B-Flow Technology

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Introduction

There is a clinical need to visualize blood flow and vessel wall structures in the diagnosis of various vascular diseases. Also, it is believed that the vessel architecture can be an important indicator for lesion or disease assessment. Traditionally, Angiography, CT scans or MRI scans are used for this purpose. However, these modalities are more costly, access may be limited, and some use ionizing radiation and/or expensive contrast agents.

Ultrasound can be a desirable additional tool due to its non-invasive, non-ionizing radiation, real-time and economical nature. Unfortunately, B-mode, Harmonics and Color Flow imaging have inherent limitations that may hinder their ability to assess flow hemodynamics in larger blood vessels such as the carotid artery or visualize small vessels as in the kidney.

LOGIQ* B-Flow* imaging mode based on Agile Acoustic Architecture from GE Healthcare has shown great potential for addressing these clinical challenges.

Limitation of other ultrasound imaging modes

To appreciate the innovative property of B-Flow imaging technology, it's helpful to understand the challenges involved with other ultrasound imaging modes.

Blood vessels are displayed as black (anechoic) in the 2D gray scale image. The echoes from red blood cells are typically 1/1000th of the strength of signals from the surrounding tissue (i.e. –60 dB). The dynamic range of the human eye is approximately 40 dB, therefore humans can see only echoes that are greater than 1/100th of the signal strength of tissue (i.e. –40 dB). For echo strength that is less than 1/100th of the signal strength of tissue, the ultrasound system will display it as black. For echo strength that is greater than normal tissue, such as echoes from the diaphragm, an ultrasound system will display it as white, as illustrated in Figure 1.

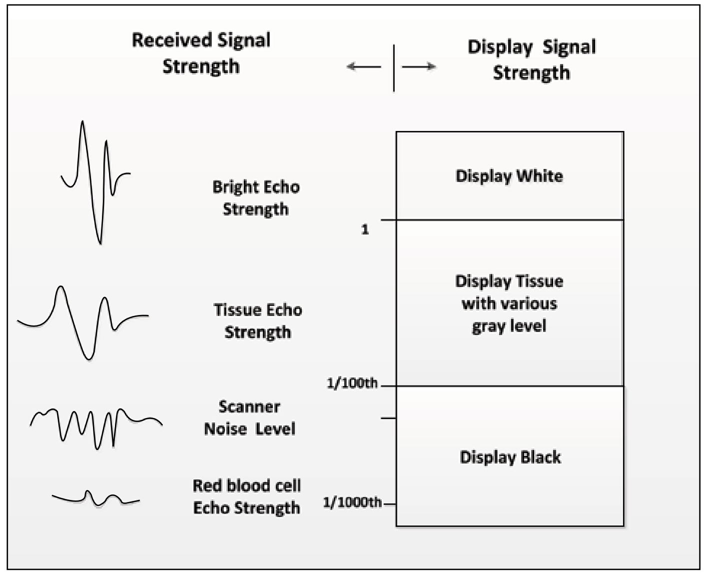

Figure 1. Displayed echo strength VS actual echo strength.

In order to observe blood flow signal in ultrasound, a large signal must be transmitted so that echoes from red blood cells are strong enough to be displayed on the screen. Doing so, however, causes echoes from surrounding tissue to be further boosted as well. If both blood flow signal and tissue are displayed on screen, the tissue will be fully saturated and appear as white signal. In order to display both blood flow and surrounding tissue, in Color Doppler mode, two sets of transmit signals are sent. Transmit signal A is sent into the body to generate the gray scale image, e.g. B-mode image. Transmit signal B is used to generate the flow image. After a transducer receives echoes from both transmit signals A and B, the ultrasound system will process the received signal to form both the gray scale image and the flow image. The system will overlay the flow image on top of the gray scale image to form a single displayed image.

As mentioned earlier, echoes from blood cells are about 1000 times weaker than that from normal tissue. Using a large transmit pulse will increase echo strength from blood cells. But the large transmit amplitude can cause undesirable biological effects inside the body. Regulatory agencies have set certain limits on the amplitude of the transmit pulse.

To boost echoes from blood cells without exceeding regulatory limits, ultrasound systems typically use a long pulse and large number of transmit signals, also known as packets. This enhances the signal to noise ratio of the echoes from blood cells and helps to visualize weak blood echoes at greater depths. Unfortunately, such depth come with trade-offs. A larger packet size results in a slower frame rate that may reduce the ability to display true hemodynamics of the blood flow. A long transmit pulse results in poor flow spatial resolution as the spatial resolution is inversely proportional to the transmit pulse length.

To maintain an adequate frame rate in Color Doppler mode, flow signal is only displayed inside a region of interest (ROI). The ROI is usually set to be smaller than the entire image display area.

Bleeding, color overwrite, or color on bright artifacts are inevitable due to the long transmit pulse and overlay technology used in Color Doppler imaging. Various techniques are used to help reduce this problem, but it is not possible to eliminate it completely and it remains one of the fundamental limitations of Color Doppler imaging.

Another fundamental principle used by Color Doppler imaging is the Doppler Effect. The main drawback of the Doppler Effect is angle dependency. When the ultrasound beam approaches 90 degrees to the blood flow, there is no Doppler effect, thus flow velocity is near zero and no blood flow is displayed inside the vessels. Angle dependency also adds challenges when accessing tortuous vessels.

Power Doppler Imaging (i.e. PDI) uses similar signal processing as in Color Doppler mode. Therefore it has similar limitations except PDI helps reduce the angle dependency by displaying flow intensity without velocity information.

B-Flow Imaging Mode

The B-Flow imaging technique displays the blood flow signals in gray scale imaging throughout the entire field of view. The displayed flow intensity is not affected by the interrogation angle of the ultrasound beam as it is with Color Doppler. In addition, B-Flow is capable of displaying true flow hemodynamics with spatial resolution similar to that of gray scale imaging. Finally, B-Flow doesn't suffer from blooming or wall overwriting as with Color Doppler mode, as B-Flow is attained simultaneously with B-mode data. Figure 2 shows jugular vein flow as it is displayed in B-Flow mode. Note: in B-Flow, the user can choose either to display flow only or display both flow signal and surrounding tissue.

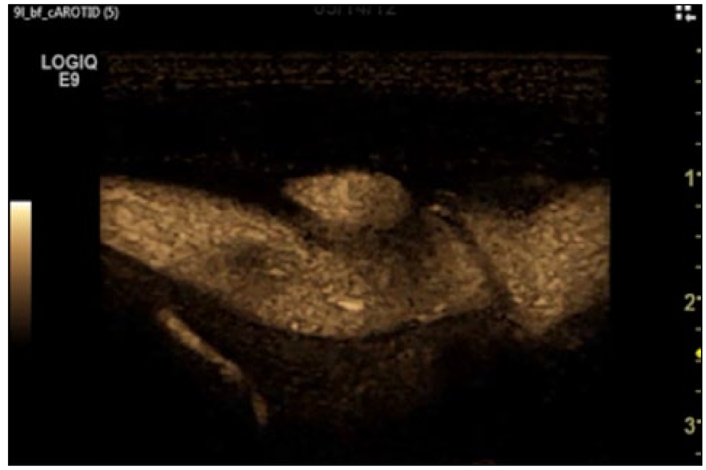

Figure 2. Jugular vein flow in B-Flow.

How B-Flow Works

B-Flow Imaging mode based on the LOGIQ Agile Acoustic Architecture from GE Healthcare employs several of GE Ultrasound's patented technologies.

First, it uses GE's proprietary Digitally Encoded Ultrasound (DEU) technology to boost weak blood cell echoes. The fundamental principle of DEU technology is illustrated in Figure 3.

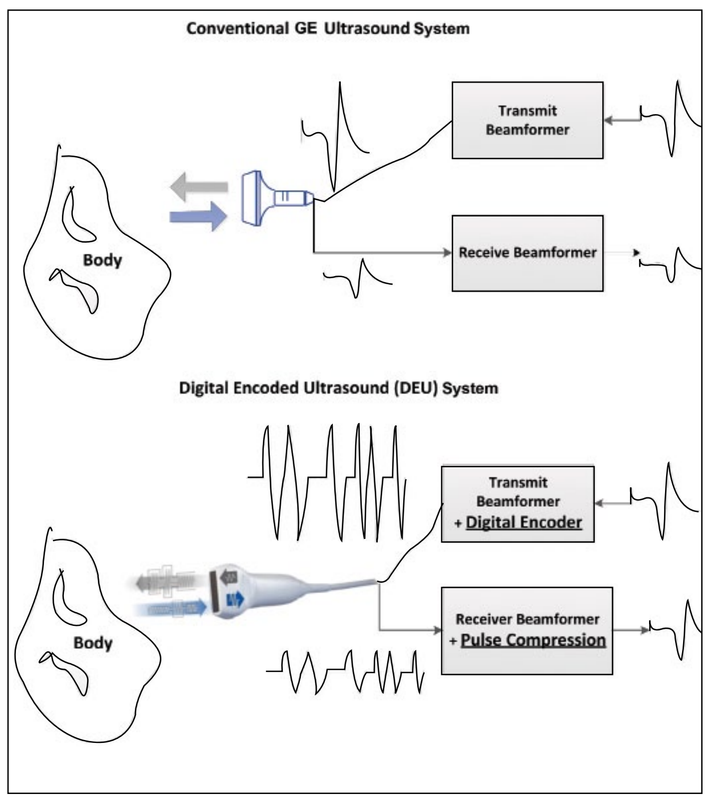

Figure 3. Fundamental principle of DEU technology.

In Figure 3, a wideband signal used in gray scale imaging is digitally encoded to form a long pulse that contains total energy many times stronger than the original pulse. This long pulse drives a transducer to send a long acoustic pressure burst into body. The echoes from both tissue and blood cells are then received by the transducer. The ultrasound system that is based on GE's Agile Acoustic Architecture employs patented technology to digitally compress or decode the long pulse into a pulse similar in length to the original pulse but with much larger amplitude as compared to a conventional GE system. This allows B-Flow imaging to display blood flow signal with spatial resolution similar to gray scale imaging.

Secondly, B-Flow uses Tissue-Blood Equalization (TBE) technology to suppress tissue signal. As mentioned earlier, the DEU technology boosts both blood flow signal and tissue signal. Without TBE technology, the tissue signal would be displayed as white on the screen. TBE technology is able to differentiate the flow signal from tissue and apply more amplification to the flow signal and less amplification on the tissue. Figure 4 shows the basic principle of the TBE technology.

Imagine you are standing in front of a huge tube with one giant red blood cell in it. The blood cell is moving from left to right as shown in Figure 4A. You take a picture of the red blood cell when it is just in front of you as shown in Figure 4B. You take a second picture when the red blood cell disappears from your vision (Figure 4C). Later, you look at these two pictures and see the only difference between the two pictures is the red blood cell. The first one has the red blood cell, and the second one doesn't. You do some photo processing and display a picture that shows the difference between the two pictures, which is the red blood cell. Now, imagine that there are many red blood cells in the tube and they pass in front of you one by one. You repeat the same process for each red blood cell. When you display the processed picture over time, you would see a red blood cell staying in front of you all the time. What would happen if you take pictures at many locations as shown in Figure 4D and then do the same process as before? You would see a stream of red blood cells as shown in Figure 4E.

In Figure 4, the tube is surrounded by tissue. TBE has a capability to display a certain amount of the surrounding tissue without tissue saturation.

TBE technology requires the picture to be taken at the interval that correlates with the speed of the red blood cell. If the moving speed of red blood cells is very slow, you will have to increase the interval of picture taking time in order to see the difference between the two consecutive pictures.

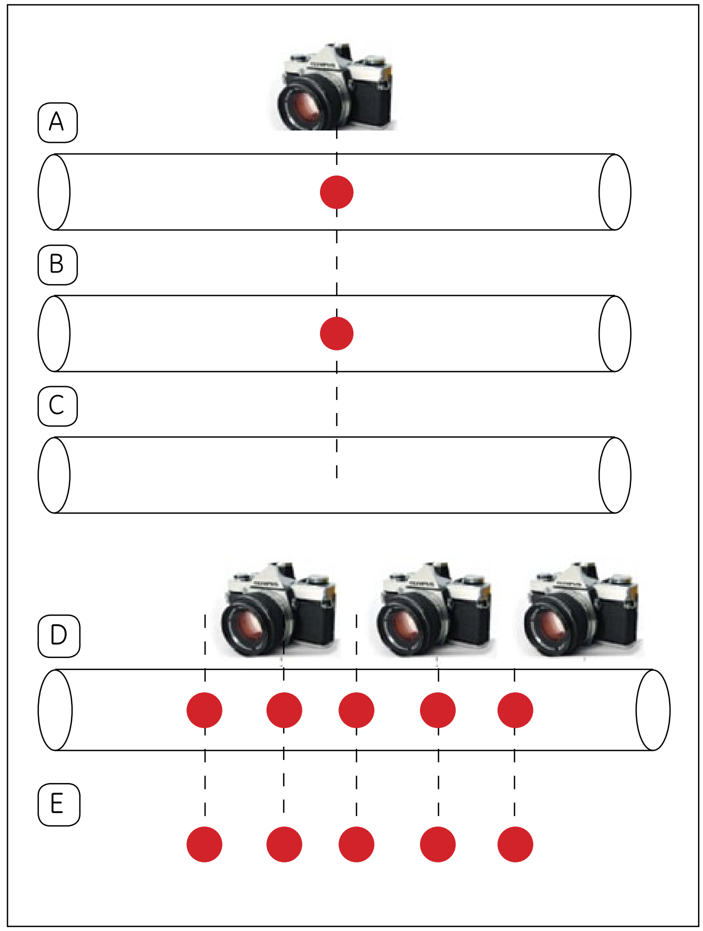

Figure 4 (A, B, C, D, E). Illustration of TBE technology.

B-Flow Color

There are scanning situations where it is desirable to maintain the background B-mode image, while visualizing vasculature. B-Flow Color mode provides high spatial resolution for flow, simultaneously with tissue imaging. This mode amplifies weak blood echoes by using DEU technology as mentioned previously, but adds directional information similar to Directional Power Doppler Imaging (PDI) mode. As a result, it provides enhanced spatial resolution, and less "bleeding" as compared to PDI mode. Also in many cases, DEU technology requires fewer transmits as compared to PDI to boost weak blood flow signal. This allows for increased frame rates and enhanced display of true hemodynamics of the blood flow. Similar to PDI, B-Flow Color helps maintain the background B-mode image quality as compared to B-Flow. See Figure 5.

Figure 5. B-Flow Color depicting detailed spatial resolution extending throughout this neonatal brain.

Flow Modes Comparison

Table 1 lists the advantages and disadvantages of Color Doppler, PDI, B-Flow and B-Flow Color mode.

	COLOR DOPPLER	PDI	B-FLOW	B-FLOW COLOR
Color Display of Flow Direction	Yes	Yes (directional PDI)	No	Yes (directional map)
Display Flow Velocity	Yes	No	No	No
Aliasing†	Yes	No	No	No
ROI	Yes	Yes	No (flow is displayed in the entire image)	Yes
Spatial Resolution	1	1	3	2
Hemodynamics	1	1	3	2
Presence of Color Overwrite	1	1	3	2
Flow Angle Dependency	1	2	3	2
Background B Image Quality	3	3	2	3
Penetration	3	3	1	2

Table 1. Comparison of different imaging modes (Rating 1-3, 1 is least and 3 is most desirable).

†There is the potential for aliasing in directional PDI and B-Flow Color with directional map.

Clinical Applications

GE's Agile Acoustic Architecture uses advanced models of sound interaction with different tissue types and powerful distributed intelligence to help enhance image quality on a broad variety of patients with few user adjustments required. This architecture makes it possible for B-Flow to display fine vessel details and flow hemodynamics. B-Flow may have clinical applications throughout the body, whether looking at large vessel flow profiles, small vessel differentiation, or organ perfusion.

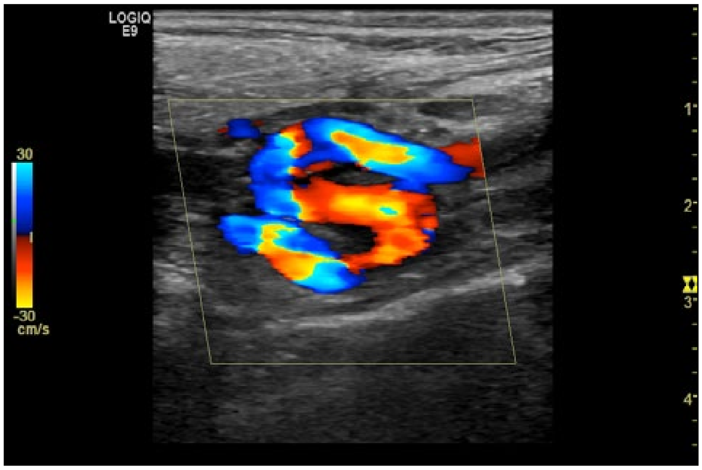

Image 1 and 2. A tortuous carotid artery demonstrated in Color Flow imaging and B-Flow Color Mode, respectively. The continuity of the vessel is easily visualized throughout the field of view in B-Flow Color mode.

Image 3. Common carotid artery with B-Flow allowing a clear delineation of the wall defect caused by plaque.

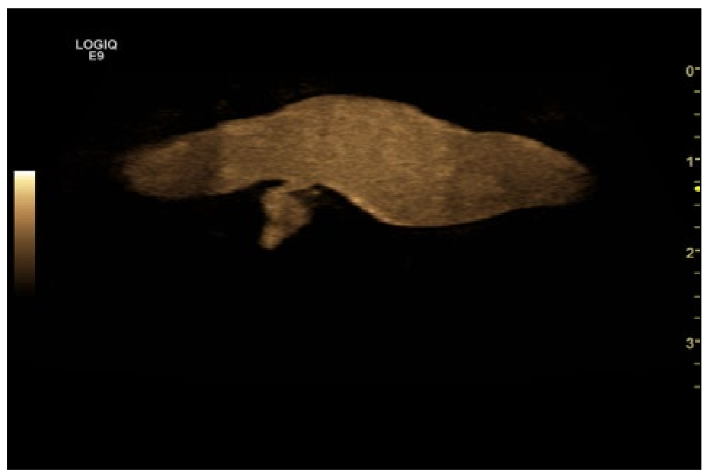

Image 4. B-Flow of a fistula, demonstrating the flow profiles and clear boundary definition.

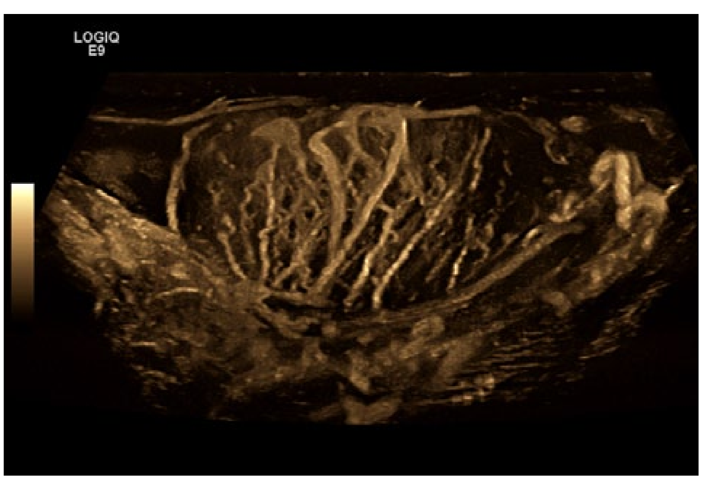

Image 5. B-Flow sensitivity demonstrating vascularity throughout this testicle.

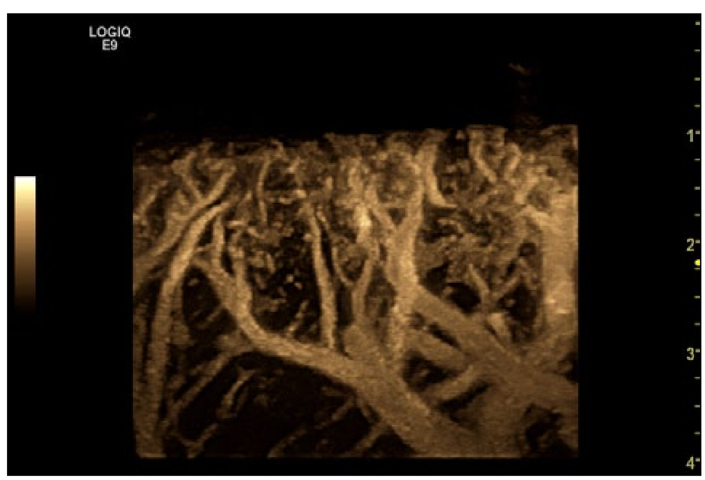

Image 6. B-Flow with Cine Capture clearly demonstrating small vessel branches to the capsule in this spleen.

Conclusions

Excellent spatial and temporal resolution of B-Flow imaging allows the user to visualize blood flow and surrounding vessel wall structure without the limitation of Color Flow "bleeding." Both B-Flow and B-Flow Color imaging modes complement the existing GE Color Doppler and Power Doppler imaging modes to help enhance clinicians' confidence in hemodynamics profiles, vessel patency in organ assessment, and help assess various vascular diseases.

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