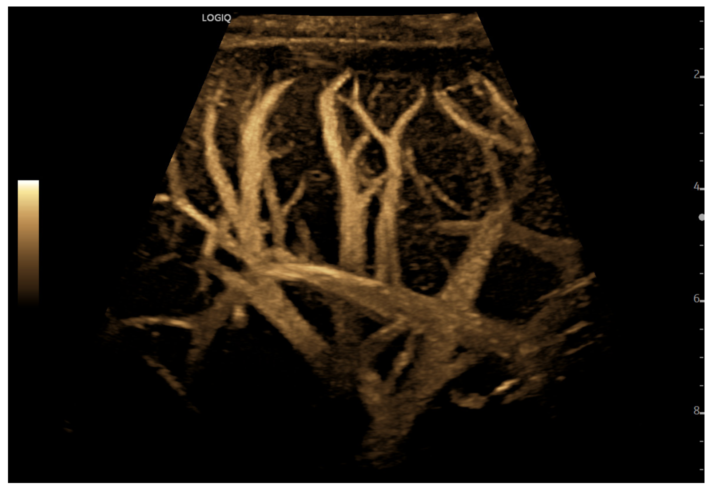


Figure 23. Liver vasculature using B-Flow cine capture.

In addition, B-Flow may be useful in:

- Assessing neonatal head perfusion (Figure 24)
- Assessing a lymph node or area of inflammation for vascularity
- Improving visualization of a hernia or ureteral jets
- Placenta perfusion

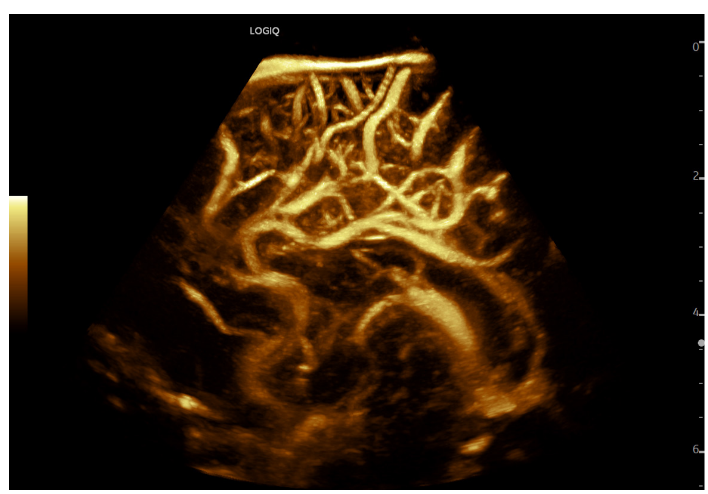


Figure 24. Neonatal head using B-Flow Capture to assess perfusion.

LOGIQ E10 Series Flow Modes: Comparison of Clinical Applications

	CF	PDI	B-Flow	MVI
Abdomen	When deep penetration is needed, such as in the aorta; Separation of arteries and veins	To evaluate an area of ischemia; When more sensitivity is needed to assess a liver lesion	Hemodynamics within large vessels in the abdomen; Perfusion through organs to assess small vessel structures	Image a superficial lesion to assess small vessel patterns; Kidney transplant to assess perfusion for areas of ischemia
OB/GYN	Assessing flow in a fibrotic uterus; Umbilical cord to see separation of the vein and arteries	Evaluation for torsion in deep ovarian vessels; Use directional PDI to assess the chambers in fetal heart and great vessels	Evaluate placental perfusion; Circle of Willis in the fetal brain	Evaluate placental perfusion
Vascular	Assess velocity information and direction; Slow flow in deep arteries and veins	Assess slow flow in deep arteries and veins	Assess high velocity stenosis; Evaluate true vessel diameter around an area of soft plaque	Very slow flow in superficial veins, such as varicose veins
Small Parts	When a deep breast lesion requires more penetration	Evaluation of testicular torsion or hyperemia in the epididymis	Depict the true vessel diameter in very small vessels in a lesion or through an organ to assess tortuosity of the vessels	Finger or wrist to assess inflammation; Improve visualization of a foreign body
Pediatrics	When deep penetration is needed: Velocity assessment of hepatic artery in a post liver transplant patient	Evaluate pyelonephritis: Evaluate neonatal head perfusion through entire brain	Assess ureteral jets; Perfusion through neonatal brain to assess tortuous vessels around a shunt or superficial vessels	Pediatric scrotal exams to detect small vessels with slow flow; Lumps and bumps to evaluate vasculature, such as arteriovenous malformation
Urology	When deep penetration is needed through the prostate	When additional sensitivity is needed to assess the prostate	Not currently available on the endocavitary probe	Not currently available on the endocavitary probe
Cardiac	Use color in most cases	Not typically used in cardiac exams	Use to assess hypertrophy of the heart	Not currently available on the cardiac probes

LOGIQ E10 Series Flow Modes: Comparison of Technical Attributes

	CF	PDI	MVI	B-Flow
Quantify velocity	X			
Show flow direction	X	X		
No aliasing		X	X	X
Flow angle independent				X
Background B-Mode	X	X	X	X
Whole image flow (no ROI)				X
Best penetration	X	X		
Best hemodynamics			X	X
Best spatial resolution			X	X

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