AIXPLORER MultiWave

White Paper

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Angio PL.U.S.

PLaneWave UltraSensitive™ ultrasound imaging

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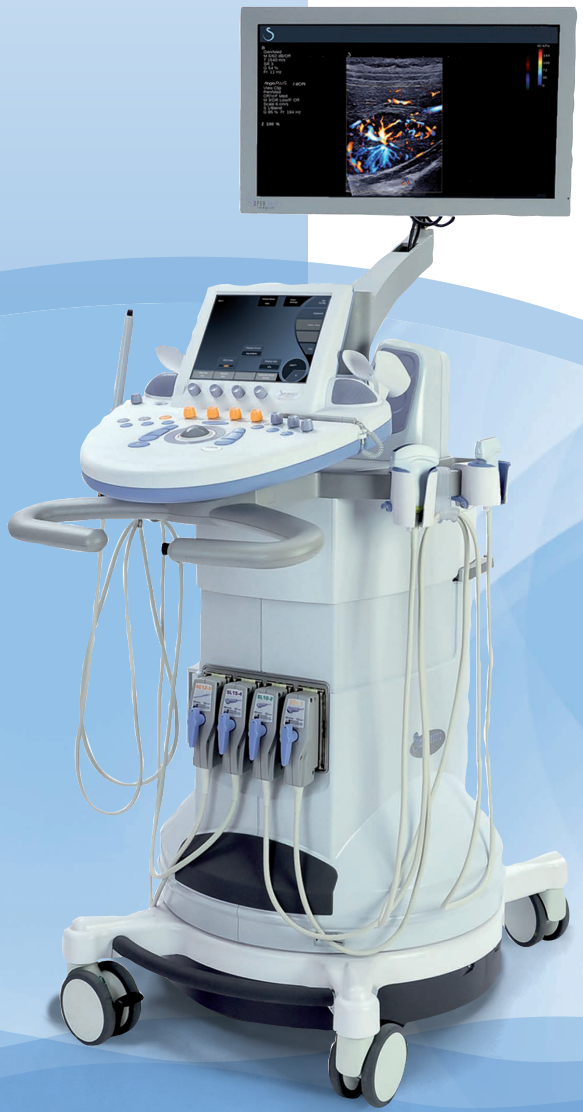

Introduction

Color Flow Imaging (CFI) has significantly changed diagnostic ultrasound with its ability to dynamically visualize blood flow, moving Doppler exams from a blind and difficult procedure to an easier, faster and more accurate one. However, CFI has not reached a sufficient level of performance to properly image microvascularization in small vessels.

With the recent advent of UltraFast™ ultrasound imaging [1], the performance paradigm of Doppler imaging mode is changing. The possibility to insonify a wide area of the body at several thousands of images per second breaks limitations and tradeoffs imposed by conventional ultrasound systems.

For fast flows, for example, UltraFast Doppler can provide simultaneously imaging and quantification of blood flow, merging the benefits of CFI and Pulsed Wave (PW) in one mode. UltraFast Doppler increases patient throughput, and makes the ultrasound exam easier and more reliable.

CFI can also be rethought using ultrafast imaging to better detect and image slow flows - moving ultrasound towards a full non-invasive angiography exam. The new technique called Angio PL.U.S. (PLanewave UltraSensitive™ imaging) is available on the Aixplorer® ultrasound system (SuperSonic Imagine) and provides much more detailed information for better and earlier diagnosis of pathologies.

Challenges of blood flow imaging in Ultrasound

To allow the detection and velocity tracking of flow in vessels, CFI addresses two main challenges: detecting very weak signals from red blood cells (usually 1/1000 weaker than tissue) and extracting them from tissue motion.

This is performed by sending a set of high-energy ultrasound-focused pulses in the body (typically 5 to 6 times longer than B-mode imaging pulses) and wall-filtering the back-scattered echoes to suppress tissue motion from the blood flow signals [2]. Wall filtering is performed assuming tissue is moving more slowly than flow.

This assumption does not apply in small vessels where flows move much more slowly. The number of red blood cells “caught” by the ultrasound beams is also smaller, reducing the amplitude of the back-scattered ultrasound signal. CFI is therefore unable to image small vessel flow (below 100 micrometers) and detect the presence of microvascularization.

In Figure 1, the slow flows missed by CFI are represented by the overlap area between tissue and blood spectra.

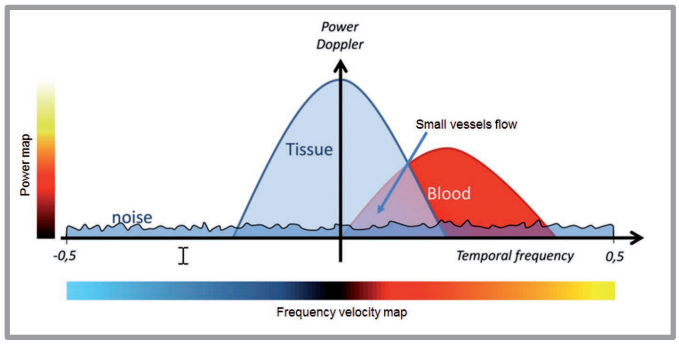

Fig. 1. *Doppler frequency distribution of tissue and flow*

Other imaging techniques have been developed in an attempt to move towards improved flow visualization, in particularly in small vessels. They can be summarized in two main approaches:

- B-mode-based flow imaging
- Continuous acquisition of flow imaging.

B-mode-based flow imaging

In such imaging modes, blood flow is directly visualized in B-mode. Instead of sending narrow-band ultrasound pulses, coded excitations are used to keep high energy while improving temporal resolution. Scattered signals are filtered to extract flow and enhanced to clearly appear on the image, as illustrated on the image below

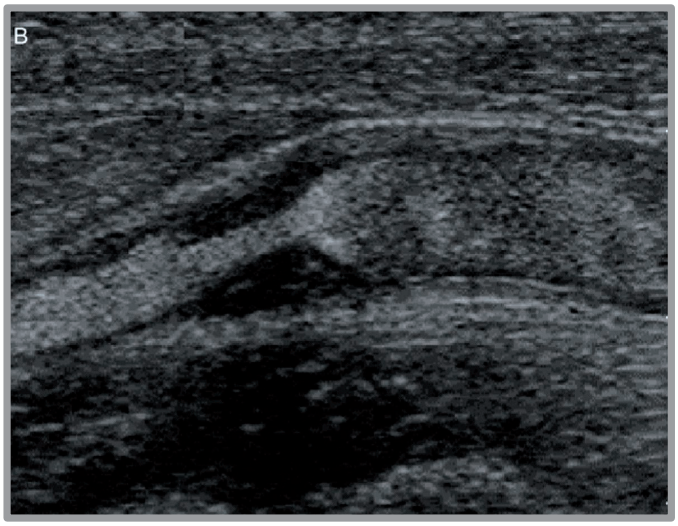

Fig. 2. *B-mode-based flow imaging. Courtesy of [2]*

Flow imaging can benefit here from resolution and frame rate of the B-mode; Compared to CFI, B-mode-based flow imaging methods rely on better frame rate and resolution but sacrifice sensitivity and velocity information.

Continuous acquisition of flow imaging

Another approach uses time interleaving with very large interleave factors so that a Color line corresponding to a given direction can be interrogated continuously at a constant rate. Velocity scales are fixed at the lowest value and the B-mode lines required to form the full B-mode frame are assembled gradually in a sub-sector manner.

The main benefit of this time-interleaved approach is that the Color wall filter operates on continuous streams of Color data like in PW Doppler, and can therefore remove tissue motion more effectively than in conventional CFI where the sequences to be filtered have short duration and are discontinuous.

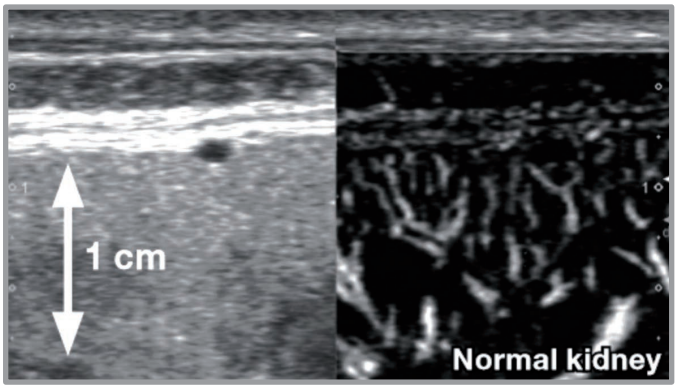

Fig. 3. *Continuous acquisition of flow imaging. Courtesy of [2]*

The sensitivity of the mode is increased as directly related to the fixed and low PRFs used, but aggressive motion compensation processing is required to avoid the typical low PRFs flash artifacts.

This technique does not offer any type of flow quantification, reduces B-mode quality and, by design, removes the ability to change the velocity scale.

The figure 4 summarizes the performance canvas of the two different strategies compared to classical CFI. The first one, B-mode-based flow imaging, increases resolution at the expense of sensitivity and quantification. The second one, continuous acquisition of flow imaging, increases sensitivity at the expense of scale adjustment, B mode quality and quantification.

Neither of the techniques proposed so far are able to provide high performance microvascularization imaging without impacting the classical CFI workflow or performance profile.

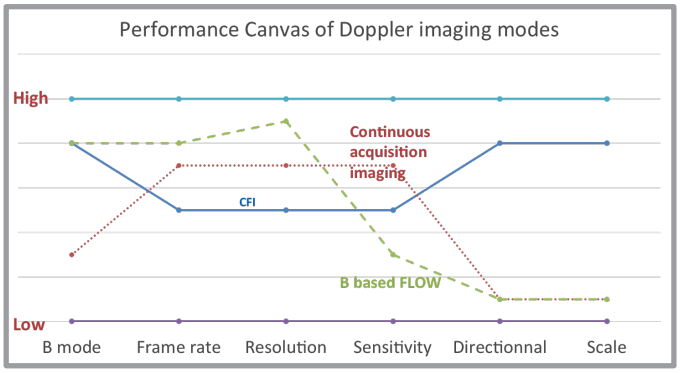

Fig. 4. *Performance canvas of different Doppler imaging modes. (Performances shown are indicative of true performances found in the literature)*

Changing the rules with Angio PL.U.S.

In order to reach a new paradigm in Doppler performance, one must rethink the way flow information is acquired and processed. Angio PL.U.S. relies on two key pillars to achieve that goal: unfocused or plane waves and 3D wall filtering.

Enhancing sensitivity and resolution with Planewave Ultrasensitive imaging

In Angio PL.U.S., plane or unfocused waves are sent into the body at the maximum allowed pulse repetition. Thanks to the ultrafast capabilities of Aixplorer, all pixels of the explored tissue can be reconstructed from a single unfocused insonification (see the figure 5 below).

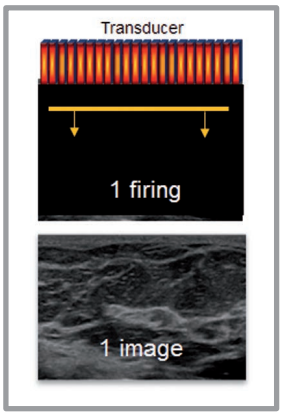

Fig. 5. *Principle of UltraFast acquisition: 1 firing = 1 image*

Consequently, electronic lateral beam scanning is not needed anymore to build an image and each pixel can be interrogated continuously and with significantly higher sampling rate (5 to 10 times faster) than in classical CFI, as illustrated in figure 6.

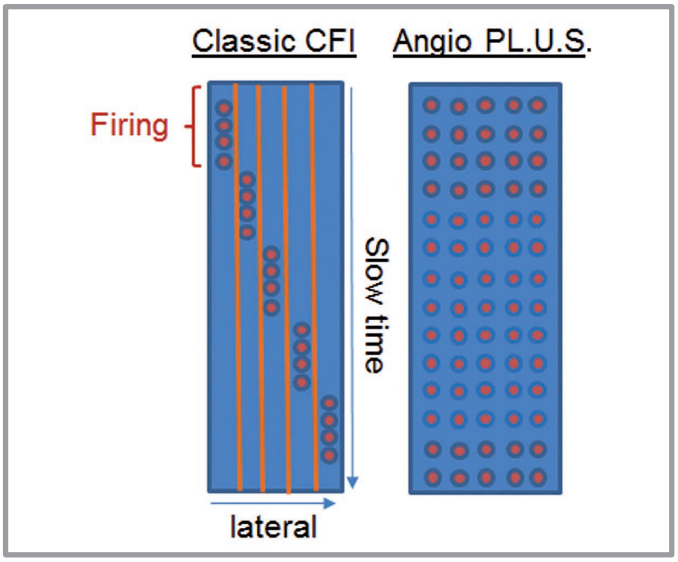

Fig. 6. *Comparison of sampling schemes for CFI and Angio PL.U.S. Angio PL.U.S. offers continuous and high frequency sampling of Doppler information*

The continuous and higher data sampling increases imaging sensitivity and resolution and therefore allows for a better detection of flow in small vessels.

Figure 7 below illustrates the gain in data sampling: while in conventional CFI each pixel is insonified 10% to 15% of the time, in Angio PL.U.S. it reaches more than 90%, the remaining 10 % being devoted to the B- mode sequence acquisition.

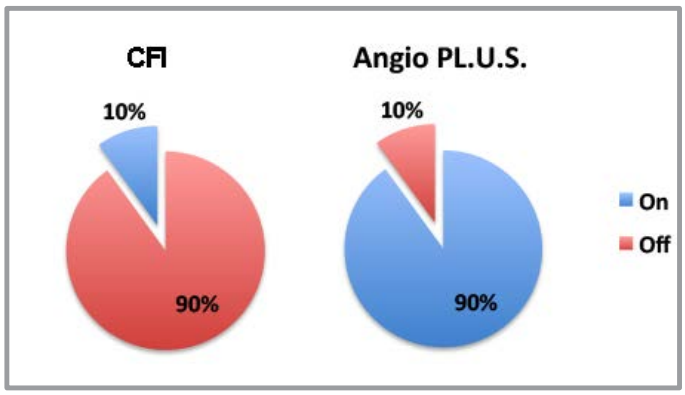

Fig. 7. *Active insonification time in CFI and Angio PL.U.S.*

From 1D to 3D Wall Filtering

Extraction of flow information is classically performed using the so-called “wall filtering”, able to suppress slow movements from higher flow velocities. As stated above, wall filtering is unable to extract flow that moves as fast or slower than tissue (such flow is represented by the overlap area in the figure below), as this is case in small vessels.

While wall filtering only analyzes a small set of temporal signals, Angio PL.U.S. introduces the concept of continuous 3D wall filtering which consists in analyzing tissue motion in the time, space and amplitude domains. As illustrated in figure 8, the spatial and temporal perspective offered by UltraFast imaging allows an efficient discrimination of flow and tissue in cases where temporal/velocity filtering is ineffective.

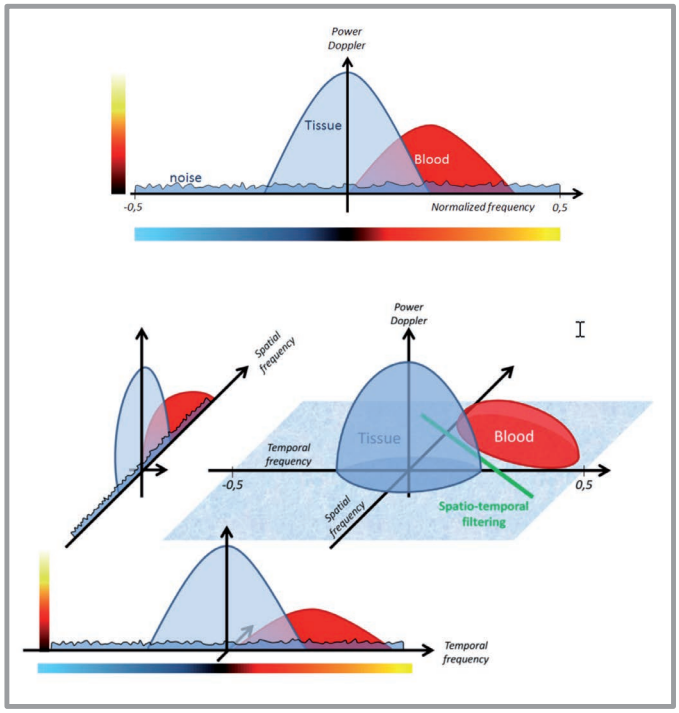

Fig. 8. *3D wall filtering.*
Blood signal can be effectively extracted from tissue by analyzing space time and amplitude information.

The combination of enhanced sensitivity, improved resolution and 3D smart wall filtering creates a new level of performance in microvascularization imaging.

In figure 9 is an updated performance canvas including Angio PL.U.S. Sensitivity and resolution are enhanced to better visualize small vessels while maintaining workflow and performance of other CFI characteristics.

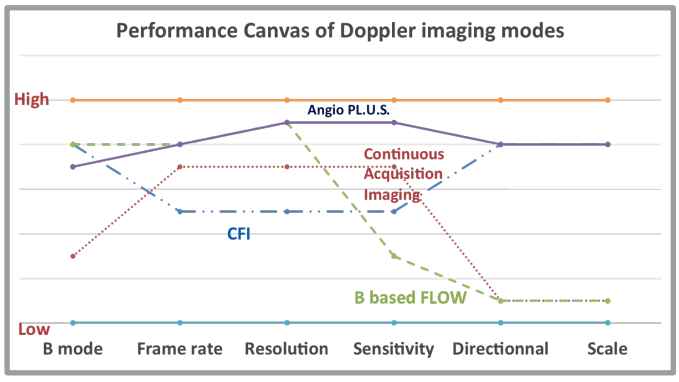

Fig. 9. *Performance canvas of Angio PL.U.S. compared to classical modalities*

Angio PL.U.S. Real Time and Angio PL.U.S. High Definition

The maximum firing rate used in Angio PL.U.S. is usually set either by the time of flight of ultrasound waves (for the chosen interrogated depth) or by the thermal constraints of the probe. In real time mode (Angio PL.U.S. RT) it is the thermal heating of the probe surface that limits the firing rate. Typical values reached are around 4 to 5 times higher than in conventional CFI.

To break this limitation and offer maximized performance, a high definition single acquisition mode is available called Angio PL.U.S. HD. A prospective clip is launched at a firing rate corresponding to the time of flight of ultrasound. The system is then frozen and the clip can be reviewed offline. In HD, it is possible to increase data sampling by a factor 10 to 15 compared to CFI, providing even better sensitivity than in the RT mode. The HD mode can be seen as a beauty shot acquisition of the real time mode.

Unchanged Workflow

Contrary to other Doppler optimized modes, Angio PL.U.S. does not sacrifice workflow to improve performances of imaging: scale adjustment, velocity quantification and directional power mapping are still fully functional and behave the same way as in conventional CFI. This is a significant advantage for ease of use and fast examination time. Angio PL.U.S. does not require an additional or a specific scanning protocol. It is simply replacing CFI with better imaging performance.

Examples and potential clinical applications

Some examples are provided below in various clinical applications, demonstrating the performances of Angio PL.U.S. to better display small vessel vascularization in organs and lesions.

Liver

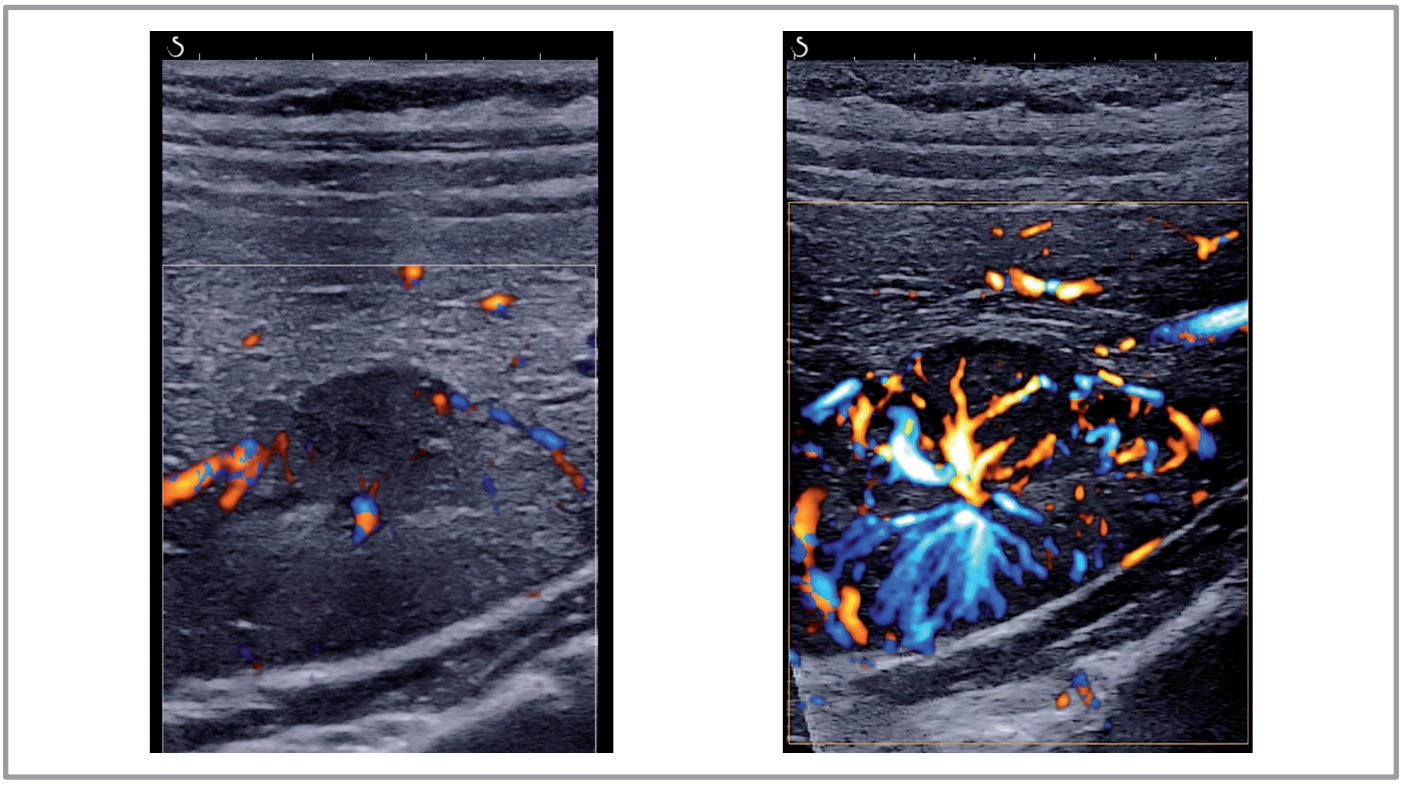

Fig. 10. *Example of a Liver FNH in CFI and Angio PL.U.S.*
While CFI shows little vascularization, Angio PL.U.S. HD allows visualization of the lesion vascular structure in bike wheel - usually only detected using contrast agents

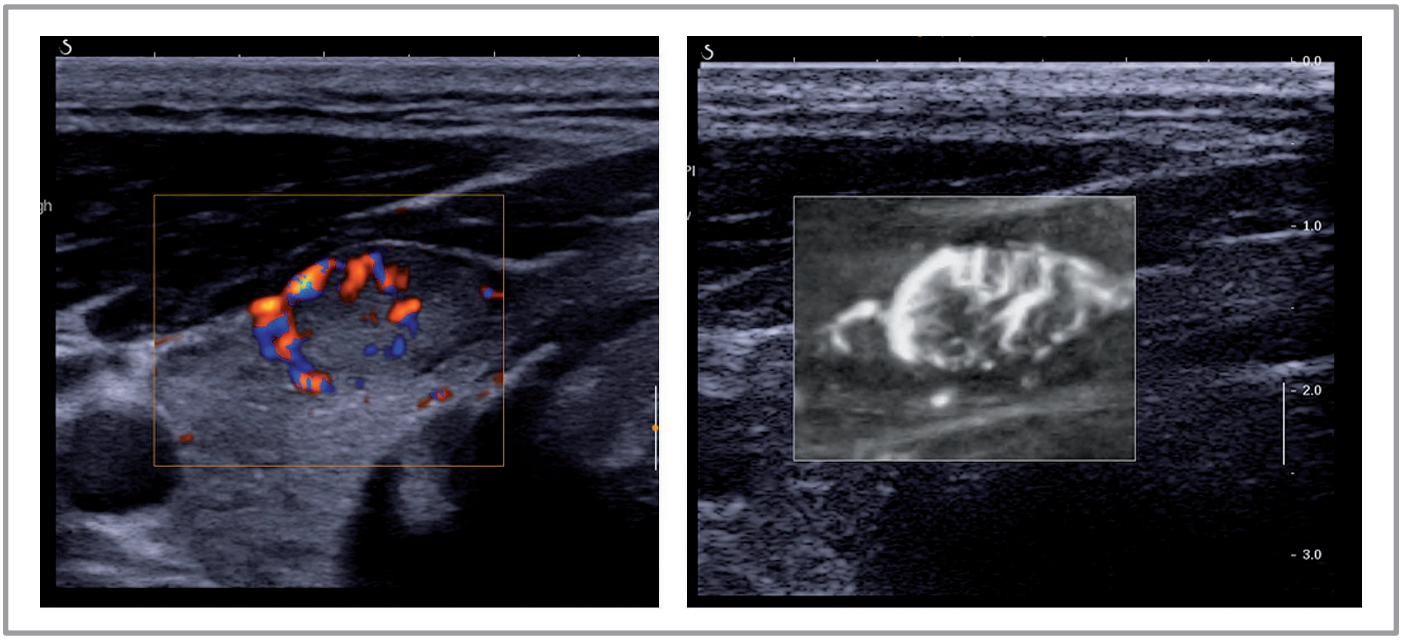

Fig. 11. *Thyroid nodule with clear depiction of very fine vessels in Angio PL.U.S. that are not detectable in CFI. This example shows the user-selectable grayscale map available in Angio PL.U.S.*

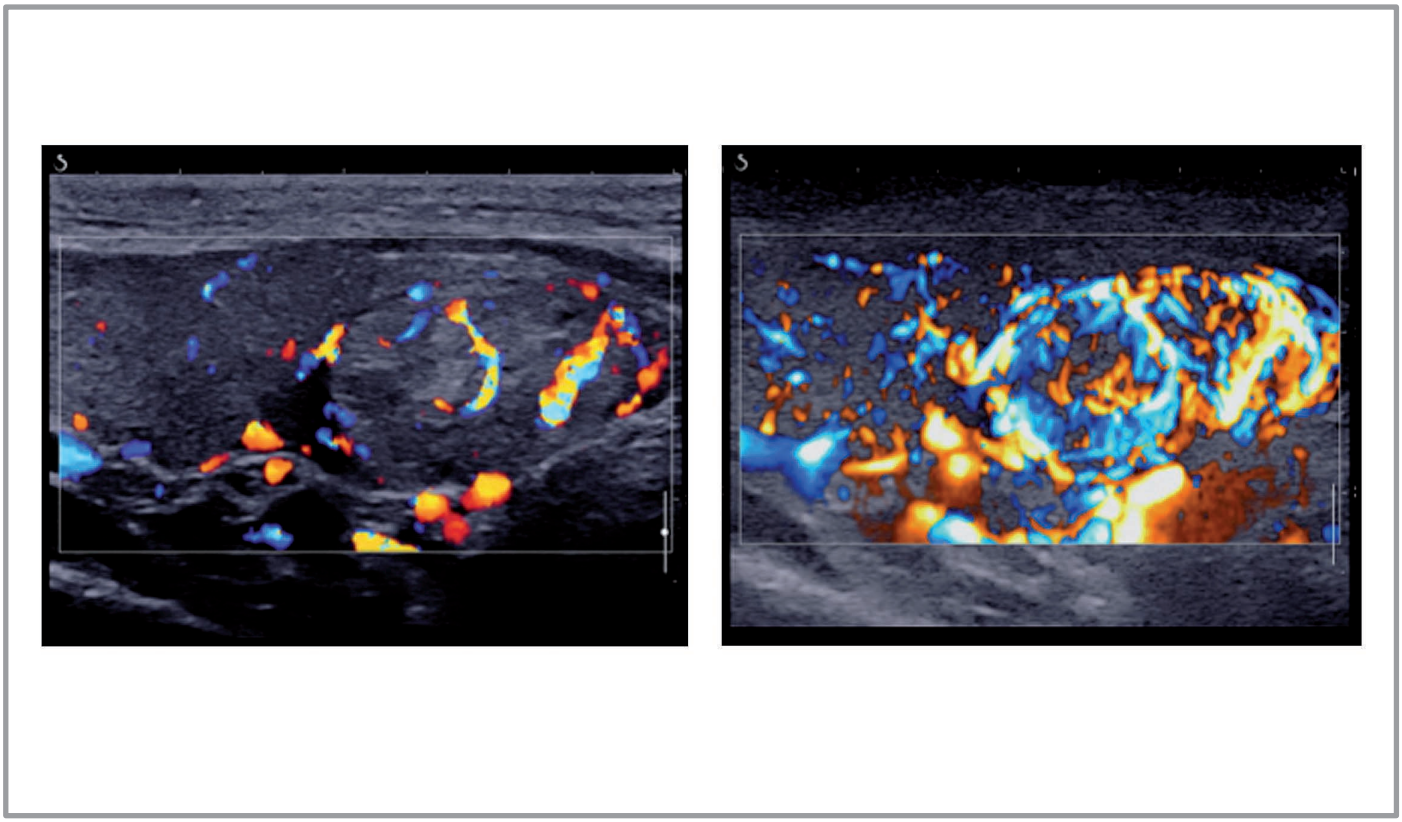

Fig. 12. *Hypervascularized thyroid nodule. Angio PL.U.S. shows perinodal flows with greater sensitivity and resolution*

Musculoskeletal

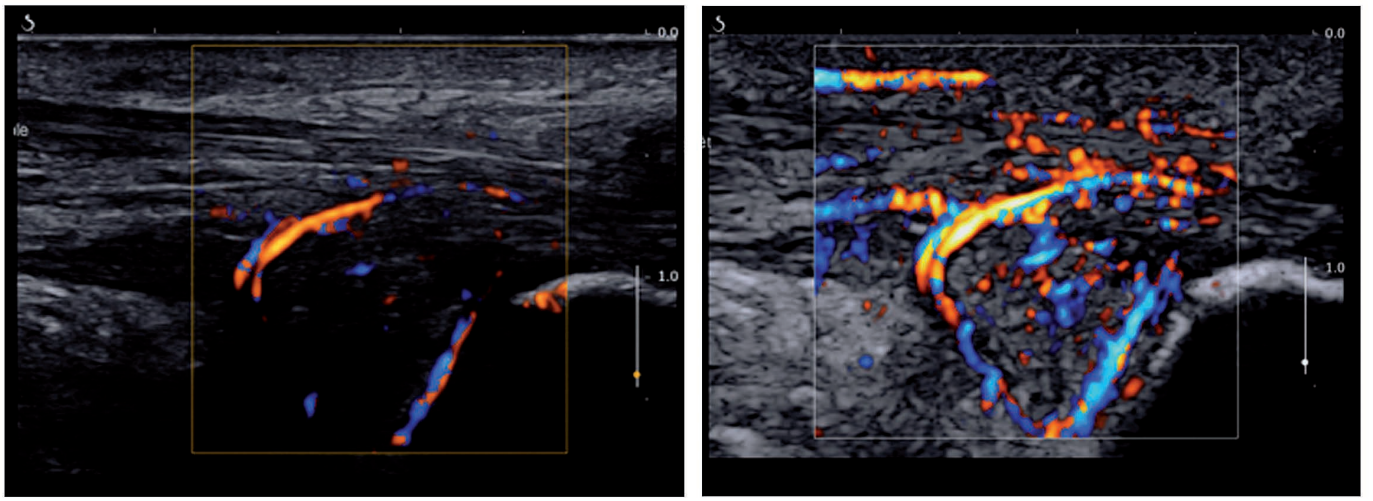

Fig. 13. *Injured Achilles tendon. Tendon inflammation visualization is enhanced in Angio PL.U.S.*

Lymph Node

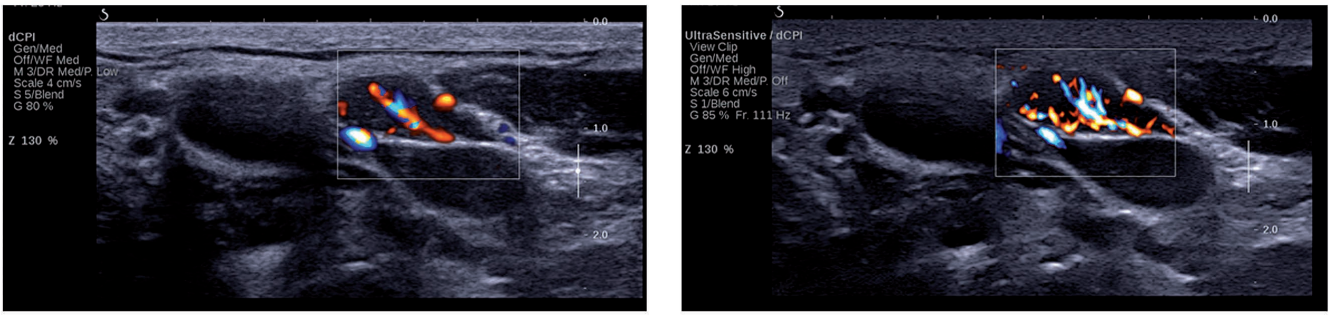

Fig. 14. *Normal lymph node in Dcpi and Angio PL.U.S.*

Conclusion

Angio PL.U.S. leverages the combination of ultrafast imaging and 3D wall filtering to create a leap in ultrasound doppler imaging performance. Thanks to its ability to detect microvascularization in different types of lesions this new mode opens the door to added clinical information and diagnostic perspectives, in both benign and malignant lesions.

References

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2. T. Szabo, Diagnostic ultrasound Imaging Inside Out second edition, Elsevier, 2014.

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