

The Added Value of B-Flow Technique in Assessment of Lower Limb Arterial Lesions with Densely Calcified Atheromatous Plaques

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Abstract:

Background: Diagnostic CTA is the gold standard for assessment of PAD. However, ultrasound is more desirable for being non-invasive, real time and using non-ionizing radiation. As such, GE healthcare has introduced “B-Flow” as a new ultrasound imaging mode that can overcome some limitations of CDU, especially densely calcified plaques. **Aim:** To assess the added value of B-flow technique in assessment of lower limb arterial lesions in presence of densely calcified atheromatous plaques. **Patients and methods:** Our study included 30 cases having densely calcified arterial atheromatous plaques. All subjects were examined by CDU with spectral analysis and BFI; and the results were compared to the gold standard CTA. **Results:** BFI has higher discrimination than CDU in presence of densely calcified plaques at the femoral segments. It is also better in detecting sites of collaterals take-off at the infra-popliteal segments. However, extensively calcified plaques, depth and edema represent major limitations. **Conclusion:** B-flow has the potential to improve US imaging in patients with PAD. However, it is not free of limitations. As such, we do not encourage the use of B-Flow as a sole ultrasound imaging mode, but as a complementary technique to use in situations where CDU findings are inconclusive or unclear.

Key words: PAD, B-Flow, BFI, dense calcifications, CDU.

List of abbreviations: CDU: color Doppler ultrasound, PAD: peripheral arterial disease, BFI: B-Flow imaging, CTA: Computed tomography angiography, CFA: common femoral artery, SFA: superficial femoral artery, POPA: popliteal artery, PTA: posterior tibial artery, ATA: anterior tibial artery, DPA: dorsalis pedis artery, FOV: field of view, PPV: positive predictive value, NPV: negative predictive value.

Introduction

Peripheral arterial disease (PAD) is a nearly pandemic condition that has the potential to cause loss of limb or even loss of life¹. Diagnosing of PAD is based on careful history, physical examination and a variety of diagnostic tools. Arteriography has been considered the gold standard for the investigation of PAD as it provides anatomical details that cannot be obtained from other imaging techniques. However, arteriography is invasive, expensive, with limited access, and depends on usage of ionizing radiation or contrast agents. As such, it cannot be used as a screening modality and it may be associated with some morbidity. In addition to that, it has technical some limitations, such as inaccurate estimation of the hemodynamic effect of arterial lesions and detection of patency of distal arteries subjected to low flow¹.

On the other hand, Color Doppler Ultrasound (CDU) is a good method for screening and follow-up, as well as for the definitive diagnosis of peripheral arterial disease². It is often more desirable for being non-invasive, non-ionizing radiation, real-time and economical. Besides that, with the usage of Pulsed-wave, CDU can show the exact flow velocity of each arterial

segment and determine the degree of severity of the stenosis based on an analysis of the pulsed-wave Doppler spectral waveform³. So, CDU can provide information not only about vessel wall, but also hemodynamic information. However, color images of blood flow can be seen to overwrite the vessel boundaries and calcified plaques might cause acoustic shadowing obscuring details². Other limitations include angle dependence, aliasing, and difficulty in separating background noise from true flow in slow-flow states in multilevel stenosis¹. Hence comes the new technology “B-flow” introduced from GE Healthcare that has shown great potential for addressing these challenges².

B-Flow is a new, unexplored, non-Doppler US imaging mode that was developed trying to overcome the various limitations of CDU. It applies digitally encoded ultrasound (DEU) technology to directly visualize the flowing blood cells⁴. Its flow images are provided by highlighting the weak flow reflectors (red blood cells) and suppressing the signals from the surrounding stationary tissue⁴.

B-flow is exempt from movement, blooming

and aliasing artifacts. It shows higher frame rate for hemodynamic imaging, and higher spatial resolution for vascular anatomy⁵. It can also simultaneously visualize the flowing blood and the surrounding stationary structures.

Aim of Work

To assess the added value of BFI in assessment of lower limb densely calcified arterial plaques, highlighting the potential advantages and limitations of this technique.

Patients and Methods

This is a prospective case-control study. It included 30 cases with densely calcified atheromatous plaques. The study was prospectively done at El Tahra radiology center, during the period from July 2018 to June 2020. Approvement was gotten from the ethics committee of the institute and informed consents were obtained from the patients.

Inclusion Criteria

- Patients with suboptimal US assessments caused by the densely calcified atheromatous plaques that obscure an arterial segment.
- All the patients underwent further assessment using CT angiography as gold standard.

- All the included patients approved to be included in this study.

Exclusion Criteria

- Patients lacking the required investigations (No CT scan was done).
- Patients who didn't follow up.
- Patients who didn't agree to be included in this study.

Methodology

All examinations were done by the same examiner. No patient preparation was requested.

A linear transducer with a variable ultrasound frequency of 7-12 MHz is generally used, but a convex transducer with a lower frequency was used as well with thick patients and for evaluation of the iliac arteries in the pelvic cavity.

The examination is usually performed with the patient placed in the supine position. The patient's hip is generally abducted and externally rotated, and the knee is flexed like frog legs in order to easily approach the POPA in the popliteal fossa and the PTA in the medial calf.

We start the examination by visualizing the CFA at the inguinal region in a transverse plane then the transducer is rotated 90° for longitudinal scanning. With B-mode, we

assess the arterial wall for intima thickness, any lumen irregularities and the atheromatous plaques, especially the densely calcified ones. Then CDU is applied with color box tilt parallel to the arterial axis and the color gain is set as high as possible without displaying background noise, the vessel is then assessed for its homogenous color filling and flow direction, visualizing the color flow at the stenotic segments, looking for aliasing or any possible collaterals. After that we apply spectral Doppler with Doppler angle between 50° and 60° to assess blood flow regarding direction, velocity, and acceleration. Lastly, we use BFI to display blood flow signal at the stenotic segments, especially at the densely calcified plaques that cause acoustic shadowing artifacts, visualizing the residual patent lumen that couldn't be viewed by CDU, allowing Doppler velocities to be sampled in regions that were otherwise obscured by the acoustic shadowing artifact. Possible collaterals are scanned by B-Flow mode as well, because they are much easier to be detected by this mode, thanks to its extended FOV and angle independency.

The examination is continued by moving a transducer distally along the SFA on the medial aspect of the leg, down till the POPA at the popliteal fossa. The arteries were

assessed by the same means as mentioned before using B-mode, CDU, Spectral Doppler and BFI.

As for the InfraPopliteal arteries, the PTA is examined from the ankle behind the medial malleolus and continued proximally along the medial aspect of the leg, and the ATA is examined from the ankle anterior to the talus neck and continued proximally, the transducer is traced from the anterior ankle to the dorsal foot as well to evaluate the DPA. All the InfraPopliteal arteries were examined by the same means as mentioned before using B-mode, CDU, Spectral Doppler and BFI.

Test results of CDU and BFI were first analyzed separately and each compared with the reference CTA. Results were interpreted by calculating sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV).

Equipment:

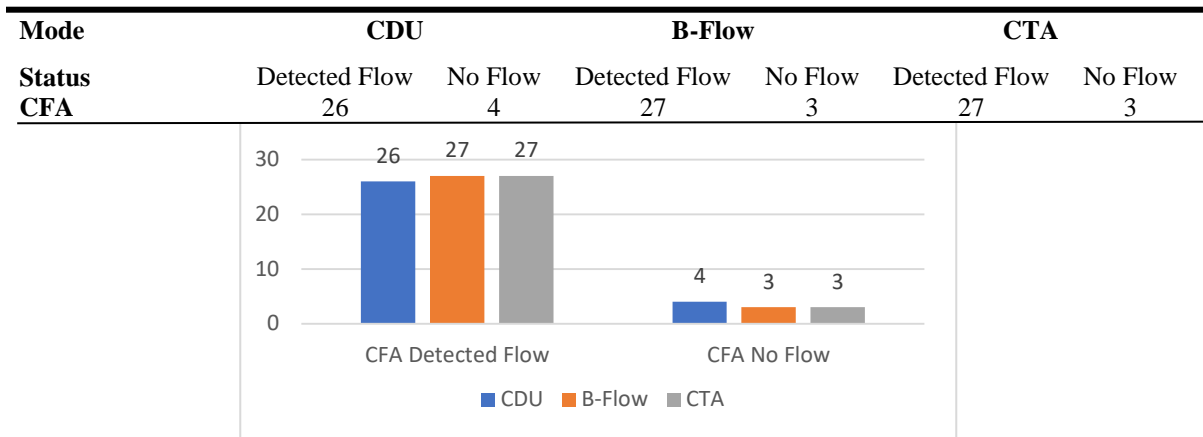
- Ultrasound was performed using LOGIQ S7 ultrasound system which supports B-flow and can combine real time B-mode imaging system with pulsed and continuous wave Doppler facilities together.
- CT was performed by using 16 channels MSCT helical, Toshiba.

Results

The study included 30 patients, 22 males and 8 females, all of them had densely calcified atheromatous plaques scattered along the arterial system with different degrees of stenosis. 330 different arterial segments were

examined by CDU with spectral analysis and BFI, and the results were compared to the gold standard CTA.

Table 1: The CFA results

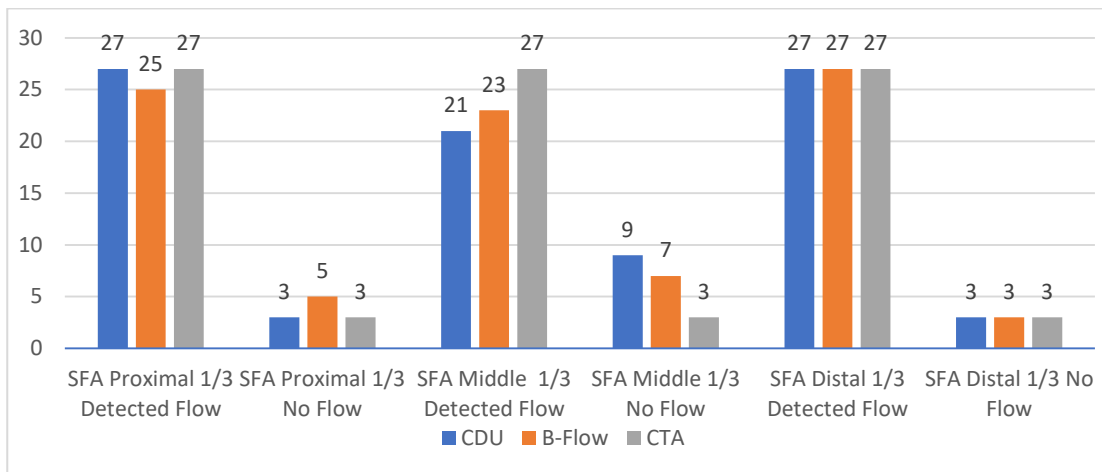


Graph 1. The CFA results

- The incidence of detected blood flow at the CFA was 86.6% by CDU and 90% by both BFI and CTA.
- The incidence of no flow at the CFA occlusion was 13.3% by CDU and 10% by both BFI and CTA.
- The sensitivity of CDU at the CFA in our study was 100%, the specificity was 96.3%, the positive predictive value was 75% and the negative predictive value was 100%.
- The sensitivity of BFI at the CFA in our study was 100%, the specificity was 100%, the positive predictive value was 100% and the negative predictive value was 100%.

Table 2. The results of the different segments of the SFA

Mode Status	CDU		B-Flow		CTA	
	Detected Flow	No Flow	Detected Flow	No Flow	Detected Flow	No Flow
SFA	27	3	25	5	27	3
SFA Proximal 1/3						
SFA	21	9	23	7	27	3
SFA Middle 1/3						
SFA	27	3	27	3	27	3
SFA Distal 1/3						

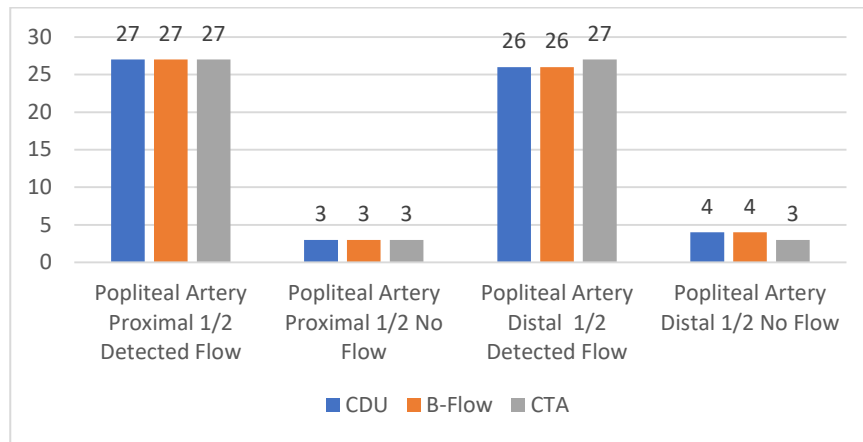


Graph 2. The results of the different segments of the SFA

- The incidence of detected flow at the SFA was 83.3% by both CDU and B-flow, while it was 90% by CTA.
- The incidence of no flow at the SFA was 16.6% by both CDU and B-flow, while it was 10% by CTA.
- The sensitivity of CDU at the SFA in our study was 100%, the specificity was 92.6%, the positive predictive value was 60% and the negative predictive value was 100%.
- The sensitivity of B-flow at the SFA in our study was 88.8%, the specificity was 91.3%, the positive predictive value was 53.3% and the negative predictive value was 98.6%.

Table 3. The results of the different segments of the Popliteal artery

Mode	CDU		B-Flow		CTA	
Status	Detected Flow	No Flow	Detected Flow	No Flow	Detected Flow	No Flow
Popliteal A. Proximal 1/2	27	3	27	3	27	3
Popliteal A. Distal 1/2	28	2	28	2	27	3

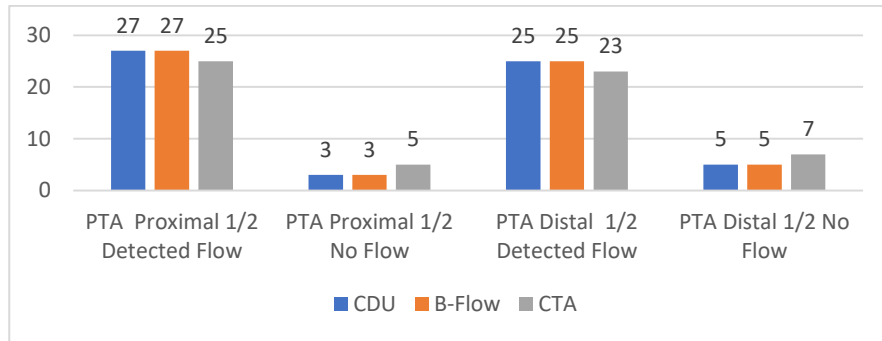


Graph 3. The Popliteal artery results

- The incidence of detected flow at the popliteal artery was 91.6% by both CDU and B-flow, while it was 90% by CTA.
- The incidence of no flow at the popliteal artery was 8.3% by both CDU and B-flow, while it was 10% by CTA.
- The sensitivity of CDU at the popliteal artery in our study was 83.3%, the specificity was 100%, the positive predictive value was 100% and the negative predictive value was 98.2%.
- The sensitivity of B-flow at the popliteal artery in our study was 83.3%, the specificity was 100%, the positive predictive value was 100% and the negative predictive value was 98.2%.

Table 4. The results of the different segments of the PTA

Mode	CDU		B-Flow		CTA	
	Detected Flow	No Flow	Detected Flow	No Flow	Detected Flow	No Flow
PTA Proximal 1/2	27	3	27	3	25	5
PTA Distal 1/2	25	5	25	5	23	7

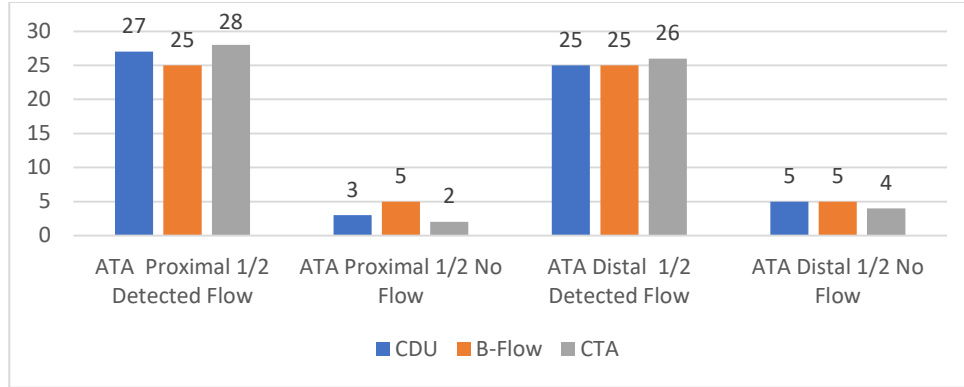


Graph 4. The results of the different segments of the PTA

- The incidence of detected flow at the PTA was 86.6% by both CDU & B-flow, while it was 80% by CTA.
- The incidence of no flow at the PTA was 13.3% by both CDU & B-flow, while it was 20% by CTA.
- The sensitivity of CDU at the PTA in our study was 58.3%, the specificity was 97.9%, the positive predictive value was 87.5% and the negative predictive value was 90.3%.
- The sensitivity of B-flow at the PTA in our study was 58.3%, the specificity was 97.9%, the positive predictive value was 87.5% and the negative predictive value was 90.3%.

Table 5. The results of the different segments of the ATA

Mode	CDU		B-Flow		CTA	
	Detected Flow	No Flow	Detected Flow	No Flow	Detected Flow	No Flow
ATA Proximal 1/2	27	3	25	5	28	2
ATA Distal 1/2	24	6	24	6	25	5

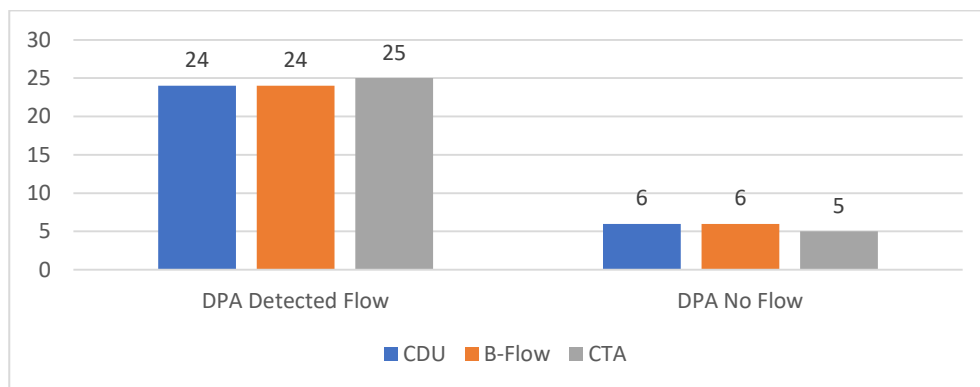


Graph 5. The results of the different segments of the ATA.

- The incidence of detected flow at the ATA was 85% by CDU, 81.6% by B-flow, while it was 88.3% by CTA.
- The incidence of no flow at the ATA was 15% by CDU, 18.3 % by B-flow, while it was 11.6% by CTA.
- The sensitivity of CDU at the ATA in our study was 85.7%, the specificity was 94.3%, the positive predictive value was 66.6% and the negative predictive value was 98%.
- The sensitivity of B-flow at the ATA in our study was 85.7%, the specificity was 90.5%, the positive predictive value was 54.5% and the negative predictive value was 97.9%.

Table 6. The results of the different segments of the DPA.

Mode	CDU		B-Flow		CTA	
Status	Detected Flow	No Flow	Detected Flow	No Flow	Detected Flow	No Flow
DPA	24	6	24	6	25	5



Graph 6. The results of the different segments of the DPA.

- The incidence of detected flow at the DPA was 80% by CDU & B-flow, while it was 83.3% by CTA.
- The incidence of no flow at the DPA was 20% by CDU & B-flow, while it was 16.6% by CTA.
- The sensitivity of CDU at the DPA in our study was 100%, the specificity was 96%, the positive predictive value was 83.3% and the negative predictive value was 100%.
- The sensitivity of B-flow at the DPA in our study was 100%, the specificity was 96%, the positive predictive value was 83.3% and the negative predictive value was 100%.

Discussion

Firstly, BFI examination does not require separate equipment and it can be performed

by using the same Doppler equipment which is advantageous in terms of time and cost.

As for our comparative study, BFI at the CFA showed better results than CDU. The densely calcified plaques cause posterior acoustic shadowing artifacts that obscure luminal details. However, this shadowing artefact was often less pronounced during BFI, allowing the visualization of a residual patent lumen that could not be seen using CDU alone; and as such, spectral Doppler could now be sampled in regions that were otherwise obscured (Figure 1). Moreover, visualizing the plaque surface was more satisfactory during BFI, because it has higher spatial resolution, and it is exempt from movement, blooming and aliasing artifacts; with a better chance to show excavations that might be associated with an increased risk of developing thromboembolic events (Figure 2) ⁶.

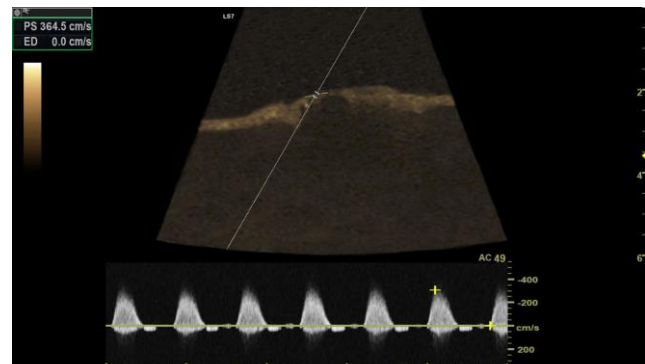
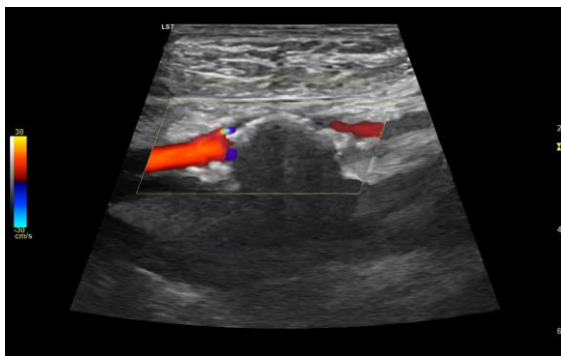


Figure 1: a) CDU showing a large dense plaque at the CFA obscuring blood flow with no residual lumen can be seen. b) BFI at the CFA showing the residual patent lumen. spectral Doppler can now be applied to regions that showed no flow by CDU.

At the different segments of SFA, BFI failed to detect any flow with markedly obese patients, as the boosted sent signals are scattered by the subcutaneous fat, beside that the arteries are deeply located. As for CDU, which has better penetration, detecting flow could be done (Figure 3). On the other hand, BFI showed higher discrimination than CDU in presence of densely calcified plaques with regular patients, despite not being completely free of its acoustic shadowing effects. In some cases, no flow could be visualized within the SFA using either mode, although CTA proved their patency.

At the different segments of popliteal artery. Both CDU and BFI displayed similar results. A collateral artery feeding the TPT was mistaken for the main popliteal artery.

At the PTA segments, both modes displayed similar results. A congenital absence and a thrombosed PTA, replaced by collateral

branches, were mistaken for a patent PTA. Both modes as well failed to detect flow in some cases at the distal segments with densely calcified plaques, although CTA proved their patency.

At the proximal half of ATA, CDU showed better results than BFI in detecting flow in presence of remarkable subcutaneous edema, as BFI has poor penetration; however, it was easier in regular patients to detect sites of collaterals take off by BFI, thanks to its angle independency and the extended FOV (Figures 4 & 5). At the distal half of ATA, both modes displayed similar results, a densely calcified artery with low flow was mistaken to be thrombosed, proved to be patent by CTA.

At the DPA, both modes displayed similar results. a densely calcified artery with low flow was mistaken to be thrombosed, proved to be patent by CTA as well.

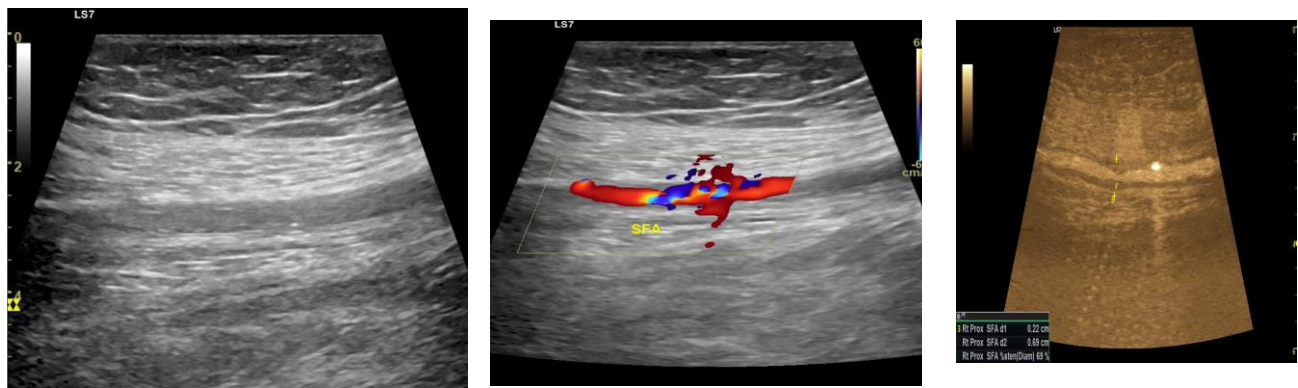


Figure 2: a) B-mode of the SFA with no clear demarcation between the soft plaque and the preserved lumen. b) CDU showing aliasing denoting the presence of a stenosis. c) B-flow examination with preservation of background echoes the stenotic segment can be clearly identified from the blood flow column.

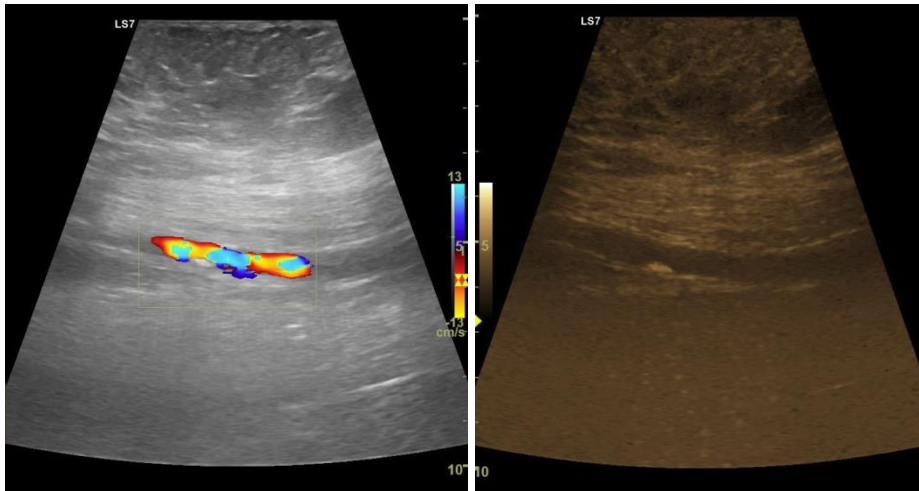


Figure 3: a) CDU in a markedly obese patient showing a small dense plaque at the proximal segment of the right SFA with no aliasing can be seen. b) B-Flow mode with preservation of background echoes showing a small plaque. No flow can be seen however.

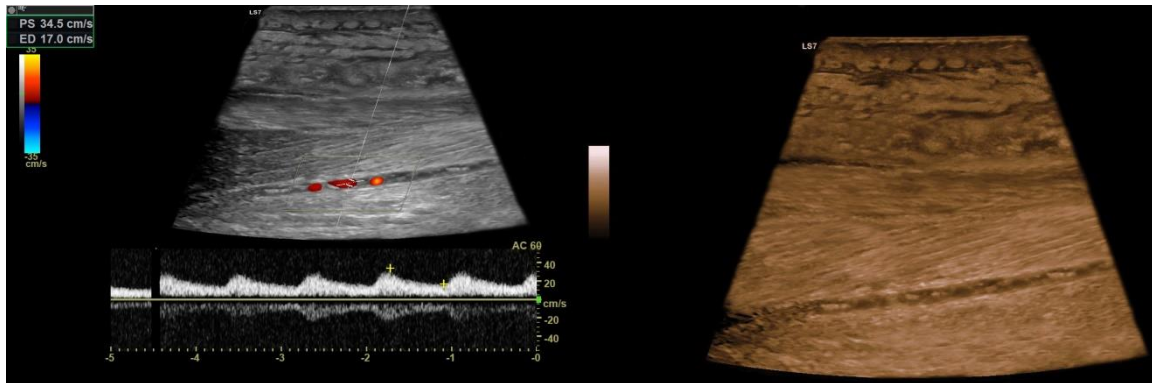


Figure 4: a) CDU with spectral Doppler in a patient with prominent subcutaneous edema and densely calcified ATA showing beaded color flow and tardus parvus waveform. b) B-Flow mode with preservation of background echoes; however, no blood flow can be seen

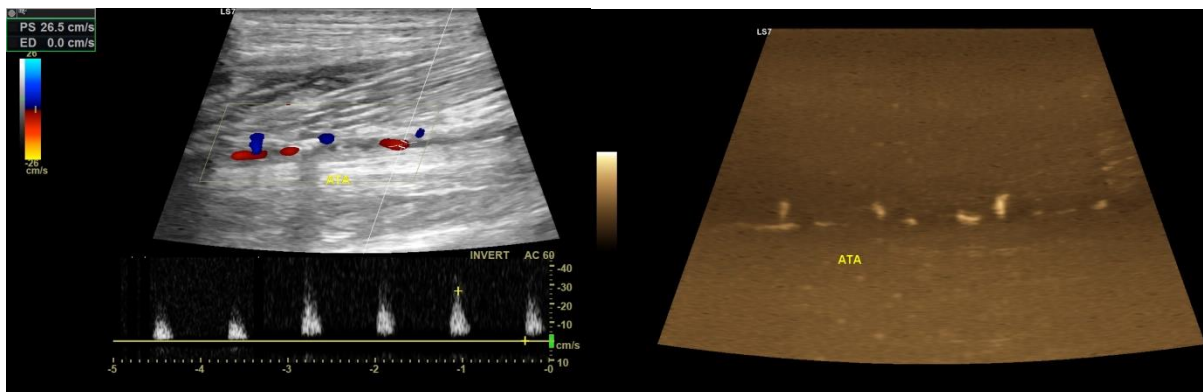


Figure 5: a) CDU of the ATA showing beaded color flow and a single collateral artery can be visualized within the color box. b) BFI displays multiple defects within the blood flow column and multiple collaterals can be seen at the same time

Generally speaking, BFI introduced additional features promoting the non-invasive methods of diagnosing PAD. It has higher discrimination in presence of densely calcified plaques, better in detecting sites of collaterals take-off, and better in visualizing

the plaque surface. However, it is not free from limitations like extensive plaque calcification, depth and edema (Table 7).

Table 7. Brief comparison of different imaging modes (Rating 1-3, 1 is least and 3 is most desirable) ⁶

Color Display of Flow Direction	Yes	No
Display Flow Velocity	Yes	No
Aliasing	Yes	No
Region of Interest	Yes	No (extended FOV)
Spatial Resolution	1	3
Hemodynamics	1	3
Presence of Color Overwrite	1	3
Flow Angle Dependence	1	3
Background Image Quality	3	2
Penetration	3	1

Concordant results of CDU at the Femoro-Popliteal segments show better sensitivity, slightly better specificity, much lower PPV and higher NPV. Concerning the infraPopliteal segments, the concordant results show similar sensitivity, slightly higher specificity & PPV, and a much higher NPV. Unfortunately, BFI lacks similar studies and no comparative data could be found.

Finally, this study included a low number of cases, and the lacks of other comparative

studies represent other further limitations. Therefore, more prospective comparative studies with gold standard imaging modalities are required to clarify the sensitivity and specificity of B-Flow in study of PAD.

Conclusion

At the femoral segments, BFI has higher diagnostic accuracy than CDU in presence of densely calcified plaques. As for the infrapopliteal segments, CDU displayed better results; however, BFI was better in

detecting sites of collaterals take off. Unfortunately, BFI is not free of limitations like depth and subcutaneous edema. As such, we do not encourage the use of B-Flow as a sole ultrasound imaging mode, but as a complementary technique to use in situations where CDU findings are inconclusive or unclear, providing better diagnostic accuracy than either method alone.

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