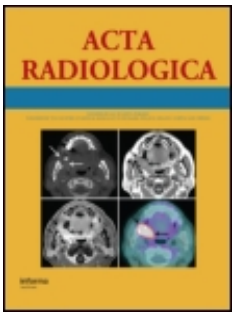

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Review Article

COLOR DOPPLER US FINDINGS IN THE DIAGNOSIS OF ARTERIAL OCCLUSIVE DISEASE OF THE LOWER LIMB

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Abstract

Peripheral arterial occlusive disease (PAOD) of the lower limb is a widely spread disease at the present time. After clinical examination, which includes a comprehensive history of the patient, different imaging modalities are competitive in the exact assessment of PAOD. Besides digital subtraction angiography and MR -angiography, color Doppler US is an established imaging modality in the diagnosis of PAOD.

This article illustrates the typical color Doppler US findings in PAOD of the lower limb. Duplex images of normal and pathological findings are presented, and the limitations of the method are pointed out. Color Doppler US examination strategies in patients suffering of PAOD are outlined.

Key words: Peripheral arterial occlusive disease; ultrasound, Doppler studies.

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Atherosclerosis is the leading cause of peripheral arterial occlusive disease (PAOD) in patients over 40 years of age. Risk factors for PAOD are diabetes mellitus, nicotine abuse, hypertension, hyperlipoproteinemia, hypercholesterolemia and age. The disease is mainly characterized by pain, numbness and cramp, which occurs during exercise and is relieved by rest – intermittent claudication (11). In patients with severe PAOD, rest pain is persistent. The clinical manifestations are determined by the degree of arterial narrowing, the rate of development of the obstruction, the extent of collateral circulation, the location of the arterial obstruction, and the presence of coexisting disease. There are several signs of PAOD in the affected extremities: absent or diminished dorsalis pedis pulse, coolness and/or paleness, rubor of the skin and trophic lesions. In the end, severe ischemia results in ulceration. The Fontaine classification is an accepted system for clinical evaluation of PAOD (Table).

Over many years invasive angiography has been the gold standard in diagnostic imaging of PAOD. The technique has changed from conventional film-screen angiography to digital subtraction angiography (DSA). Additional improvements such as pulsed fluoroscopy, roadmapping for interventional procedures and the newly developed step translation DSA led to a decrease in radiation exposure, amounts of contrast medium used and a reduction of examination time (4).

After assessment of physical findings, an objective evaluation of the severity of the disease should be obtained by non-invasive imaging techniques, of which color Doppler US plays an important role, especially considering the cost-effectiveness (16).

Table

Fontaine classification system of peripheral arterial occlusive disease (PAOD)

Stage	History
I	asymptomatic
IIa	mild claudication, walking distance >200 meters
IIb	moderate to severe claudication, walking distance <200 meters
III	ischemic rest pain
IV	tissue loss or ulceration

Compared to DSA, color Doppler US has an overall sensitivity in the detection of stenoses and occlusions of 92%, for the femoral arteries 95% and femoropopliteal region 100%. Slightly lower sensitivities have been reported for the iliac region (89%), and the run-off vessels of the lower limb (82%) (1, 2). Other authors report similar sensitivities (93.5%) both for significant and non-significant stenoses, with overestimations in 7% and underestimations in 5% of stenoses (13).

In recent years, non-invasive imaging of peripheral arteries by MR angiography (MRA) has increased in clinical practice and plays a more important role than formerly (9, 20). Contrast-enhanced MRA has a sensitivity of 94% for substantial stenoses (>50%) and an overall sensitivity of 91% (18).

During the past few years the performance of US imaging systems has improved considerably. Most notably, the advances in Doppler technique have added the possibility that this non-invasive imaging method could be the primary modality in examination of vascular diseases in peripheral vessels. The developments include color flow imaging (6), which facilitates rapid assessment of blood flow in peripheral arteries, and of duplex US (3), which allows accurate localization and quantification of PAOD. The combination of these techniques, named **color duplex US,** has in clinical practice greatly broadened scanning by integrating functional and anatomical data.

Color duplex US already plays an important clinical role in determining the degree of arterial stenosis (10, 16). As in all other cross-sectional modalities, one main problem of color duplex US in peripheral arteries is to demonstrate the complete vascular tree (e.g., from the abdominal aorta distal to the renal vessels to the ankle of both legs). However, keeping this potential limitation in mind, color duplex US has known advantages, such as widespread availability, possibility of bedside examination and simultaneous evaluation of morphology and function. Moreover, the lack of radiation exposure enables repetition as often as required. Due to these advantages, color duplex US is a valuable tool in detection of PAOD and in planning further therapy. This article illustrates the current clinical applications and points out future perspectives for US in the assessment of PAOD.

Doppler techniques

Pulse-wave Doppler US/duplex US: The Doppler technique is based on the frequency shift of insonated ultrasonic echoes. Echoes, which return to the transducer from stationary structures, come back with the same frequency, whereas echoes from moving objects (e.g., blood cells) towards or away from the transducer, return with a higher or lower frequency, i.e., **Doppler effect**. The scanner detects any change in frequency, and can calculate the actual speed of the target provided the angle between the direction of the ultrasonic beam and the direction of the object movement is known. Pulse Wave Doppler US provides information about the depth of the tissue, from where the echo originates. The combination of gray-scale US and **pulse wave** Doppler technique is **called duplex US.**

Color Doppler US: Color Doppler US uses multiple gates to produce flow information from different depths simultaneously. This is then superimposed on the B-mode US image. Color Doppler US assigns a single representative number (usually the mean Doppler frequency shift) to each site, which is then represented as different color saturations (different colors show flow direction and magnitude of blood velocity). The absence of flow is coded black.

Color duplex US/triplex mode: Color duplex US combines duplex and color Doppler US. Color duplex US should be the current technical state-of-the-art in US devices used for vascular imaging studies. The simultaneous color flow imaging superimposed on a gray-scale B-mode US image combined with the Doppler frequency velocity waveform profile on the US screen is also named **triplex mode.**

Power Doppler US: The limitations of color Doppler US include angle dependence and difficulty in displaying low-volume and low-velocity blood flow. In an attempt to address these limitations, an additional color flow imaging technique termed **power Doppler US** has been developed in which color encodes the integrated energy – power – of the Doppler signal instead of its mean Doppler frequency shift (17). The blood flow is also visualized in superimposition on the B-mode image in real-time.

US examination technique in PAOD patients: For vascular scanning a linear-array probe with 5–10 MHz is recommended. The iliac region and the aorta are examined using a 3.5–5 MHz sector probe.

The color Doppler US examination comprises both functional and morphological data. The examination should start with a functional test, the ankle/brachial index (ABI). The ratio of ankle to

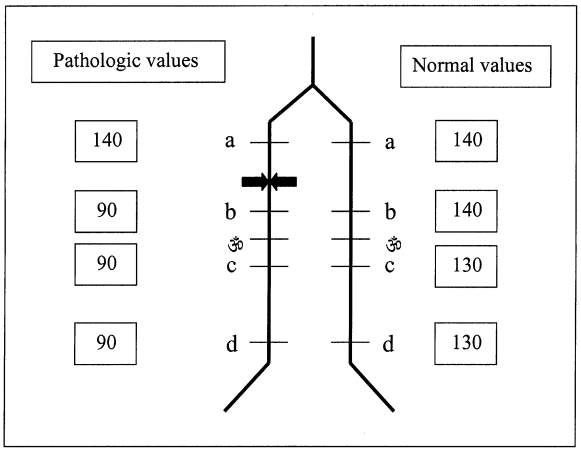

Fig. 1. Schematic drawing of the arteries of the lower extremity. Ankle/brachial index (ABI) of systolic blood pressure (mmHg), sites of measurements (a: proximal upper leg, b: distal upper leg, c: proximal lower leg, d: distal lower leg; ॐ:knee joint); on the right side normal pressures, on the left pathologic ABI with an occlusion in the superficial femoral artery, seen in a decrease of blood pressure between proximal and distal upper leg.

the periphery as a sign of proximal stenoses or occlusions. Additional sites for segmental measurement are the proximal lower leg followed by distal and proximal upper leg (Fig. 1). The use of different cuff sizes in order to adjust for the varying diameter of the extremity is mandatory. Contraindications for measuring the blood pressure of the leg are ulcerations of the skin, surgical bypass or vascular segments after percutaneous transarterial angioplasty (PTA) or stent implantation. In diabetic patients with media sclerosis, calcified vessel walls lead to a diminished compressibility and thus to elevated ankle pressure, so that the ABI may be misleading. Normal ABI, spectrum and waveform of the distal posterior and anterior tibial artery exclude hemodynamic relevant stenosis requiring therapy.

In the absence of normal findings or in case of suspected media sclerosis, further examination must be carried out by evaluating the vessels from the aorta to the vessels of the lower leg. The transducer

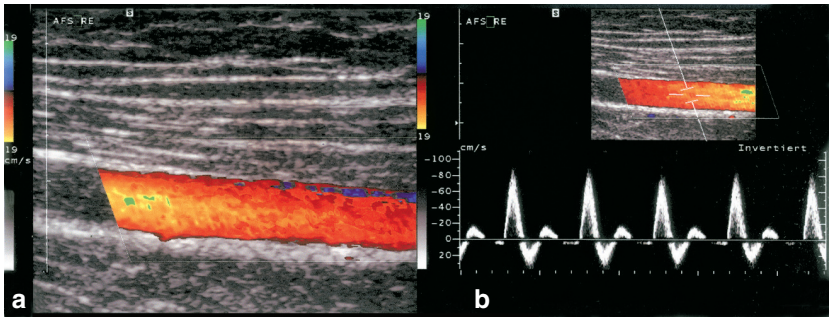

Fig. 2. Normal superficial femoral artery. a) Color Doppler US shows a laminar flow without turbulences. b) Triplex mode reveals triphasic normal spectrum with a systolic peak velocity of 90 cm/s, a short diastolic reflux followed by an end-diastolic forward flow.

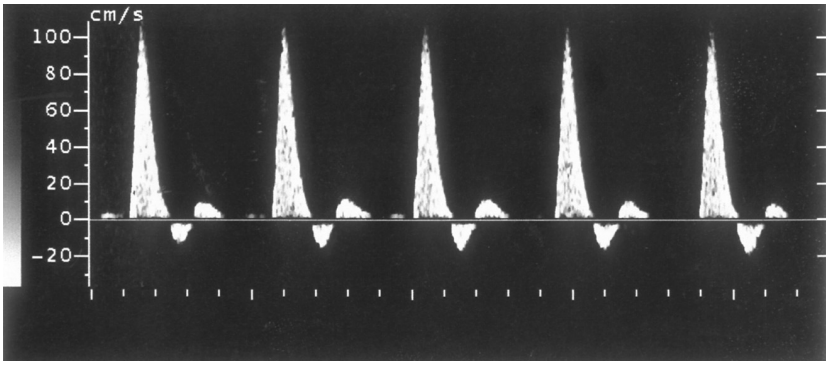

Fig. 3. Normal triphasic spectrum of the anterior tibial artery, peak velocity 100 cm/s, steep incline of the velocity slope.

brachial systolic arterial blood pressure is normally greater than 1.0 and ratios below 0.9 are considered abnormal (11). For this test the blood pressure is determined over the brachial artery and then over the ankle of the lower leg. In the latter case, the US probe is positioned over the anterior and posterior tibial arteries. The blood pressure at which color signals appear when the cuff is deflated is the systolic blood pressure. The diastolic blood pressure is not measured. At the same time the waveform of the spectrum gives information about the perfusion of

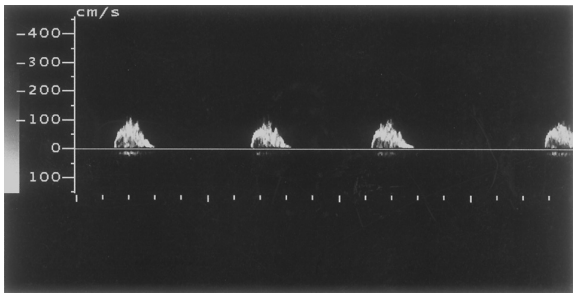

Fig. 4. Pathologic, monophasic poststenotic broadened spectrum with a less steep systolic rise, no diastolic retrograde flow.

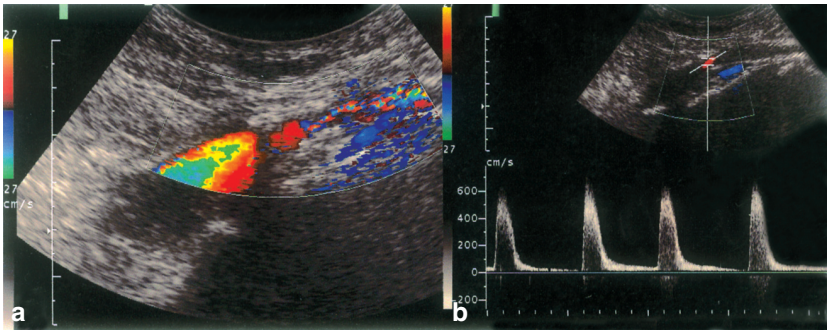

Fig. 5. High-grade stenosis of the external iliac artery. a) Color Doppler US: color aliasing in the iliac artery, turbulences and a mixture of colors are seen in high-grade stenosis. b) Triplex mode: the highest peak velocity is detected at the site of maximal lumen narrowing.

is placed on the vessels in the longitudinal plane, which is used routinely to examine all peripheral arteries; however, the transversal plane is needed in case of excentric stenosis. Primarily, the examination is performed in color Doppler US. In each vascular segment as well as in regions with turbulence, triplex mode is recommended (Fig. 2).

Color duplex US findings in PAOD

Stenosis: The normal wave form of the arterial spectrum is bi- or triphasic (Fig. 3). Tri- or biphasic spectra with a peak systolic velocity between 90 and 140 cm/s can be observed. A monophasic spectrum indicates a proximal stenosis or occlusion (Fig. 4). Different classification schemes for evaluating peripheral stenosis have been developed. The criteria include peak systolic velocity (12, 14), description of the waveform of the spectrum as well as reduction of vessel diameter (7, 8). The spectral changes in stenosis with increase of velocity are highest at the point of maximal lumen reduction (Figs 5–7). Increase of the peak systolic velocity as well as turbulence indicate a hemodynamic relevant stenosis. A 50% stenosis yields a fourfold increase of velocity. Two stenotic lesions in series (tandem stenosis) may be additive with respect to hemodynamic relevance.

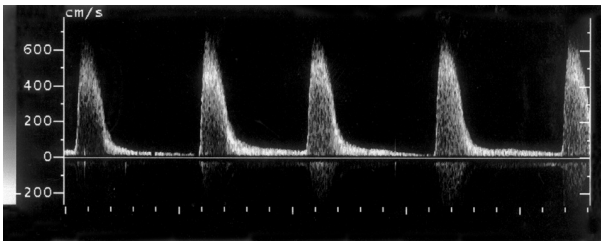

Fig. 6. High-grade stenosis of the external iliac artery: the spectrum shows a peak systolic velocity of 600 cm/s, representing a stenosis with 80–90% reduction of the lumen. The diastolic reflux is missing.

Occlusion: Complete occlusion shows an absence of color signals even with scanning parameters able to depict low blood flow. The typical preocclusive spectrum shows high peripheral resistance with narrow, small systolic peak and absence of diastolic flow (Fig. 8). Collateral vessels (Fig. 9) as well as the level of re-entrance in case of distal perfusion can be localized. The postocclusive spectrum is characterized by a monophasic waveform with reduced and

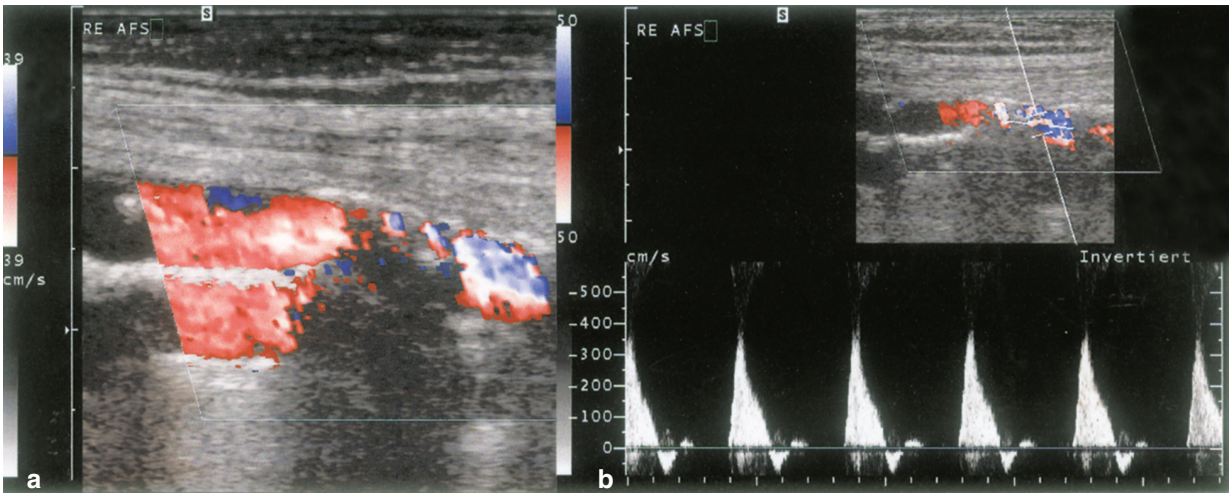

Fig. 7. High-grade stenosis of the superficial femoral artery. a) Narrowing of the lumen is seen in color Doppler mode as well as color aliasing and turbulence. b) An increase of the peak systolic velocity to 350 cm/s representing a high-grade stenosis is shown in triplex mode.

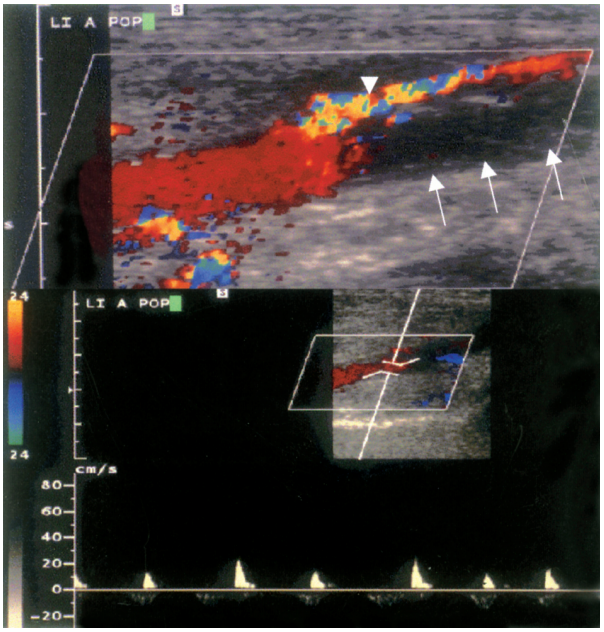

Fig. 8. Acute occlusion of the popliteal artery. a) The occlusion is depicted by missing color signals in the vessel (arrows), above the occlusion a collateral vessel branches off showing color aliasing (arrowhead). b) The triplex mode demonstrates a preocclusive spectrum with narrow peak, a low peak systolic velocity and a missing diastolic forward flow, indicating an abnormal high peripheral resistance.

lower rising systolic peak velocity. A special form is the embolic occlusion that can be suspected if a convex shaped flow void is found typically above the vessel bifurcation (Fig. 10).

Plaque morphology: Plaque characterization in peripheral arteries can help to predict the initial success of PTA. Increasing echodensity of plaques shows a correlation to restenosis after PTA (15). Hypoechogenic plaques may arise in intimal hyperplasia after PTA (Fig. 11). Calcified plaques may lead to difficulty in visualizing the lumen. An examination from another scanning window should be tried in cases of excentric calcified plaques. If a direct visualization is not possible, the poststenotic area can yield information in terms of turbulence or increased velocity (Fig. 12). Evaluation of plaque morphology can be improved by using **tissue harmonic imaging (THI)** which brings about better delineation of the vessel wall and plaque morphology (Fig. 13).

Aneurysm: The increase in diameter produces a reduction of velocity requiring a setting for low blood flow. Thrombosed parts of an aneurysm can be easily visualized in color or power Doppler US (Fig. 14). Pseudoaneurysms, most often of iatrogenic origin, e.g., formed at angiography, are easily

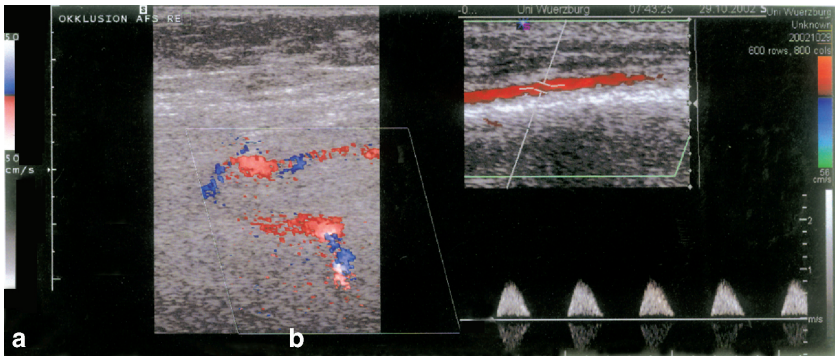

Fig. 9. Occlusion of the superficial femoral artery. a) Collateral vessels in the color Doppler US can be traced from the original superficial artery to the popliteal artery. b) Post-occlusive spectrum in the popliteal artery with low peak systolic velocity, a broadened systolic peak and a monophasic waveform of the spectrum and low diastolic forward flow.

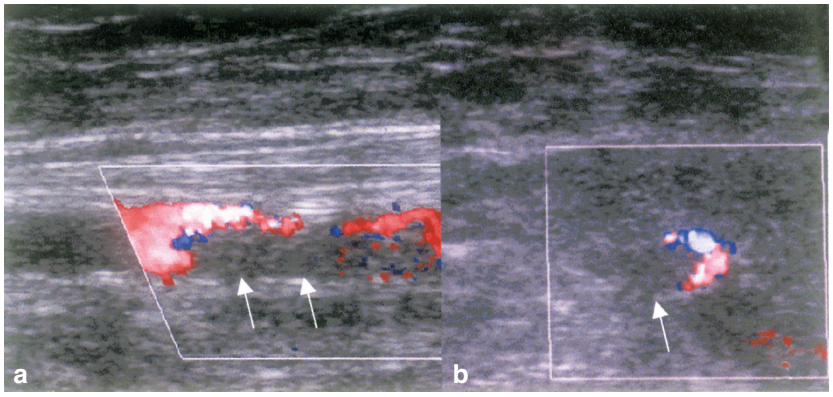

Fig. 10. Embolus in color Doppler US: flow void (arrows) with a rounded shape in the longitudinal (a) and in transversal (b) planes. Typical location of an embolus is usually above a bifurcation.

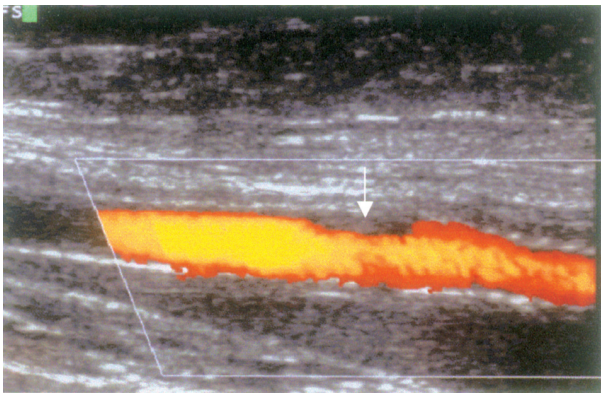

Fig. 11. Intimal hyperplasia (arrow) with low echogenicity after stent implantation in the superficial femoral artery (power Doppler US).

diagnosed by color Doppler US. In pseudoaneurysms, the communicating neck with a flow to and from the aneurysm can be noted. US provides the option for closing pseudoaneurysms by compression therapy (Fig. 15) (19).

Posttherapeutic findings in PAOD: Color Doppler US is a useful tool in follow-up of patients with PAOD after therapy. Occlusions of a bypass graft can be easily detected (Fig. 16). Complications of interventional angiography such as dissection (Fig. 17) or arteriovenous fistulas can be sensitively diagnosed using color Doppler US. In B-mode US a dissection membrane may be seen as a linear echogenic web. Arteriovenous fistulas present with a burst of color and a bandlike spectrum (Fig. 18).

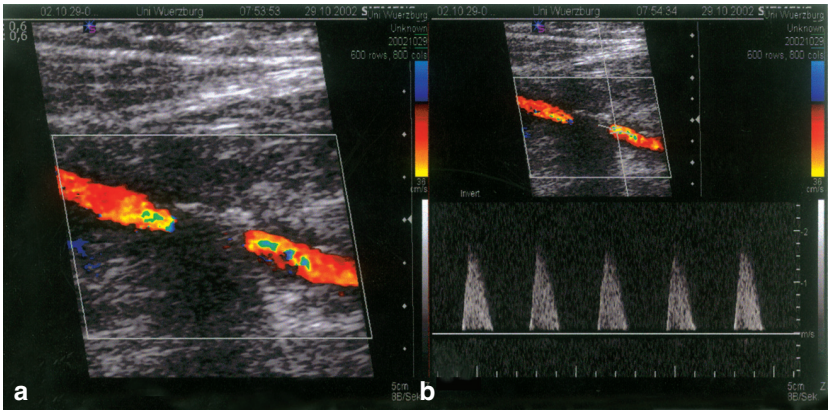

Fig. 12. Calcified plaque in the superficial femoral artery. No visualization of the lumen behind the calcified plaque area due to acoustic shadowing (a). Turbulence and increase of peak systolic velocity to 180 cm/s indicate a moderate stenosis (b).

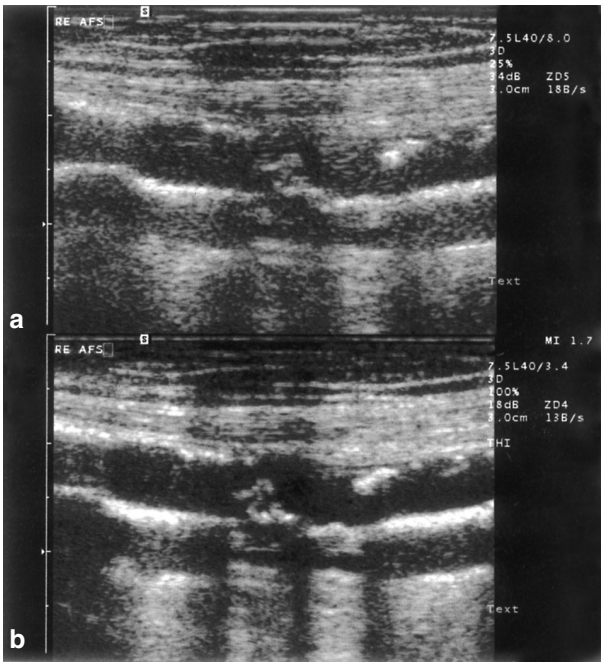

Fig. 13. Echogenic plaques in the superficial femoral artery without (a) and with (b) tissue harmonic imaging (THI) – better delineation of plaque morphology with THI.

To localize the origin of the arteriovenous fistula, proximal compression diminishing the turbulence by reducing the blood flow is often helpful.

Pitfalls: An underestimation of stenosis occurs in tandem stenoses. The second stenosis has a reduced peak velocity and reduced turbulence. Fully developed collateralization can hide a proximal stenosis or an occlusion by not showing pathologic spectra in the

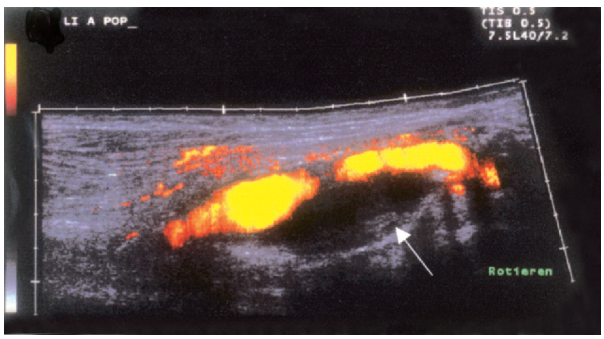

Fig. 14. Extended field-of-view in power Doppler US: partially thrombosed aneurysm of the popliteal artery. The arrow marks the thrombosed part of the aneurysm, extended field-of-view US in power Doppler US enables a better morphological overview.

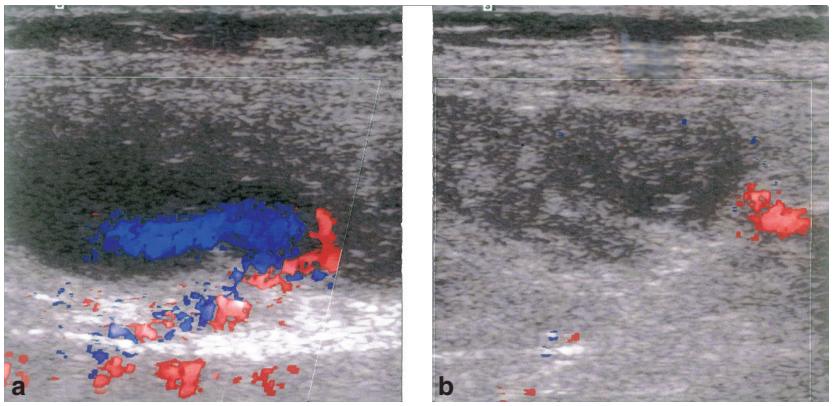

Fig. 15. Pseudoaneurysm of the common femoral artery. Pre- (a) and post (b) US compression therapy. The pseudoaneurysm demonstrates a systolic inflow and a diastolic outflow. After successful US compression therapy, no color signals are detected within the pseudoaneurysm.

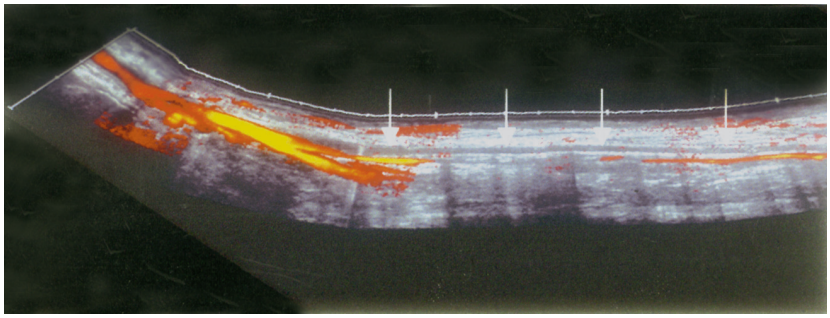

Fig. 16. Occlusion of a bypass graft (arrows) in extended field-of-view in power Doppler US can provide the morphological information for therapy planning.

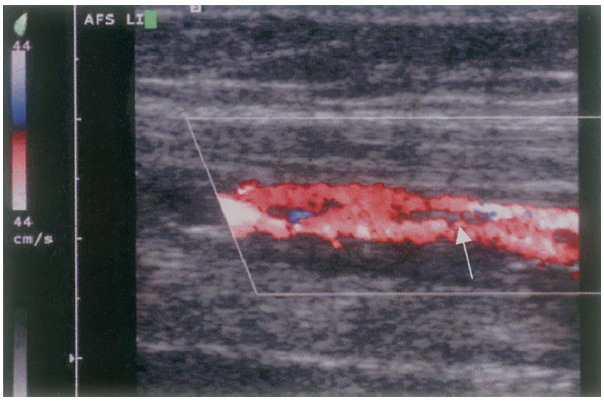

Fig. 17. A dissection is detected as a linear flow void (arrow) in color Doppler US.

distal portions. Another pitfall might be to differentiate between stenosis and occlusion, missing minimal flow if the examination is carried out using only parameters detecting high blood velocity. Further cause of error is an incorrect Doppler angle. Exact positioning of the Doppler angle is needed in order to accurately measure peak systolic velocity.

Conclusion

Many radiologists have some concerns regarding the use of color Doppler US, as the results are dependent on the experience of the sonographer. As radiologists we are involved in all fields of vascular imaging and interventional procedures, and color Doppler US should be part of them. Color

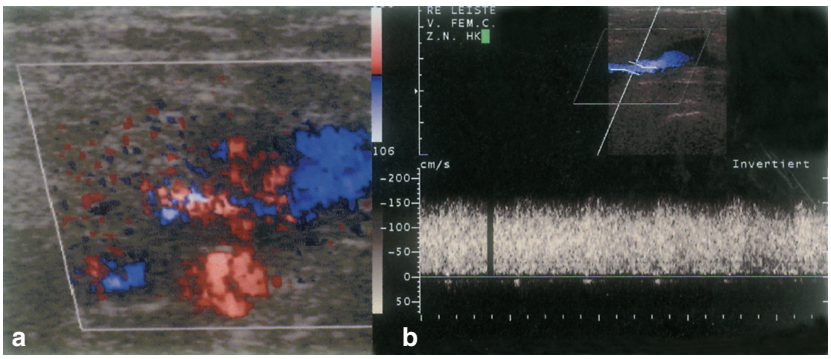

Fig. 18. An arteriovenous fistula after angiography presents with a burst of color in color Doppler US (a), a bandlike spectrum is depicted in the fistula (b).

Doppler US is a non-invasive imaging technique useful for screening for PAOD, as it combines morphologic and functional data in the vascular system. The widespread availability enables the use of color Doppler US not only for primary diagnosis of PAOD, but also for therapeutic guidance and follow-up after therapy.

Future perspectives

Developments in US such as extended field-of-view US in combination with power Doppler US and 3D US might bring improvements in the diagnosis of PAOD (17). US contrast agents can produce an increase in Doppler signal intensity, which may lead to a better delineation of iliac arteries as well as collateral vascularity or peripheral small vessels (5, 21). With the development of contrast agents with prolonged enhancement of Doppler signals by extending the stability of microbubbles, vascular diagnosis might even be improved further. Another new technique for detection of blood flow is the "B-(brightness)-flow"-mode (22), demonstrating a better spatial resolution than color Doppler US (1). Whether this method, especially in combination with superimposed color scale (color-coded B-flow), will be successfully integrated in US strategies of the peripheral arteries in patients with PAOD cannot be estimated at the present time. Despite the advances in cross-sectional imaging, because of both morphology and functional evaluation, US will still maintain its primary role as the initial diagnostic modality for patients with PAOD.

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