IMAGING OF THE PERIPHERAL VASCULAR SYSTEM

Edited by

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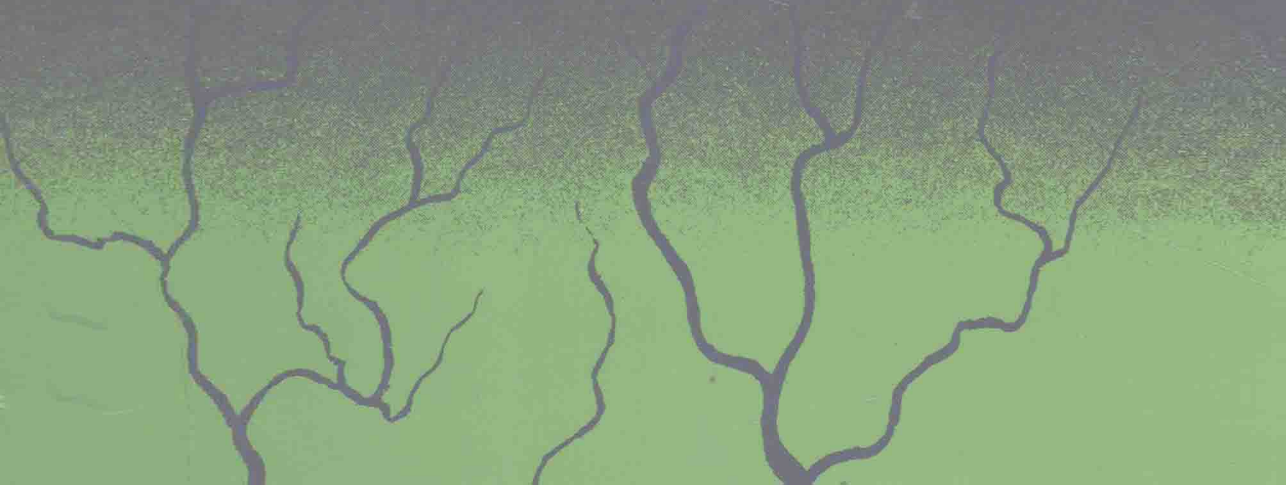

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MULTIPLE IMAGING PROCEDURES

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To our families.

PREFACE

The imaging of abnormalities of the peripheral vascular system is not limited to the usual radiologic modalities. In preparing this volume, it therefore became necessary to include input from not only all of the modalities in radiology, but also from the vascular flow laboratory. Like so many other areas in diagnostic imaging, many new developments are taking place and it is difficult to remain up-to-date on all the modalities. During the course of preparation of this text, the very exciting new technique, digital subtraction angiography, was added to the modalities already being reviewed. In addition to the diagnostic modalities, we consider the radiologist's role in therapeutic angiography. In general, there are so many modalities to study the peripheral vessels that we have not attempted to recommend one modality for each pathologic condition. These modalities are so new that definitive answers on the modality of choice have not been determined. The rapid developments in all of the imaging modalities make the future of imaging of the peripheral vessels an exciting area for research. We look forward to a determination of the appropriate modality for each condition. It was our intent, however, to inform the physician about the procedures that can be used and the advantages of each of the modalities.

All too often the radiologist is not familiar with the techniques available in the blood flow laboratory, and likewise, the vascular surgeons and internists are not familiar with all the new modalities available to the radiologists. We have provided a description of all the modalities currently available to ensure that both the referring physicians and the radiologists can select the best procedure for each condition and patient.

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1
Introduction to Vascular Imaging

Peripheral vascular surgery is a relatively new discipline. The era of modern vascular surgery began in 1948, when Gross et al.[1] published their report showing that a human arterial graft could be used to bypass a chronically diseased artery. Several years later, DuBost[2] successfully excised an abdominal aortic aneurysm and replaced it with a homograft. In 1954, Eastcott et al.[3] successfully carried out an endarterectomy of a symptomatic carotid artery stenosis. The repair of diseased peripheral arteries now constitutes one of the most common surgical procedures done in the United States and has stimulated the growth of newer and better techniques of vascular imaging.

In the early 1970s, the diagnosis of peripheral vascular disease was based on a patient history, a physical examination, and contrast arteriograms. The arteriogram has occupied a central position in the management of these patients because it generates critical anatomic information regarding inflow, run-off, the degree and extent of stenosis, and the location of adjacent vascular structures. The arteriogram, however, is often not pivotal in deciding if surgery is indicated. That decision is usually based on history and physical findings.

The history of contrast angiography began in 1896, when Haschek and Lindenthal[4] injected a viscous radiopaque solution into the blood vessels of an amputated hand. The next few decades were marked by the introduction of less viscous solutions. In the 1950s, Renografin® (Squibb) and Angio-Conray® (Malinckodt) were introduced and now enjoy universal acceptance.

The other important development in the history of contrast angiography was the development of catheter angiography. In the 1940s, angiography was carried out by direct puncture of the involved artery, such as the femoral, carotid, or the abdominal aorta, from the translumbar approach. Although satisfactory data could be obtained, the information was limited to the region of the single artery.

In 1952, Seldinger[5] introduced the catheter technique. This simple but elegant method involves the insertion of a catheter over a previously placed guide wire. Since

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the catheter is the same size as the puncture hole in the artery, hemorrhage rarely occurs. This approach makes all the major vessels accessible through a single puncture in the femoral artery.

Although contrast arteriography is essential in the evaluation of patients with vascular disease, it does have disadvantages. The most important disadvantage is that it does not provide physiologic information. For example, an arteriogram may demonstrate a completely occluded superficial femoral artery, but it does not give information regarding distal perfusion pressures, which may or may not be reduced (for reasons that are not clear at present, similar patterns of arterial occlusion may be associated with quite different perfusion pressure patterns). A second drawback to arteriography is its invasive nature, which leads to several unappealing consequences: the patient must be hospitalized for these studies; the studies themselves are at least unpleasant and usually painful; arteriography generally cannot be used as a screening device for serial follow-up studies; the patient is exposed to a small but finite radiation dose; and there is a small but real risk of complications such as thrombosis or hemorrhage from the arterial puncture site. Despite these problems, arteriography remains invaluable in the management of patients with peripheral vascular disease.

Approximately 15 years ago Yao et al.[6] published papers describing the measurement of ankle systolic pressure, thereby introducing noninvasive blood flow techniques into clinical medicine. In rapid succession, techniques to measure carotid artery as well as leg vein flow dynamics were also introduced. These new noninvasive modalities have not replaced traditional arteriography, since they produce indirect anatomic information; they do, however, generate significant physiologic data. Noninvasive techniques are best used either as screening devices to identify patients who might require arteriography or in the follow-up of patients who require multiple studies over an extended period of time.

In addition, other techniques using nuclear imaging, computerized axial tomographic scanning, and digital subtraction angiography have also entered the mainstream of clinical practice. In the following chapters, we will describe how all of these modalities can be used in the diagnosis of peripheral vascular disease.

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2

Blood Flow Laboratory Techniques of the Arteries

While percutaneous angiography can identify certain anatomic defects in the arterial tree, it does not provide sufficient information about the functional significance of specific lesions.[1] Doppler ultrasound, on the other hand, can be used to determine if any significant arterial occlusive disease is present; if the lesion is responsible for the symptoms; the location of the lesion; which of multiple lesions is the most significant; whether an ulcer or amputation will heal; the risk of gangrene in a limb; if a bypass or percutaneous transluminal angioplasty has been successful; and whether new symptoms are the result or a bypass or reconstruction that has failed or the result of new lesions.

Noninvasive techniques such as Doppler ultrasound and pulse volume recording thus can be used by the clinician to rapidly confirm the presence of, categorize, and evaluate the functional significance of arterial occlusive disease. Invasive arteriography can then be reserved for use in those patients in whom angioplastic or surgical intervention is deemed necessary.

DOPPLER ULTRASOUND

Technique

The Doppler effect forms the basis for the measurement of blood flow in peripheral arteries and veins. Briefly stated, the measured velocity of blood flow is proportional to the difference in frequency between sound transmitted toward and reflected from a vessel containing a moving stream of blood. Formally,

$$V_{mean} = (U \times F_d)/(2 \times F_t \times \cos \theta)$$

where V_{mean} is the mean blood flow velocity, U is the velocity of sound in the tissue

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being studied, F_t is the frequency of transmitted sound, F_d is the measured difference between transmitted and received frequencies, and θ is the incident angle of sound and blood flow.

Current instruments use continuously generated and transmitted sound and are called continuous-wave Dopplers. Most instruments use a frequency of transmitted sound between 2 and 10 MHz. The frequency chosen allows the examiner to select the depth at which the blood vessel being studied can be optimally examined.

Schematically, most machines in use have transmitting and receiving crystals set at a small angle to each other in a common probe. The probe is coupled to the skin with a gel to provide better transmittance of acoustic signals. The received signal is amplified to provide an aural or graphic representation of flow velocity, which can then be recorded and measured (Fig. 2-1).

Clinically, the most useful information gathered with the use of ultrasound techniques is from the measurement of segmental limb pressures (SLPs).[2-4] Segmental limb pressures are measured by placing inflatable blood pressure cuffs at various points along the extremity to be studied and noting the pressure at which flow (the Doppler signal) returns. Since flow is presumed to start at the same time in all points of an extremity, theoretically the probe may be placed at any point distal to the cuff (ankle or wrist for convenience). The cuff should be approximately 20-percent wider than the diameter of the extremity at the point of placement in order to prevent measuring a falsely elevated pressure at which flow begins.

In a study of the lower extremity, cuffs are usually placed high and low on the thigh, at the calf, and at the ankle. Any gradient or pressure drop greater than 25 to 30 mm Hg between two adjacent levels is thought to be abnormal and to represent functionally significant disease. The brachial artery pressure is also measured. Results are expressed as absolute pressure values and in the form of ratios of the segmental

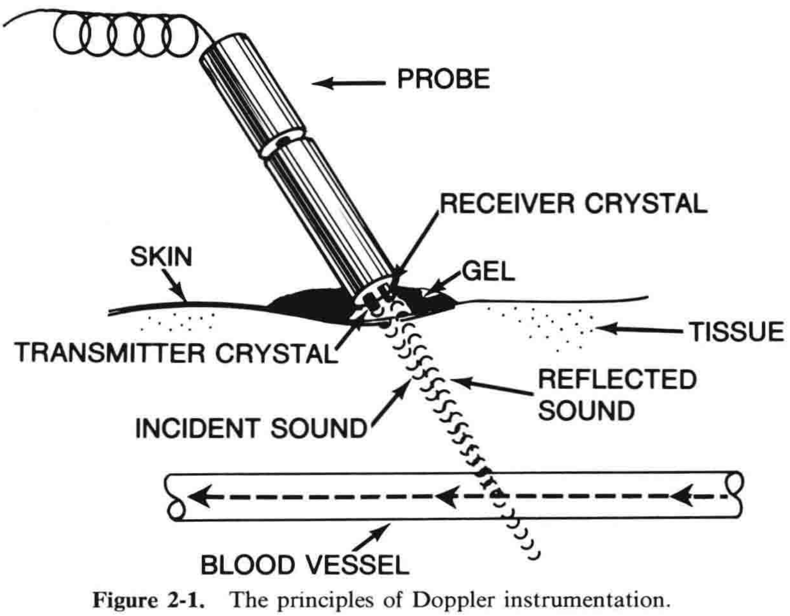

Figure 2-1. The principles of Doppler instrumentation.

Table 2-1
Normal Arterial-Brachial Pressure Ratios

Position	Ratio
High thigh	1.0–1.2
Low thigh	1.0
Calf	1.0
Ankle	0.9–1.0

pressures (systolic) to the brachial artery pressure for normalization. Pressures may also be measured in the transmetatarsal region and at the great toe. Several investigators have also measured penile pressures in studies of vasculogenic impotence.[5] Normal ratios at the various levels along the leg are listed below in Table 2-1.

Figures 2-2, 2-3, and 2-4 give specific examples of SLP measurements found in various levels of disease.

The information gathered in the measurement of SLPs is useful in determining several of the variables mentioned in the introduction to this chapter.

The Presence of Significant Disease or Occlusion

In general, if the distal pressure ratios are greater than 0.7, vascular occlusion is not highly significant at rest and certainly is not threatening to the limb.[6] A guide to the clinical relevance of the spectrum of ankle pressure ratios is shown in Table 2-2.

Stress testing may also be performed to improve the sensitivity of segmental pressure determinations. Patients may be exercised at 2 mph at a 12-percent grade for 5 minutes or until claudication occurs. Ankle pressures are measured before and after this exercise. Presumably, the muscle bed dilates, causing increased blood flow demands in the extremity. When treadmill testing is done, lesions that are asymptomatic at rest may produce an increased and prolonged pressure drop at the ankle, indicating their functional significance with exercise.[7,8] For example, a claudicator may not demonstrate a decrease in pressure at the calf until exercised on a treadmill.

As seen in Figures 2-2, 2-3, and 2-4, the levels and functional importance of disease may be determined noninvasively with an eye toward follow-up or further investigation and surgical correction, if indicated. If ankle ratios are less than 0.2, the risk of losing a limb can be considered significant. With this information at hand, a more aggressive approach can be taken and arteriography and surgery can be employed in an attempt to salvage the limb and avoid possible amputation.[9]

Table 2-2
Ankle-Brachial Pressure Ratios

Normal	≥ 1.0
Claudication	≤ 0.6–0.7
Rest pain	≤ 0.2–0.3
Impending gangrene	≤ 0.1

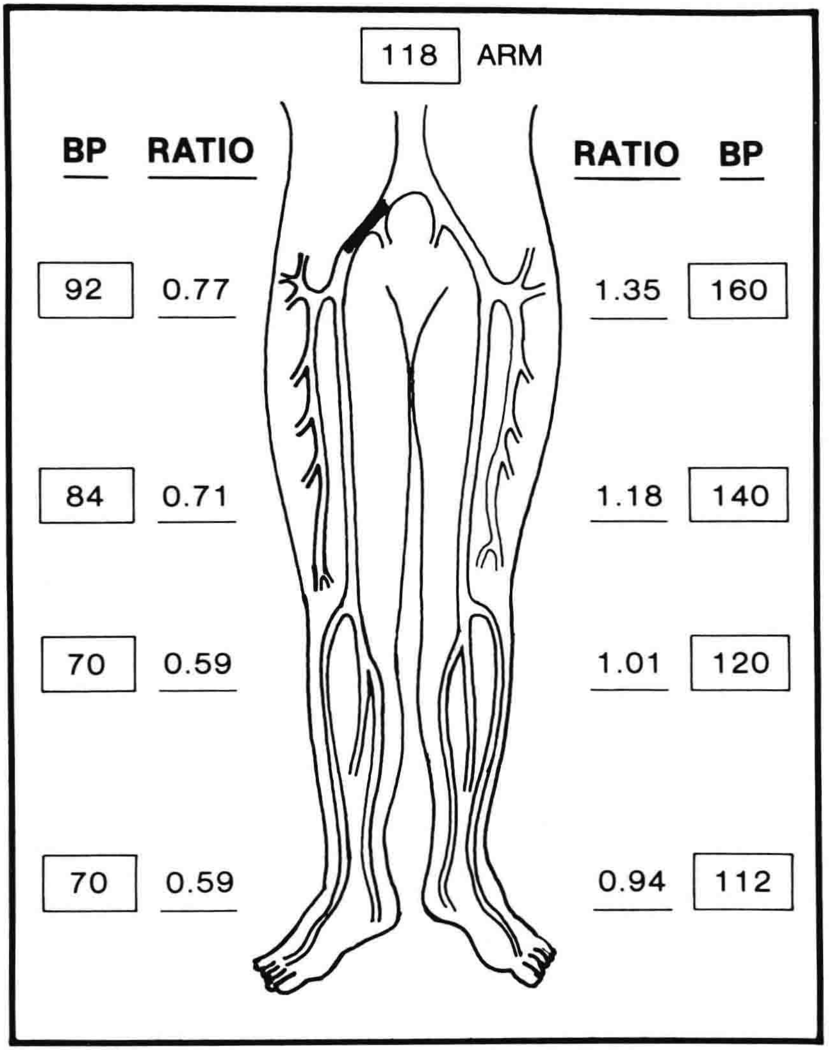

Figure 2-2. A patient with unilateral iliac occlusion exhibiting a pressure gradient at the high thigh cuff. Note the lack of gradients between other levels below the lesion.

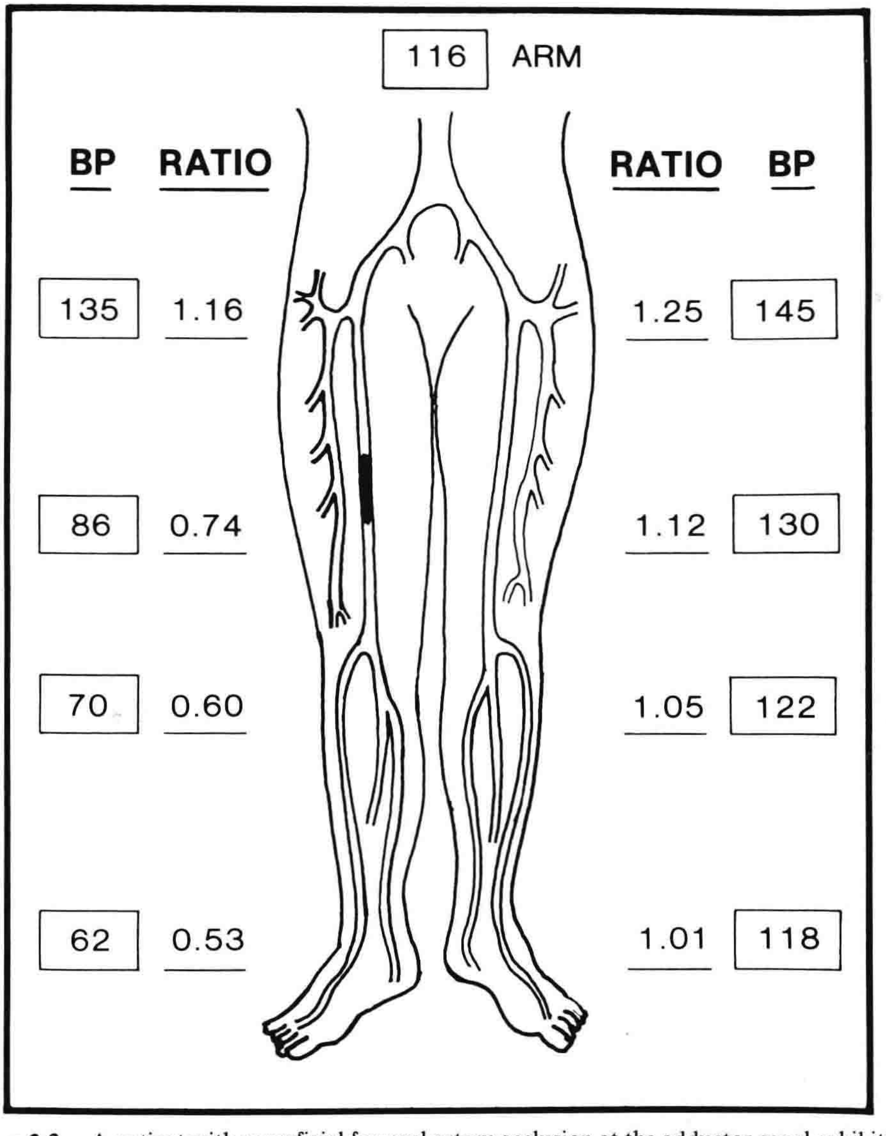

Figure 2-3. A patient with superficial femoral artery occlusion at the adductor canal exhibiting a pressure drop between the high and low thigh cuffs. There is no gradient distally.

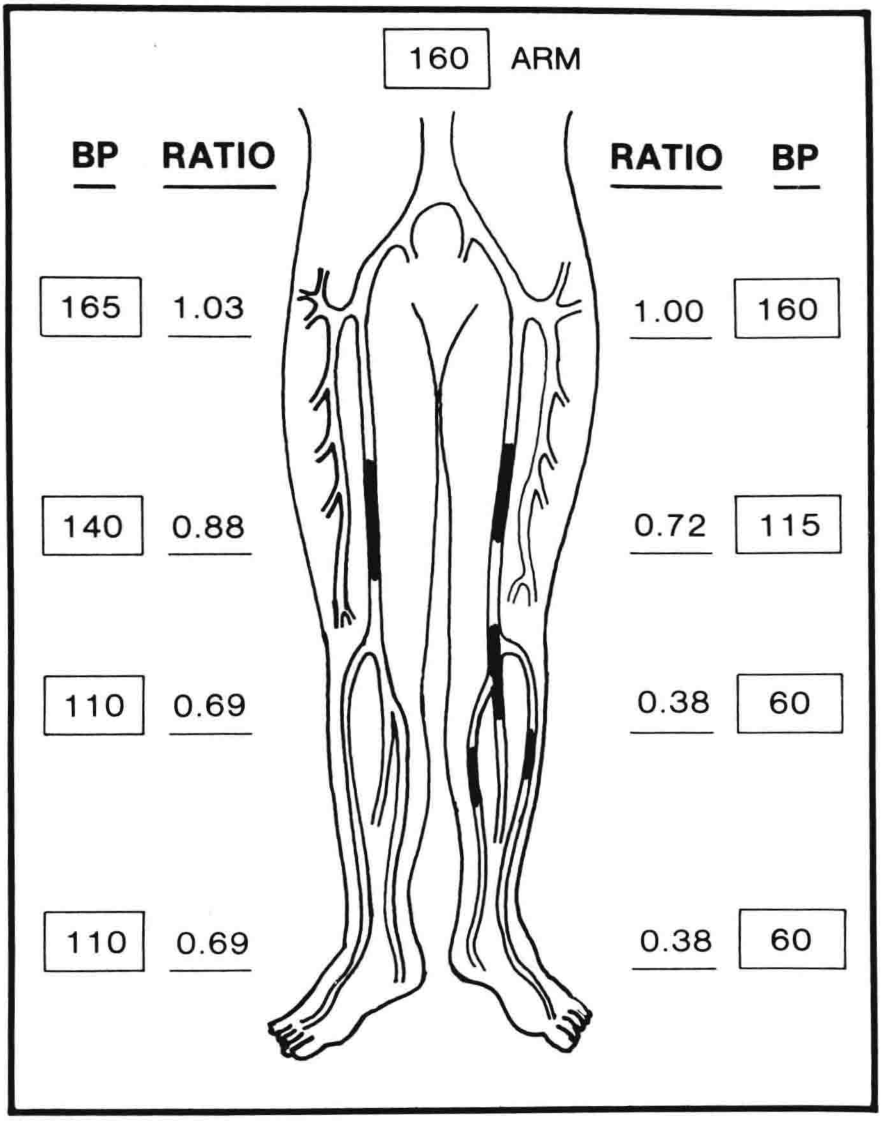

Figure 2-4. A patient with multiple levels of disease in the superficial femoral artery and in the trifurcation vessels. Note the multiple pressure gradients.

The Healing of Ulcers and Amputations

Many authors have studied the relationship between the healing of ulcers and amputations and limb pressures measured with Doppler ultrasound techniques. While there is not wide agreement on the results, a general approach can be given.

In nondiabetic patients, ulcers (ischemic) and amputation sites will generally heal (in the absence of infection) if limb pressures measured at or below the site in question are greater than 50 to 60 mm Hg. Diabetics, because of the presence of calcified,