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Initial experience with a novel microvascular flow imaging technique

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Priscilla Machado, M.D., Flemming Forsberg, Ph.D.
Radiology, Thomas Jefferson University, Philadelphia, PA


Priscilla Machado


Flemming Forsberg

Background

Doppler techniques are well established as important tools in the ultrasound imaging armamentarium. Imaging modes such as pulsed Doppler (PW) as well as color (CDI) and power Doppler (PDI) imaging are regularly used by clinicians for characterization of tumor vascularity as well as to show normal and/or abnormal vascularity in several organs and tissues. Pulsed Doppler can also be used to determine quantitative flow parameters within vessels. However, there is a limit to the evaluation of microvessels using the current commercially available Doppler techniques. This explains why in some cases blood flow can be seen better with contrast-enhanced ultrasound (CEUS), computerized tomography (CT) and/or magnetic resonance imaging (MRI).

Ultrasound manufacturers continuously try to improve the quality of their ultrasound images by developing new techniques for interpreting sound waves. Toshiba Medical Systems has recently developed a new Doppler technique called SMI. This is a microvascular flow imaging mode designed to improve the visualization of blood flow, especially slow flow signals from microscopic vessels, through a new adaptive algorithm which removes clutter dramatically while maintaining very high frame rates (> 50 fps). An initial version of the SMI algorithm was implemented on a Toshiba Aplio™ 500 US system. The SMI technology is able to remove the motion artefact (clutter) while visualizing low velocity blood flow. SMI can operate in two modes: color (cSMI) and monochrome (mSMI). cSMI simultaneously displays conventional grayscale ultrasound with color-encoded Doppler signals, while mSMI displays only the vasculature by subtracting away the background signals.

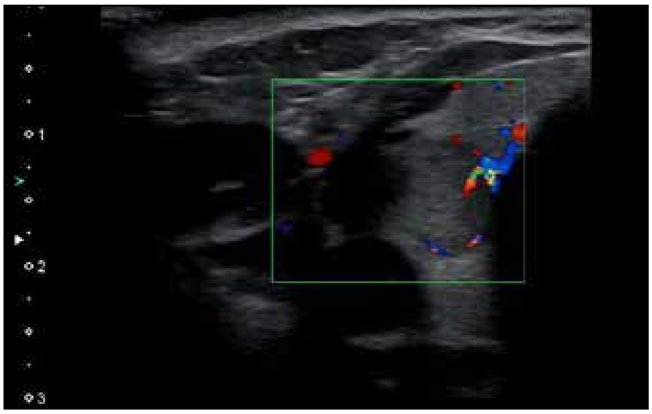
At Thomas Jefferson University, we initiated a pilot study to assess the overall clinical utility and performance of this novel ultrasound image processing technique in abdominal, vascular and small parts applications. The purpose of our study was to determine if the SMI modes can depict microflow in more detail, with better vessel continuity and smaller branches compared to color and power Doppler imaging.

We conducted a prospective clinical evaluation from August to October of 2013 involving 33 adult patients that were approached when they presented at Thomas Jefferson University Hospital for their scheduled ultrasound examination or thyroid fine needle aspiration (FNA), an ultrasound-guided procedure. Twenty-five (25) thyroid nodules, four (4) breast lesions, five (5) liver masses, four (4) lymph nodes and one (1) parathyroid were scanned with grayscale ultrasound, as well as CDI and PDI followed by imaging with the new microvascular SMI flow imaging mode (color SMI and monochrome SMI) on the Aplio 500 ultrasound system. SMI images can be acquired on their own or in a dual imaging mode with grayscale. Pulsed Doppler was also used in our study in combination with monochrome SMI to examine a few specifically selected microvessels inside the tissues being imaged in order to verify that the SMI depicted vessels which are indeed real microvasculature of the tissue.

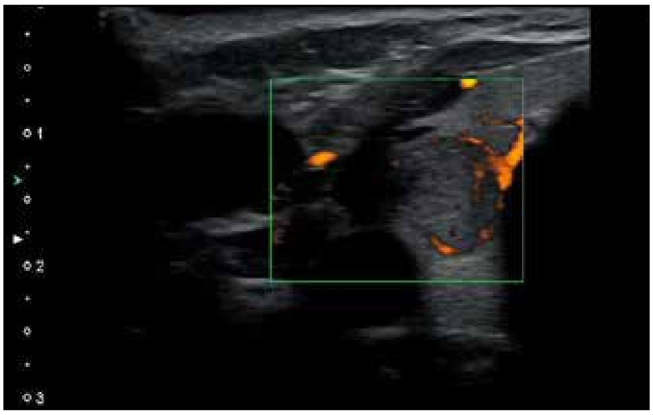
[Case 1] Thyroid - benign follicular nodule

Figure 1.1.a shows a benign follicular thyroid nodule located in the right lobe in grayscale. Figures 1.1.b and 1.1.c show the nodule in CDI and PDI, respectively, both showing peripheral vascularization on the top left of the nodule. Figures 1.1.d and 1.1.e show color SMI and dual imaging grayscale and monochrome SMI, respectively: in those two modes we can see peripheral vascularization surrounding the entire nodule as well as internal microvascularization, with small branching detailed.

1.1.a Grayscale

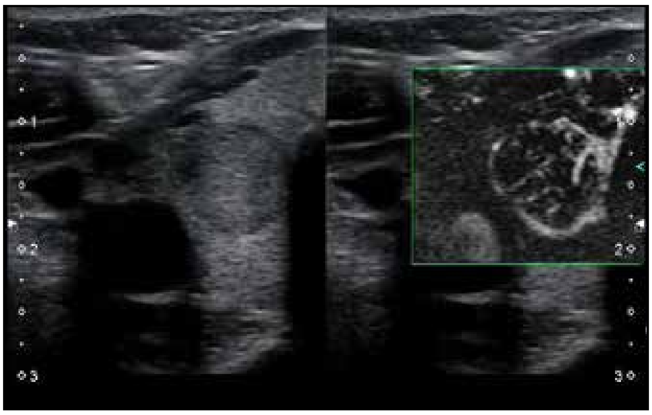


1.1.b Color Doppler (CDI)



1.1.c Power Doppler (PDI)

1.1.d cSMI

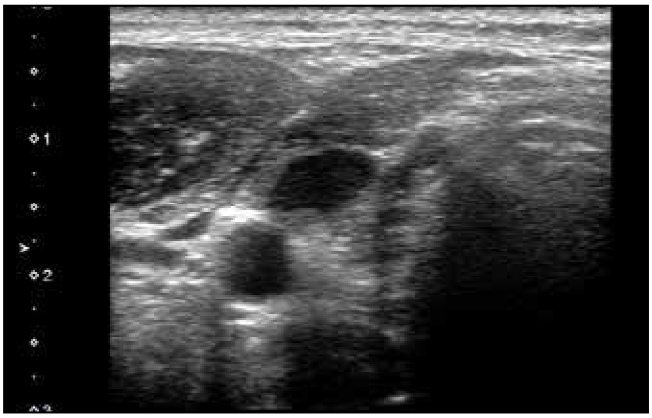


1.1.e Dual imaging grayscale and mSMI

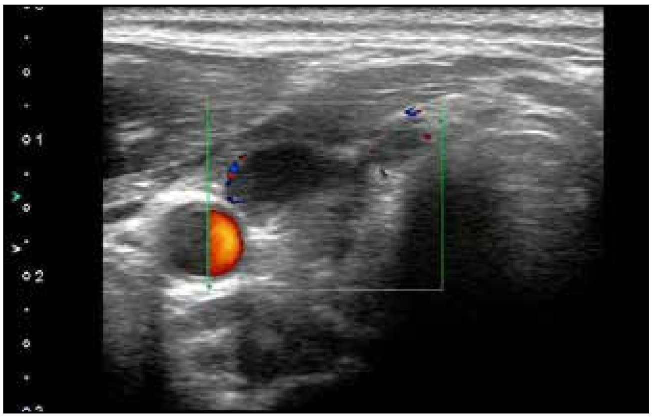
Figure 1. 1.1 Benign follicular thyroid nodule on the right lobe

[Case 2] Thyroid - reactive lymph nodes

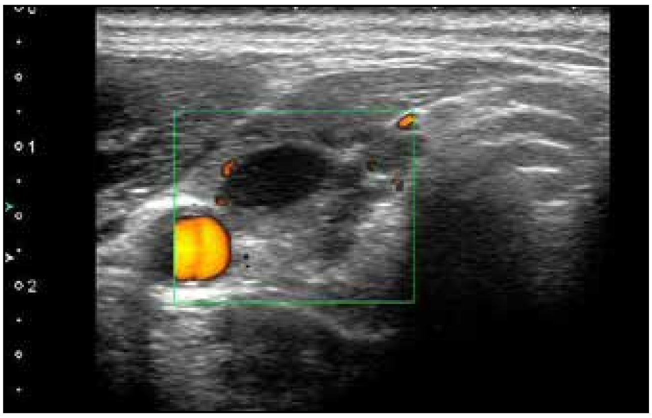
Figure 1.2.a shows a reactive lymph node in grayscale. Figures 1.2.b and 1.2.c show CDI and PDI, respectively, for both no flow was seen inside the lymph node and just some peripheral vascularization on the top right can be seen. Figures 1.2.d and 1.2.e show color SMI and dual imaging grayscale and monochrome SMI, respectively: in those two modes we can see peripheral vascularization surrounding the lymph node as well as internal vascularization, with small branching detailed.



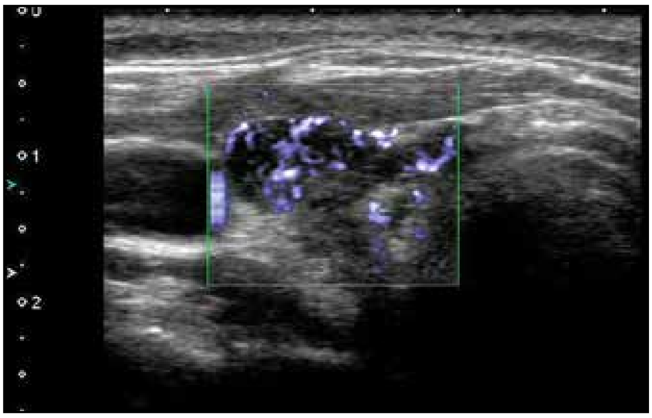
1.2.a Grayscale



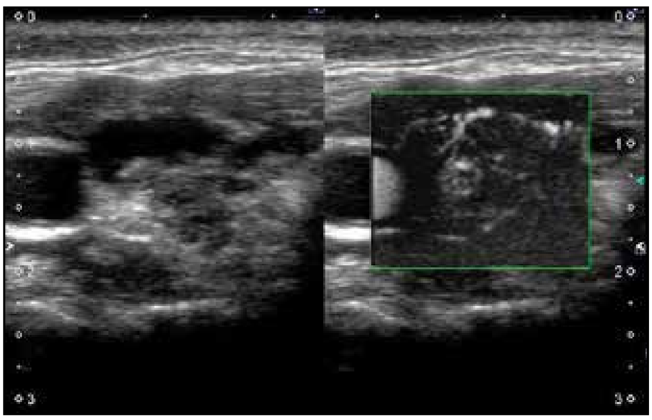
1.2.b Color Doppler (CDI)



1.2.c Power Doppler (PDI)



1.2.d cSMI

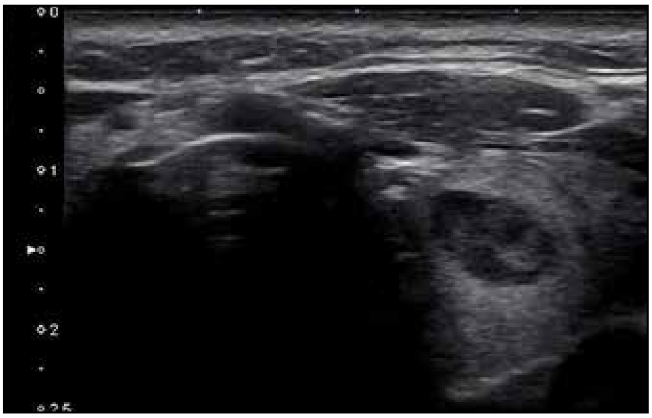


1.2.e Dual imaging grayscale and mSMI

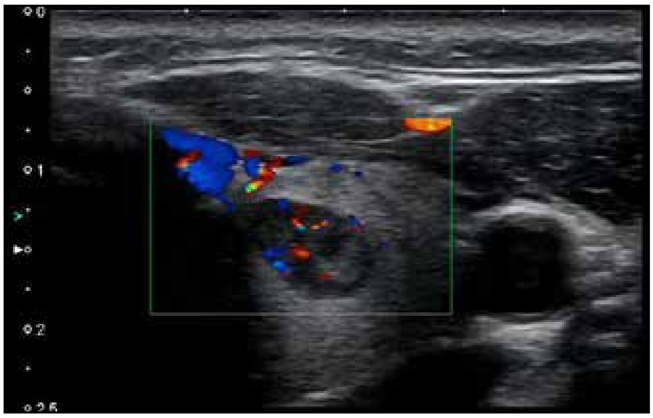
Figure 1. 1.2 Reactive lymph node located adjacent the right thyroid lobe

[Case 3] Parathyroid

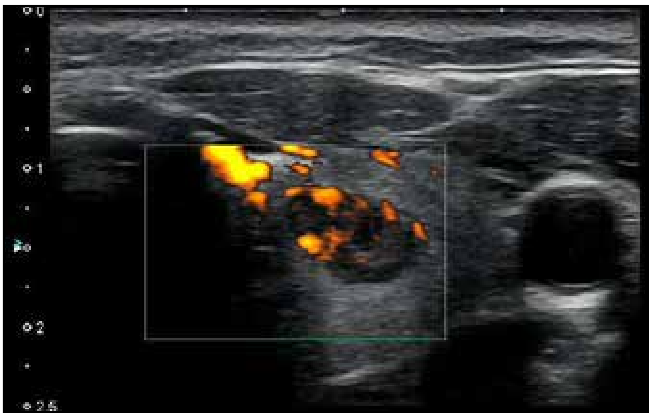
Figure 1.3.a shows parathyroid tissue in grayscale. Figure 1.3.b it is a CDI image and it shows a small area with flow inside the tissue. Figure 1.3.c corresponds to a PDI image, in that we can see a small area with flow inside the tissue and some peripheral vascularization on the top. Figures 1.3.d and 1.3.e show color SMI and dual imaging grayscale and monochrome SMI, respectively, in those two modes we can see peripheral vascularization surrounding the tissue as well as internal vascularization, with small branching detailed.



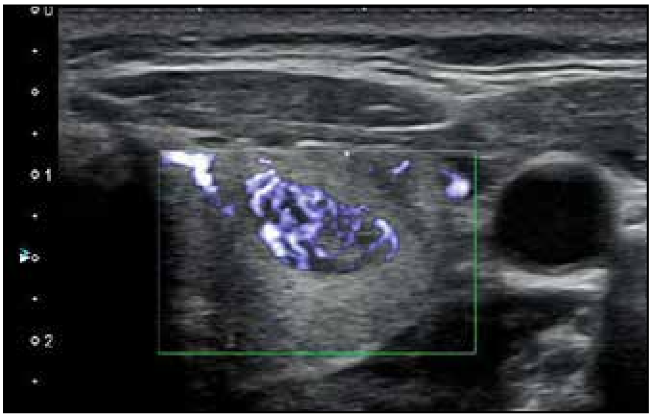
1.3.a Grayscale



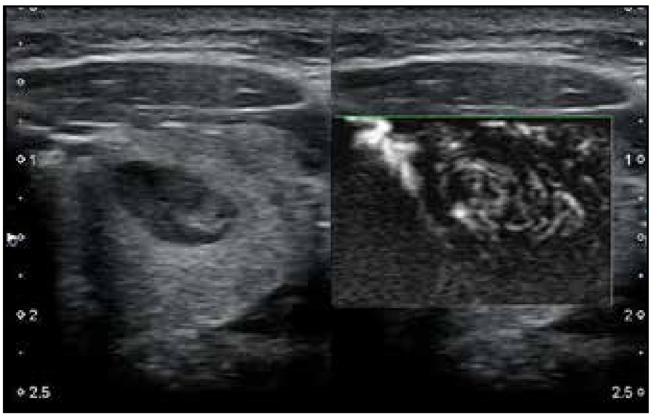
1.3.b Color Doppler (CDI)



1.3.c Power Doppler (PDI)



1.3.d cSMI



1.3.e Dual imaging grayscale and mSMI

Figure 1. 1.3 Parathyroid tissue present inside the left thyroid lobe

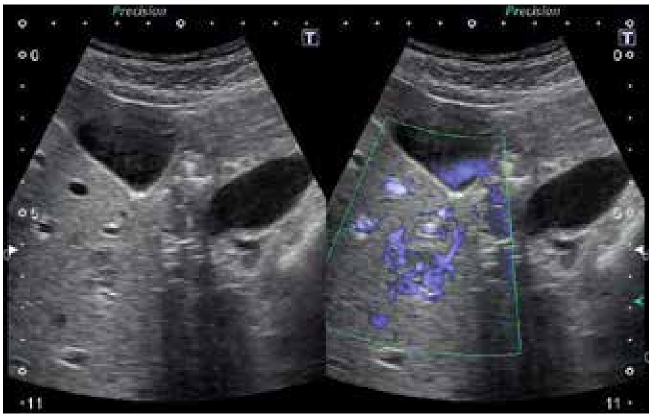
[Case 4] Liver hemangioma

Figure 2.a shows a liver hemangioma in grayscale. Figures 2.b and 2.c show CDI and PDI, respectively, with both modes demonstrating peripheral vascularization. Figures 2.d, 2.e, 2.f and 2.g show dual imaging grayscale and color SMI and dual imaging grayscale and monochrome SMI; in those two modes we can see peripheral vascularization as well as internal microvascularization, with small branching detailed.

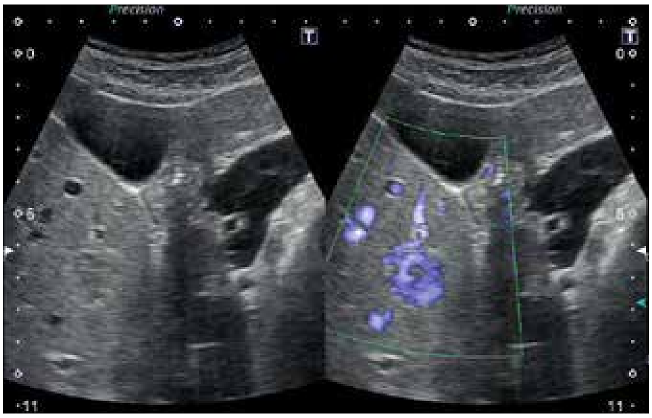
2.a Grayscale

2.b Color Doppler (CDI)

2.c Power Doppler (PDI)



2.d Dual imaging grayscale and cSMI



2.e Dual imaging grayscale and cSMI

2.f Dual imaging grayscale and mSMI

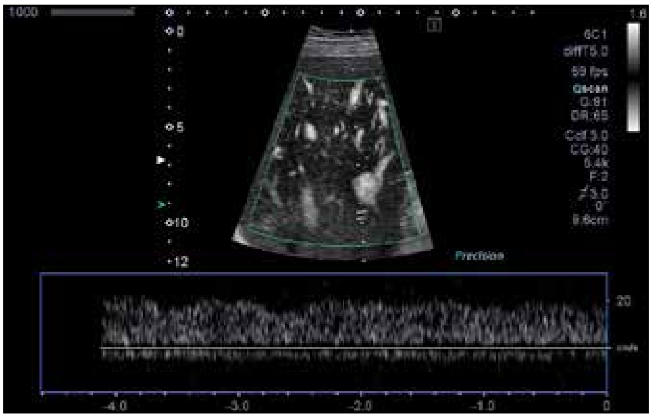
2.g Dual imaging grayscale and mSMI

Figure 2. Liver hemangioma

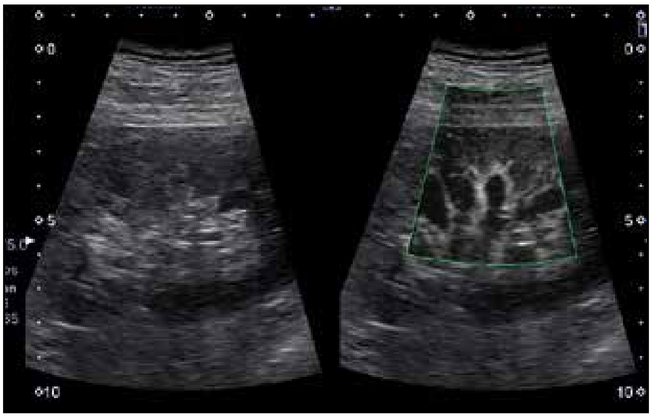
[Case 5] Liver/Kidney

Figure 3.1.a shows a small liver hemangioma with a diameter of 6 mm at a 10 cm depth in dual imaging grayscale and monochrome SMI. Figure 3.1.b shows a PW image of the small liver hemangioma in order to verify which are indeed real micro-vasculature of the tissue. Figure 3.2.a it is a dual imaging grayscale and monochrome SMI of a kidney and it shows the vascularization with more details and that is confirmed by PW image seen in Figure 3.2.b.

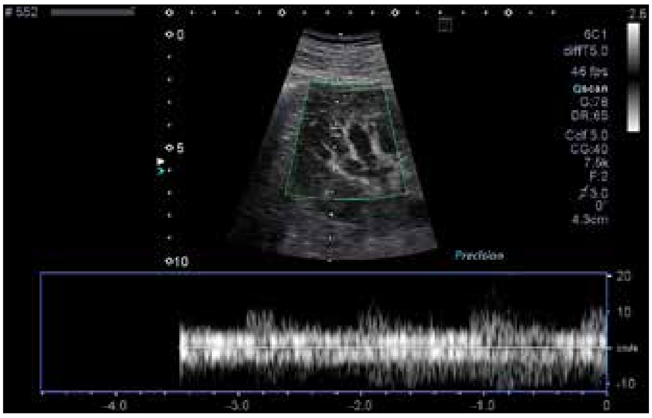
3.1.a Dual imaging grayscale and mSMI



3.1.b mSMI and pulsed Doppler (PW)



3.2.a Dual imaging grayscale and mSMI



3.2.b mSMI and pulsed Doppler (PW)

Figure 3. 3.1 Liver hemangioma / 3.2 Kidney

Discussion/Conclusion

For all thyroid, parathyroid, lymph node and liver cases SMI showed microvascular flow with vessel branching details that were observed with neither CDI nor PDI, including flow within a 6 mm hemangioma at 10 cm depth (Figures 3.1.a and 3.1.b). This was confirmed by pulsed Doppler with velocities as low as 2.4 cm/s being measured. Vessel continuity and microvessels within abdominal organs were consistently seen with SMI and to a much lesser degree with the conventional flow modes. This was particularly aided by the higher frame rates in the SMI modes. Overall, the presence of clutter did not markedly impact the correct identification of actual microvascular flow (except for the breast cases where noise was more dominant).

A new microvascular flow mode has been assessed and detailed depictions of large and small vascular structures have been obtained; albeit currently based on a limited sample size. The novel SMI mode consistently showed mode detailed flow with better vessel continuity and smaller branches than CDI, and PDI, as confirmed by PW. More work is required to precisely define the appropriate clinical applications for SMI, but we currently anticipate that gynecological imaging (e.g., adnexal masses), obstetrics (e.g., placental viability), lymph nodes, and abdominal areas such as renal transplants as well as pediatrics will become important applications.

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Model number:TUS-A500 MOIUS0071EA 2014-06 TME/D

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