Practical Arterial Evaluation of the Lower Extremity

Abstract

Sonographic examination of the lower extremity arterial system can be time-consuming and arduous if performed in its entirety on every patient that is referred to the Vascular Ultrasound Laboratory. In fact, most patients can benefit from a tailored non-invasive arterial examination that integrates clinical, physiological and imaging/Doppler modalities in answering the referring physician's questions. This paper provides an algorithm for assessing the type and level of information needed for most patients arriving in the ultrasound suite with known or suspected peripheral arterial disease.

Abbreviations used in this text	
AK	Above the knee
ABI	Ankle brachial index
BK	Below the knee
CDI	Color Doppler imaging
CFA	Common femoral artery
DP	Dorsalis pedis artery
LM	Lateral malleolar artery
PAD	Peripheral arterial disease
prn	As needed, as required
PSV	Peak systolic Doppler velocity
PT	Posterior tibial artery
q	Every (ex q3mon – every three months
SBP	Segmental blood pressures
SFA	Superficial femoral artery

Clinical Assessment

Patient history pertinent to referral

Medical History

By obtaining a limited medical history from a patient, pertinent to the lower extremity complaints, the examiner is attempting to identify risk factors, disease states and vascular history commonly associated with arterial, venous or comorbid (non-vascular) pathology. For example, there is a higher probability of ultimately diagnosing arterial disease in a diabetic, hypertensive patient presenting with post-exercise calf pain than in a patient with a history of ligation and stripping of varicose veins. Table I lists common factors and conditions frequently associated with vascular disease in the legs.[1]

Table I
Common conditions associated with peripheral vascular disease

Arterial	Venous
Hypertension	Past history of DVT
Diabetes mellitus	Recent pelvic surgery
Coronary artery disease	Recent orthopedic surgery
Cigarette smoking	Pelvic radiation therapy
Transient ischemic attacks	Leg trauma
Previous angiography	Status post pregnancy
Previous vascular intervention	Varicose veins
Family history CV disease	Previous vein stripping
	On oral anticoagulants (Coumadin)

Symptomatology

Prior to beginning the examination, the practitioner should take a few minutes to sit with the patient and discuss his/her medical history and the perceived reason for the testing that has been ordered. In the patient with a long history of vascular disease, he/she may be able to offer a sophisticated status of his/her disease along with a detailed history of any surgical, medical or interventional techniques employed in the past. In most patients, however, the perceived reason for their presence in the laboratory is simply "leg pain".

The specific type of pain provides strong clues to the nature of the underlying disease state and, therefore, it is imperative to elicit as much descriptive information from the patient as possible. Since most patients presenting to the vascular laboratory are seniors and may have comorbidity, which compromises their ability to communicate adequately, they may require assistance in characterizing and describing the type of pain. Patience on the part of the examiner is essential as is the ability to actively listen to the patient. If the patient's first attempt to describe the pain fails to provide enough specific clinical information, the examiner should attempt to acquire this information by ascertaining the following characteristics of the pain:

Intermittent pain especially associated with walking or other exercise is a classic symptom of lower extremity ischemia and is referred to as intermittent claudication.[2] Patients frequently characterize claudication as a sharp, crampy or "Charlie-horse" type of pain that occurs after walking, climbing stairs or engaging in other leg exercises. They may state that their legs feel tired or heavy after exertion. Typically the patient will state that he/she can walk a given distance and then, quite predictably, the pain will begin in the same part of the leg or legs. After stopping and resting for a few minutes, the pain subsides and they are able to continue walking the same distance before the pain resurfaces.

- ***Claudication***: Muscular discomfort of the calf, thigh, hip, or buttock with ambulation. Patients describe a cramping, aching, or pain in the muscles of their legs that is relieved by stopping the walking/exercise, and standing or sitting for 2 to 5 minutes.
- ***Rest pain***: Critical ischemia of the distal limb when the patient is at rest. Patients usually complain of pain in their toes or feet when they are lying down. The pain often awakens a patient that is sleeping, and the patient may find relief by sitting with the affected limb in the dependent position.

Sudden onset of severe leg pain, particularly in a patient with a known history of peripheral arterial disease or in a diabetic is typical of acute occlusion of a leg artery. Most commonly, acute occlusions are the result of atherosclerotic emboli or thrombotic embolus in patients who have undergone arterial diagnosis and/or intervention involving the femoral artery. It is imperative that acute occlusions be diagnosed emergently as the peripheral nerves and muscles suffer irreversible damage after 4-6 hours of severe ischemia.[3] Acute occlusions can easily be differentiated from chronic arterial or acute venous pathology in the lower extremity. In addition to the sudden onset of severe pain, the leg exhibits the classical symptoms of acute ischemia. See Table II. [4]

Table II
The 5 “P’s” of acute occlusion

Pain: sudden onset
Pallor
Paresthesias (numbness)
Pulselessness
Paralysis (sudden weakness)

Physical examination of legs

Visual inspection

The gross appearance of the patient's legs offers important information helpful in differentiating vascular versus non-vascular and arterial versus venous pathology as the cause of leg pain or other vascular symptoms.

Chronic arterial insufficiency diminishes perfusion to tissue and, over time, produces ischemic changes in the lower extremity. These changes, which include alteration in color, trophic changes and changes in temperature may vary from patient to patient and worsen with increasing severity. The color of the feet may appear normal in early stages of the disease. In more advanced states, the toes and/or feet appear red and thin-skinned. In the presence of severe disease, there may be pallor, patchy duskiness or, in the presence of a recent acute occlusion of one of the smaller arteries in the foot, cyanosis.

Postural color changes also indicate the presence of significant arterial insufficiency. Abnormal pallor on elevation and rubor on dependency with a delay in return of color on sudden dependency are pathognomonic of arterial occlusive disease, particularly if the two feet differ.[5] In assessing the severity of arterial disease with postural color changes, the feet are elevated for two minutes and then placed suddenly in a dependent position. If normal color does not return by fifteen seconds, a moderate degree of arterial insufficiency is present; a delay of thirty seconds indicates marked insufficiency; and a delay of sixty seconds or longer indicates extreme disease.[6]

Table III
Postural color changes

1. Elevate feet above head for 2 minutes 2. Place feet suddenly in dependent position	
Normal color return	
< 15 secs	Normal
15 – 30 secs	Moderate arterial insufficiency
30 – 60 secs	Marked arterial insufficiency
> 60 secs	Extreme disease

Trophic changes include scarring and shrinkage of the digits, ulcerations and gangrene. Ulcerations resulting from arterial disease typically are small and focal and occur in the distal toes, on the heel or sole of the foot or in a nail bed following infection. They may, however, present as more extensive lesions particularly in diabetics. Gangrene usually first appears in a toe as a focal, blackened area. Without treatment, it may spread to involve an entire toe, several toes, and entire foot and in extreme cases, the lower leg. Other ischemic changes associated with trophic changes include muscle atrophy, thin, scaly skin, loss of hair and thick toenails.[7]

A decrease in skin temperature can often be detected on simple palpation of the toes and foot in an affected limb. This finding is much more significant if there is a palpable difference in temperature between the two feet than if both feet are equally cold. Sudden decrease in temperature of a foot along with pallor is suggestive of an acute occlusive event.[8 9] Table IV summarizes the signs and symptoms of atherosclerosis obliterans in the lower extremity.[10]

Table IV
Signs and symptoms of LE atherosclerotic disease

Intermittent claudication
Cold feet
Rest pain (at night)
Rest pain with dependency
Absent pulses
Blanching on elevation
Dependent rubor
Atrophy of subcutaneous fat
Shiny skin
Loss of hair on foot and toes
Thickened nails
Gangrene

Palpation of pulses

Palpation of leg pulses offers invaluable clinical information about the status of the integrity of the perfusion to the lower extremity. The rule of thumb is that a diminished, or absent, pulse is indicative of hemodynamically significant disease above that level. For example, absent pedal pulses in a leg with strong femoral and popliteal pulses is consistent with tibio-peroneal (arterial runoff) disease; absent popliteal pulse in the presence of a strong femoral pulse is consistent with significant femoral artery (arterial outflow) disease; and absent femoral, popliteal and pedal pulses is consistent with aortoiliac (arterial inflow) disease. Usually no appreciable decrease in palpable pulses occur until the associated stenotic lesion reaches the so-called "critical" value of 75-90% reduction in arterial lumen. Complete absence of a pulse requires an almost complete occlusion of the vessel (≈99%).[11]

The following pulses should be palpated in each leg: femoral, popliteal, dorsalis pedis, and posterior tibial. The pulse force can be graded on a four-point scale. See Table V.[12]

Table V
Pulse force grading

3+	Full, bounding
2+	Normal
1+	Weak, thready
0	Absent

The femoral arteries lie just below the inguinal ligament halfway between the pubis and anterior superior iliac spines. To help expose the femoral area, particularly in obese people, ask the patient to bend his or her knees out to the side in a froglike position. Press firmly and then slowly release, noting the pulse tap under your fingertips. Should this pulse be weak or diminished, auscultate the site for a bruit.

The popliteal pulse is a more diffuse pulse and can be difficult to localize. With the leg extended but relaxed, anchor your thumbs on the knee, and curl your fingers around into the popliteal fossa. Press your fingers forward hard to compress the artery against the bone (the lower edge of the femur or the upper edge of the tibia). Often it is just lateral to the medial tendon. If you have difficulty, have the patient turn to the prone position and lift up the lower leg. Let the leg relax against your arm and press in deeply with your two thumbs. Often a normal popliteal pulse is impossible to palpate.

For the posterior tibial pulse, curve your fingers around the medial malleolus. Normally, it should be felt right behind the malleolus in the groove between it and the Achilles tendon. If you cannot palpate it in this position, try passive dorsiflexion of the foot to make the pulse more accessible.

The dorsalis pedis pulse requires a very light touch. Normally it is just lateral to and parallel with the extensor tendon of the big toe. Do not mistake the pulse in your own fingertips for that of the person.

In adults over 45 years, occasionally either the dorsalis pedis or the posterior tibial pulse may be hard to find, but not both on the same foot. Absence of both pedal pulses in the same foot is further indication of significant arterial disease in the lower extremity.[13]

Non-invasive examination

Segmental pressure and Ankle-Brachial Index (ABI)

The segmental blood pressure (SBP) examination is a simple, noninvasive method for diagnosing and localizing arterial disease. This method was first introduced by Winsor in 1950[14] and still remains a very sensitive indicator of arterial disease. Typically, pressure cuffs are placed around the patient's ankles, below the knee (BK), above the knee (AK) and at one or more locations in the thigh. The SBP may be obtained using standard pneumatic cuffs with a hand-held aneroid manometer. However, considering the time involved for multiple measurements, in some clinical settings where multiple cuffs are used, is may be advisable to use an automated, computerized system. In addition to multiple pressure measurements, a full SBP examination also includes obtaining and evaluating Doppler waveforms at various levels in the leg usually in the pedal, popliteal, superficial femoral and common femoral arteries. SBPs are not a routine part of the protocol presented in this paper. Instead, clinical symptomatology and pulse palpation direct the examiner's attention to the most likely segment, or level, of disease in the arterial tree.

Ankle Brachial Index (ABI) Calculation	
$\frac{\text{Ankle systolic pressure}}{\text{Brachial systolic pressure}}$	= ABI

The ankle-brachial index (ABI) is a simple, reliable index that is essentially free of technical artifacts and that defines the severity of arterial disease in the lower extremities quickly, inexpensively and relatively easily. It is simply the ratio between the systolic pressure in a pedal artery (dorsalis pedis (DP), posterior tibial (PT), lateral malleolar (LM)) to the systolic pressure in the arm (brachial artery). The ratio equation is shown in the accompanying text box. Each ankle systolic pressure is divided by the highest brachial systolic pressure to obtain this ratio. The normal ABI value is one or slightly greater ($\geq$ 1.0); an abnormal value is anything less than one ($<$1.0).[15]

The brachial systolic pressure is used as the reference standard and is used to calculate the ABI. Systolic pressure recordings should be obtained from both arms, and the higher value becomes the standard. A pneumatic cuff is placed on the upper arm, and a continuous wave (CW) Doppler probe is placed over the brachial or radial artery. The pneumatic cuff is inflated above the systolic pressure, at which time the Doppler signal disappears. The cuff is then allowed to slowly deflate until the Doppler signal re-appears. When the Doppler signal re-appears, the systolic pressure is recorded.

Both right and left brachial systolic pressures should be obtained in all patients when possible. There should be no more than 10 mmHg difference in the brachial systolic pressures. If the difference exceeds 10 mmHg, the side with lower pressure indicates a possible stenosis or occlusion of the ipsilateral innominate, subclavian, axillary, or proximal brachial artery. In this situation, a carotid ultrasound examination, which includes duplex evaluation of the subclavian and vertebral arteries, is required to look for occlusion, stenosis or vertebral steal patterns.[16]

After the brachial systolic pressures are taken, the lower extremity systolic pressures are obtained in a similar manner. The cuff is placed around each ankle about 3 fingers-breadth above the inferior margin on the lateral malleolus. CW Doppler is used to locate the strongest signal in the ankle (DP or PT) and, the pressure is taken as described above.

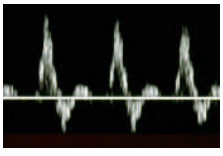
There are two divisions in the abnormal ranges, classified according to patient symptoms and abnormal ABI values as follows:

- ***Claudication (ABI 0.6 to 0.9).*** Claudication is seen in moderate stenosis and occlusive states. Claudication presents as intermittent pain associated with exercise. This condition is due to the inability of the collateral circulation to meet the needs of the exercising muscle. Thus, all patients whose ABI ranges from 0.6 to 0.9 should have systolic pressure measurements taken after exercise. Stress or exercise testing is also indicated in those patients who are symptomatic but in whom pressure measurements are borderline or normal under resting conditions. The ABI in these patients usually ranges from 0.9 to normal at rest.
- ***Severe occlusive states (ABI <0.5).*** If the ABI is 0.5 or less, there is no need for exercise testing. Doppler waveform analysis is performed to complete the examination and to correlate with the segmental pressures. The ABI defines the severity of the disease, whereas the segmental pressures localize the area of involvement.[17]

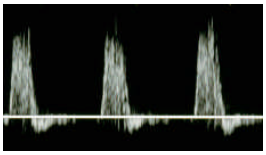
Doppler waveforms

Doppler waveforms obtained from normal peripheral arteries are ***triphasic*** in nature and represent three distinct flow components: an initial, rapid upsweep to peak systolic velocity (PSV); a small flow reversal in early diastole; and a final forward flow in late diastole. Triphasic waveforms are normally obtained from the common and superficial femoral, popliteal, posterior tibial, and dorsalis pedis arteries in the normal non-vasoconstricted lower extremity at rest.

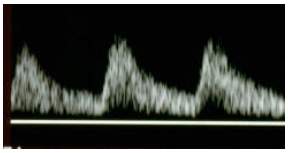
As the atherosclerotic disease process begins to diminish the elasticity and compliance of the arterial wall, the Doppler waveform becomes ***biphasic*** with a loss of the flow reversal in early diastole. Late diastolic forward flow is maintained. As the disease progresses, blood flow becomes ***monophasic*** with both the early and late diastolic phases absent and only the systolic forward component present. These waveform changes are summarized along with other duplex criteria for grading arterial stenosis in Table VII below.



Triphasic



Biphasic



Monophasic

Exercise testing

Exercise testing (sometimes referred to as stress testing) should be performed in all patients when the ABI is consistent with claudication. It is especially beneficial in patients with borderline pressure values at rest but who present with symptoms strongly suggestive of claudication. Patients with mild to moderate atherosclerotic disease typically have sufficient collateralization and dilatation of the arteries so that the ABIs may measure slightly low to normal (0.8 – 1.0). However, with exercise, the increased perfusional demands of the calf muscle and the increased resistance of the distal extremity vessels will exceed the supply capability of arterial flow, resulting in a significant decrease in the pressure value.

Exercise testing can be performed by having the patient walk or use a treadmill with a 12° grade moving at 2 miles per hour. The patient walks for 5 minutes or until the pain or familiar leg symptoms occur. It is recommended that electrocardiogram monitoring be performed if treadmill testing is used and, therefore, this method of stress testing may not be suitable in many ultrasound laboratories. A simple and effective alternative exercise that induces claudication in most patients with peripheral arterial disease, and does not require cardiovascular monitoring, is “toe-ups” or “toe-raises”. The patient is instructed to stand on the floor, bracing him/herself against a chair or counter and raising up and down briskly on his/her toes. The time it takes for symptoms to first appear is recorded and, in the author’s experience, typically occurs well before 5 minutes of this type of exercise.

Immediately following the exercise period, ABIs are repeated. It is important to re-measure the arm with the highest brachial pressure as it may raise several mmHg after exercise. In the normal response to exercise, there is usually no significant drop in the ABI. There may even be elevation in the pressure measurement. The abnormal response to exercise testing is a noticeable decrease in the ABI (<0.8). Such a drop in pressure is an indicator of the presence of PAD and helps confirm or refute the patient’s complaints of claudication.

Time-sequential ankle pressures taken after exercise add a further dimension in the assessment of the severity of peripheral arterial disease. They are obtained, initially at 30-second intervals for the first 4 minutes and then every minute until the pressure measurement returns to normal or to the pre-exercise level. Two ankle pressure cuffs are extremely useful in obtaining sequential ABIs. In cases of severe occlusive disease, it may take 30 minutes or longer for pressures to return to normal; however, 10 to 15 minutes is sufficient recording time to evaluate vascular status. Any drop in pressure is an indicator of significant disease, and the degree of impairment will be reflected in the time it takes for the pressure to return to normal. Usually, when a single level of disease is present, the pressure will return to normal values within 2 to 6 minutes. With multiple levels of disease, it takes up to 12 minutes for pressures to return to normal. In a patient with a severe occlusive state, it may take up to 30 minutes or longer for pressures to return to normal.[18] See Table VI.

Triplex Imaging

Color Doppler Imaging (CDI) has become an integral part of the non-invasive diagnosis and evaluation of peripheral vascular disease. In addition to providing two-dimensional gray scale images of the gross morphology of the arterial tree, CDI permits easy and accurate evaluation of flow patterns and hemodynamic status within selected segments of vascular structures in the lower extremity. This makes CDI, as an adjunct to well-established physiologic and Doppler examination techniques, an important component in increasing the sensitivity of ultrasound examination of the lower extremity and in reducing examination time and complexity.[19 20]

Duplex arterial testing has been proven to be a highly sensitive, specific and accurate method of assessing the patient with peripheral arterial disease (PAD) and in many cases can be obviate the need for angiography in patient's considering interventional or surgical treatment. [21 22 23] Duplex ultrasound is a reliable method of helping in the selection of treatment modalities for patients with infrainguinal PAD and is also an effective method of post-operative infrainguinal graft surveillance and in the detection of pseudoaneurysms. [24]

The primary utility of duplex imaging in patients with PAD is to:

- Distinguish between a stenosis and a complete occlusion in a vessel;
- Establish the length of the disease segment in an artery;
- Assess patency of the distal vessels for use as possible target sites for distal graft anastomosis;
- Evaluate the results of intervention (angioplasty, stent placement);
- Diagnose aneurysms and post-operative pseudoaneurysms;
- Monitor a patient's postoperative course with regular interval bypass graft surveillance.

Method

The technique of lower extremity duplex imaging has been described in detail by many authors and is beyond the scope of this paper to repeat in full.[25 26] However, there are several important points that must be considered when incorporating duplex into a patient evaluation algorithm:

- The examination is begun in a longitudinal plane of section in the groin over the common femoral artery (CFA) and proceeds caudad through the superficial femoral, popliteal, tibio-peroneal trunk, and anterior and posterior tibial arteries to the foot.
- When CDI indicates an area of unusual flow dynamics, such as turbulence, color bruit, or high velocity jets, spectral Doppler interrogation should be performed and peak systolic velocities (PSV) should be obtained:
    a. Cephalad (upstream) to the flow disturbance
    b. At the flow disturbance, in the area of maximum flow velocity
    c. Distal to the flow disturbance, assessing degree of post-stenotic turbulence

- Spectral waveforms are obtained from a longitudinal plane of section employing careful angle correction technique and are used to estimate the degree of stenosis in all arterial and graft segments and . Diagnostic criteria are presented in Table VII.[27 28] Cross-sectional or longitudinal residual diameter measurements with or without the use of CDI are notoriously inaccurate and do not correlate well with contrast angiographic findings.
- In patients with a significant SFA stenosis or occlusion, flow into the popliteal artery should be examined with CDI to determine degree and integrity of flow reconstitution. This helps the surgeon determine whether an infrainguinal bypass graft may be anastomosed as a fem-pop bypass or whether a fem-distal technique is required for limb salvage.
- Presence or absence of collateral flow should be noted. Common sites where collateral vessels may be identified are in the groin and hip area in patients with inflow disease) aortoiliac) or around the knee in patients with outflow (femoral artery) disease. This frequently requires CDI system sensitivity to be set for detection of low flow states. (Low baseline, low velocity detection level (threshold), low amplitude enhancement)
- Duplex examination of an infrainguinal bypass graft (femoral-popliteal, femoral-tibial, etc.) is similar to that of native vessels. The graft is scanned longitudinally in its entirety from proximal to distal anastomosis. CDI is used to identify areas of significant flow disturbance and spectral waveforms are obtained as noted in item 3 above.

Table VII
Duplex criteria for grading arterial stenoses

	Peak systolic velocity (PSV)	**Spectral waveform**
Normal	70-100 cm/sec	Triphasic
<50% stenosis	30-100% increase over proximal segment	Triphasic
>50% stenosis	>100% increase over proximal segment	Monophasic Turbulent
>75% stenosis	PSV >400cm/sec Pre-stenotic:stenotic ratio; >4:1	Monophasic High velocity Bruit may be heard
Occlusion	Absent flow Collaterals may be seen adjacent	Dampened proximal to occlusion
Aortoiliac disease	PSV in CFA $\leq$ 45cm/sec[29]	Monophasic

Overall, duplex sonography is an accurate and well-accepted method of assessing the status of the peripheral arterial system in both pre and post-operative patients. When compared to contrast angiography duplex ultrasound, in the hands of an experienced examiner, has a sensitivity of 96.9%, a specificity of 96.2%, a positive predictive value of 94.6% and a negative predictive values of 97.8% with an overall accuracy of 96%.[30]

Follow-up testing

Patients with an established diagnosis of PAD frequently benefit from a tailored non –invasive testing program to monitor their lower extremity vascular health. Once the initial diagnosis has been established and the level and severity of disease has been determined either by the triplex technique described above or by contrast angiography, patients can be followed for the following reasons:

- *Watchful waiting*: Patients who are not yet candidates for vascular intervention but who remain at risk for limb loss.
- *Part of an exercise regimen*: Patients who are actively engaged in trying to improve lower extremity perfusion through a regular exercise program (walking) and medication (Trental, Pletal). While regular ABI follow-up may assist in keeping a patient interested and actively compliant in the exercise regimen, it may not increase concordantly with an improvement in leg symptoms and quality of life.[31]
- *Post-operative graft surveillance*: Duplex ultrasound is an effective method of detecting imminent graft failure and identifying those autogenous grafts at risk for future failure. Triplex imaging should be performed on all patients presenting for graft follow-up. CDI and duplex criteria listed above in Table VII for grading native artery stenoses may also be used to determine degree of narrowing of an *in situ* vein bypass graft. Other parameters that are statistically correlated with future or impending graft failures include:
  1. >30cm/s decrease in PSV in any graft segment compared with previous examination.
  2. Triphasic waveforms change to biphasic waveforms in any graft segment compared with previous examination.
  3. ABI decrease >0.15 from prior examination.[32]

  Follow-up triplex criteria for evaluation of prosthetic grafts such as Gore-tex and Dacron have not been standardized because they are not particularly reliable.

- *Pseudoaneurysm, hematoma*: Two-dimensional ultrasound quickly, easily and non-invasively detects false aneurysm formation around the proximal anastomosis of a graft or at the site of arteriotomy in patients undergoing arteriography or endoluminal vascular intervention.

Table VIII
Follow-up testing schedule

	Monitored	**Interval**
Watchful waiting (claudicator)	ABIs Δ symptoms	q3-6 months
Part of exercise regimen	ABIs (pre and post) Δ walking distance	q3 months
Post-operative graft surveillance:	ABI; duplex of graft	q 6months
Pseudoaneurysm, hematoma	Gray scale and CDI	prn

[1] Baun J. Evaluating a patient with leg pain. J Diag Med Sono. 199. 14:267-272.

[2] Rutherford RB (ed) Vascular Surgery 2nd ed. WB Saunders Co. Philadelphia, 1984 p.4.

[3]Mallon E, Tatoni G. Physio-anatopathology of acute ischemia of the extremities. J Cardiovasc Surg 1963 4:212-216.

[4] Young JR, Graor RA, Olin JW, et al. (ed) Peripheral Vascular Diseases. St. Louis, Mosby Yeaarbook. 1991, p. 686.

[5]Allen EV, Barker NW, Hines EA. Peripheral Vascular Diseases. Philadelphia, WB Saunders, Co., p. 306

[6]Carter SA. Clinical problems in peripheral arterial disease: is the clinical diagnosis adequate? in Bernstein EF. Noninvasive Diagnostic Techniques in Vascular Disease. St. Louis, CV Mosby Comapny, 1985, p. 500-501.

[7] Young JR, Graor RA, Olin JW, et al. (ed) Peripheral Vascular Diseases. St. Louis, Mosby Yeaarbook. 1991, p. 686.

[8] Jarvis CJ, Physical Examination and Health Assessment. Philadelphia, WB Saunders Co., 1992. p. 658.

[9] Baun J. Evaluating a patient with leg pain. J Diag Med Sono. 199. 14:267-272.

[10] Young JR, Graor RA, Olin JW, et al. (ed) Peripheral Vascular Diseases. St. Louis, Mosby Yearbook. 1991, p. 686.

[11] Rutherford RB (ed). Vascular Surgery, Second Edition. Philadelphia, WB Saunders Company, 1984. p. 31.

[12] Jarvis C. Physical Examination and Health Assessment. Philadelphia, WB Saunders Co. 2000. p.187.

[13] Jarvis C. Physical Examination and Health Assessment. Philadelphia, WB Saunders Co. 2000. p.202.

[14] Winsor T. Influence of arterial disease on the systolic blood pressure gradient of the extremity. Am J Med Sci 1950; 220:177-121.

[15] Gerlock AJ, Giyanani VL, Krebs C. Applications of Noninvasive Vascular Techniques. Philadelphia, WB Saunders Co., 1988. p. 309.

[16] Tan TY, Schminke U, Lien LM, Tegeler CH. Subclavian steal syndrome: can the blood pressure difference between arms predict the severity of steal?
J Neuroimaging. 2002 Apr;12(2):131-5.

[17] Gerlock AJ, Giyanani VL, Krebs C. Applications of Noninvasive Vascular Techniques. Philadelphia, WB Saunders Co., 1988. p. 301

[18] Gerlock AJ, Giyanani VL, Krebs C. Applications of Noninvasive Vascular Techniques. Philadelphia, WB Saunders Co., 1988. p. 310.

[19] Ubbink DT, Legemate DA, Llull JB. Color-flow duplex scanning of the leg arteries bu use of a new echo-enhancing agent. J Vasc Surg. 2002; 35:392-6.

[20] Alexander JQ, Leos SM, Katz SG. Is duplex ultrasonography an effective single modality for the preoperative evaluation of peripheral vascular disease? Am Surg. 2002; 68:1107-10.

[21] Bostrom AA, Ljungman C, Hellberg A, et al. Duplex scanning as the sole preoperative imaging method for infrainguinal arterial surgery. Eur J Endovasc Surg. 2002; 23:140-5.

[22] Katsamouris AN, Giannoukas AD, Tsetis D, et al. Can ultasound replace arteriography in the management of chronic arterial occlusive disease of the lower limb? Eur J Vasc Endovasc Surg. 2001; 21:155-9.

[23] Ascher E, Hingorani A, Markevich N, et al. Lower exctremity revascularization without preoperative
contrast angiography: experience with duplex ultrasound arterial mapping in 485 cases. Ann Vasc Surg. 2002; 16:108-14

[24] Bostrom AA, Lofberg AM, Hellberg A, et al. Selection of patients with infrainguinal arterial occlusive disease for percutaneous transluminal angioplasty with duplex scanning. Acta Radiol. 2002; 43:391-5.

[25] Rumwell C, McPharlin M. Vascular Technology: An Illustrated review. 2000. Pasadena. Davies Publishing Co., p. 95.

[26] Moneta GL, Strandness DE. Peripheral arterial duplex scanning. J Clin Ultrasound 1987; 15:645-651

[27] Moneta GL, Strandness DE. Peripheral arterial duplex scanning. J Clin Ultrasound 1987; 15:645-651.

[28] Cossman D, Ellison J, et al. Comparison of contrast arteriography to arterial mapping with color flow duplex imaging in the lower extremities. J Vasc Surg. 1989; 20:522-9.

[29] Shaalan WE, French-Sherry E, Castilla M, et al. Reliability of common femoral arteru hemodynamics in assessing the severity of aortoiliac inflow disease. J Vasc Surg. 2003; 37:960-9.

[30] Alexander JQ, Leos SM, Katz SG. Is duplex ultrasonography an effective single modality for the preoperative evaluation of peripheral vascular disease? Am Surg. 2002; 68:1107-10.

[31] Carlon R, Morlino T, Maiolino P. Beneficial of exercise beyond the pain threshold in intermittent claudication Ital Heart J. 2003; 4:113-20.

[32] Rumwell C, McPharlin M. Vascular Technology: An Illustrated review. 2000. Pasadena. Davies Publishing Co., p. 95.