With the longer life expectancy, atherosclerotic occlusive processes gain in clinical relevance. Atherosclerosis affects not only the coronary arteries and extracranial cerebral vessels but also the arteries of the extremities. The prevalence of symptomatic arterial occlusive disease (AOD) in men and women aged 55 to 75 is 4.5% and over 20% when asymptomatic disease is included. Atherosclerosis reduces an individual’s quality of life causing immobility and disability. Life expectancy is reduced, by about 10 years in male AOD patients. Major causes of death are coronary heart disease (55% of patients with AOD versus 36% without AOD) and cerebral conditions (11% with AOD and 4% without). AOD is the manifestation of generalized atherosclerosis affecting all vascular territories but with a high rate of concomitant involvement of the coronary and extracranial cerebral vessels, in particular in AOD of the pelvic type. Patients in whom peripheral AOD has been diagnosed require not only individual therapeutic management based on the stage of the disease and the suitability of their vascular system for surgical repair but also further prophylactic diagnostic and therapeutic measures (coronary heart disease/CHD, carotid stenosis). The wider range of therapeutic options available today, in particular the percutaneous interventions, can help to prevent the loss of a limb through reconstruction or recanalization of occluded vessel segments and to improve the patient’s quality of life through the early elimination of stenotic processes. Early diagnosis is essential for the initiation of proper treatment. Duplex ultrasonography is a well-suited noninvasive modality for an efficient and low-risk primary diagnostic workup.

2.1 Pelvic and Leg Arteries

2.1.1 Vascular Anatomy

2.1.1.1 Pelvic Arteries

At the level of lumbar vertebrae (L) 4/5, or the umbilical level when scanning from the anterior approach, the abdominal aorta divides into the two common iliac arteries. They descend into the true pelvis taking an arched course along which they bifurcate at about the most posterior point (Fig. 2.1a). The common and external iliac veins course behind the respective arteries. The internal iliac artery arises at the level of the sacroiliac joint, coursing in a posterior direction to supply the pelvic organs, pelvic wall, and buttocks. The external iliac artery is the continuation of the common iliac artery and arches into the lacuna vasorum under the inguinal ligament. It runs medial to the iliosposas muscle and gives off the inferior epigastric and deep circumflex iliac arteries shortly before it reaches the inguinal ligament. These two arteries can serve as collaterals in pelvic artery occlusion.

The vessel diameters vary between 0.6 to 1.4 cm in the common iliac artery, 0.5 to 1.0 cm in the external iliac artery, and 0.4 to 0.8 cm in the internal iliac artery.

2.1.2 Leg Arteries

The common femoral artery is about 2 – 4 cm long and below the inguinal ligament divides into the profunda femoris artery, which typically branches off on the posterolateral aspect, and the superficial femoral artery (Fig. 2.1b).
Fig. 2.1. b Schematic representation of the vessels in the groin (from Heberer and van Dongen 1993). c Schematic representation of the vessels in the popliteal fossa (from Heberer and van Dongen 1993). d Schematic representation of the lower leg arteries
The origin of the profunda femoris artery is variable and several branches may arise directly from the common femoral. Typically, one branch arises posteriorly while the main branch arises posterolaterally or, in rare cases, postero-medially. Branches of the medial and lateral circumflex arteries open into the femoral bifurcation and form the main collateral pathways in pelvic artery stenosis or occlusion. The profunda femoris artery is the most important collateral route in occlusion of the femoropopliteal segment. Somewhat distal to the femoral bifurcation, the deep femoral veins converge and unite with the superficial femoral vein. The deep veins cross the bifurcation. The superficial femoral vein runs behind the artery on its course to the distal thigh. The plexus passes posteriorly through the vastoaductor membrane at the level of the adductor canal (Hunter’s canal) and the superficial femoral artery continues as the popliteal artery.

Interventional radiologists and vascular surgeons subdivide the popliteal artery into 3 segments with the P1 segment in angiography extending to the upper edge of the patella and the P2 segment to the knee joint cleft. The P3 segment extends to the origin of the anterior tibial artery, which passes anteriorly through the interosseous membrane at the lower edge of the popliteal muscle. It continues through the extensor compartment anterior to the interosseous membrane to the upper edge of the ankle joint with its proximal segment coursing relatively close to the fibula. The popliteal artery continues as the highly variable tibiofibular trunk with a length of about 1 – 5 cm (Fig. 2.1 c), branching into the posterior tibial and fibular arteries. The posterior tibial artery is the main artery of the lower leg and passes through the deep crural fascia between the superficial and deep flexors. It continues posterior to the medial ankle to the sole of the foot, where it divides into the larger lateral plantar artery and the smaller medial plantar artery. The lateral plantar artery extends to the deep plantar arch, which completes the arch of foot via its collaterals to the dorsalis pedis artery establishing a connection to anterior tibial branches. The fibular artery courses posteromedial to the fibula, also at the level of the deep crural fascia. It ends at the distal lower leg and gives off several arteries supplying the muscles and serving as collaterals when other lower leg arteries become occluded.

The lower leg arteries vary widely in caliber. In cases of hypoplasia or, very rarely, aplasia, the other arteries act as collaterals. Collateralization through the rete malleolare at the level of the upper ankle joint has an important role in atherosclerotic occlusion or hypoplasia.

### 2.1.2 Examination Protocol and Technique

#### 2.1.2.1 Pelvic Arteries

The depth of penetration required for scanning of the pelvic arteries makes it necessary to use convex transducers with frequencies of 3.5 – 5 MHz. The proper pulse repetition frequency (no aliasing) and gain are selected in a healthy vessel segment. The examination is performed with the patient in the supine position and after an adequate period of rest in order to prevent false-positive findings due to reactive hyperemia. Exercise-induced hyperemia takes longer to return to normal in the presence of atherosclerotic occlusive processes.

A hemodynamically significant stenosis above the inguinal ligament can be identified quickly by obtaining a spectral Doppler tracing from the common femoral artery. A triphasic waveform with a peak systolic velocity above 70 cm/s (side-to-side comparison) excludes a higher-grade stenosis at the pelvic level with a high degree of likelihood. For closer evaluation, the aortic bifurcation is located in the transverse plane at the umbilicus and the common and external iliac arteries are tracked along their courses and searched for stenotic lesions in longitudinal orientation (Fig. 2.2). Bowel loops, in particular when filled with air, produce marked scattering and attenuation, impairing continuous scanning of the pelvic vessels. Air-filled bowel loops can be displaced from the insonation window by exerting continuous pressure with the transducer, or the transducer is shifted to circumvent such attenuating structures.

The iliac arteries take an arched course through the true pelvis, which makes it more difficult to achieve a small angle of incidence, in particular at the deepest point, the iliac bifurcation, where the origin of the external iliac artery is a predilection site for the occurrence of pelvic artery stenoses. The Doppler angle is optimized by moving the transducer along the course of the vessel and angling it (cf. Figs. 2.1 a and 2.1b). In patients with a poor insonation window, at least the origin of the common iliac artery from the aorta and the external iliac artery after the bifurcation and just proximal to the inguinal ligament should be scanned including spectral analysis of these vessel segments, as they are predilection sites for pelvic artery stenoses. Besides the analysis of the spectral Doppler tracings for established stenosis criteria, the comparison of the spectra from different sites will also yield indirect evidence of stenotic processes in between.

![Fig. 2.2. Positioning of transducer for pelvic artery examination (aortic bifurcation at the umbilical level) (cf. also Fig. 2.1a)](image-url)
2.1.2.2 Leg Arteries

The superficial course of the leg arteries makes it possible to use higher-frequency transducers of 3–7.5 MHz, depending on the thickness of the soft-tissue coat. Linear transducers require the activation of beam steering and careful alignment with the course of the vessel to achieve an adequate Doppler angle. Curved-array transducers with a small radius yield B-mode scans with somewhat poorer detail resolution but have the advantage of enabling fast optimization of the Doppler angle (< 60°) by angling of the transducer and placement of the sample volume at the lateral edges of the imaging field. In contrast, beam steering in most ultrasound devices enables a maximum deflection of the emitted beam of only 20°, resulting in a Doppler angle of 70° when interrogating vessels running parallel to the skin surface. Evaluation of spectral tracings for indirect signs of occlusive lesions in the vicinity of the sample volume requires an angle of less than 60°.

The femoral (Fig. 2.3 a) and anterior tibial arteries are examined in the supine position, all other lower leg arteries and the popliteal artery in the prone position with slight elevation of the distal lower leg by a support placed under the ankles.

In general, vessels are visualized in two planes. First, the vessel is identified in the transverse plane. The pulse repetition frequency and gain are set so as to ensure good color filling of the arterial lumen while avoiding aliasing. For a preliminary overview in transverse orientation, the transducer must be angled distally or cranially to achieve a small angle of insonation relative to the vessel. A survey in the transverse plane has the advantage of enabling rapid identification of vessel dilatations, stenoses that produce aliasing, and occlusions once adequate setting has been achieved. Abnormal findings need to be confirmed and quantified in the longitudinal plane. An adequate angle of insonation and verification of the Doppler angle in the B-mode scan are prerequisites for quantification of a stenosis. As in gray-scale scanning, the monitor display in vascular imaging in longitudinal orientation depicts the cranial vessel segment on the left and the distal segment on the right.

With the patient in the supine position and after an adequate period of rest (> 5 min), the common femoral artery is identified in the transverse plane and traced along its course to the bifurcation. The transducer is positioned (in most cases on the inner thigh) to view the bifurcation in such a way that the profunda femoris artery, which typically arises from the posterolateral aspect, comes to lie exactly behind the superficial femoral artery. In this way, the bifurcation is depicted as a fork in longitudinal orientation, which facilitates vessel identification and proper angle setting for evaluation of a stenosis at the origin of the profunda femoris. Especially when occlusions have been identified in the femoropopliteal segment, the profunda femoris artery should be traced to the level of second order branches and checked for the presence of more distal stenoses. The superficial femoral artery is traced in longitudinal orientation down the inner thigh. Scatter-
Fig. 2.4. Positioning of transducer for examination of fibular and posterior tibial arteries (course marked by thick black line)

The tibiofibular trunk varies in length from 1 – 5 cm, depending on the level of origin of the anterior tibial artery. Its division into the posterior tibial and fibular arteries is identified in the transverse plane. In the longitudinal view, the vessels are continuously scanned for stenosis or occlusion by following their courses distally (Fig. 2.4). If a vessel disappears from the scanning plane, it can easily be identified again by changing to a transverse view. The tibia and fibia cast acoustic shadows and can serve as landmarks. Further orientation is provided by the hyperechoic band of the deep crural fascia. Under good insonation conditions, the lower leg arteries can be visualized down to the ankle region. Time can be saved by obtaining two spectral tracings, one in the proximal and the other in the distal segment of the respective lower leg artery, which in general excludes a hemodynamically significant obstruction between the two sampling sites when both show the same flow profile and normal peak systolic velocity.

The dorsalis pedis artery and the posterior tibial artery behind the medial ankle are examined in the supine position using a high-frequency transducer (7.5 – 10 MHz). These vessels are first identified in the transverse plane to then obtain the Doppler spectrum in the longitudinal plane. From there, the course of the plantar artery can be tracked in transverse orientation and its patency determined down into the interdigital arteries.

2.1.3 Specific Aspects of the Examination from the Angiographer’s and Vascular Surgeon’s Perspective

As the therapeutic approach to peripheral artery disease is symptom-oriented (versus prognosis-oriented for the carotid territory), the diagnostic evaluation is guided by the clinical query, and vessel mapping is not done (Table 2.1). Efficient vascular evaluation is performed in stages (Fig. 2.5). If the patient’s history, clinical examination with full evaluation of peripheral pulses, and Doppler blood pressure measurement suggest arteriosclerotic occlusive disease (AOD), the next test is noninvasive duplex scanning to identify vessel obstructions and evaluate their localization and causes (embolism, atherosclerosis, compression syndrome). The ultrasound findings serve to determine the therapeutic procedure (medical treatment, radiologic intervention, surgical reconstruction). Angiography is performed only as part of a therapeutic intervention (diagnostic angiography plus angiographically guided percutaneous intervention) or in planning surgery (evaluation of outflow tract for bypass implantation and identification of the most suitable vessel segment for distal anastomosis). The use of further diagnostic procedures, in particular invasive modalities such as angiography, must always be guided by their therapeutic consequences. Hence, angiography has been abandoned for diagnosing peripheral AOD or evaluating the vascular status in patients with definitive or inconclusive symptoms of claudication because the therapeutic consequences are still unclear.

Adequate therapeutic measures in relation to the stage of disease are initiated on the basis of the clinical presentation in conjunction with the (noninvasive) duplex findings (cf. also Table 2.5, Fig. 2.6). In some cases, the site of obstruction and clinical stage allow surgical repair without prior angiography.

For instance, the indication for thromboendarterectomy (TEA) can be established without performing angiography if duplex ultrasound demonstrates a stenosis of the common femoral artery or of the origin of the profunda femoris artery – with occlusion of the superficial femoral – and excludes a vessel obstruction of the pelvic artery territory or, in occlusion of the superficial femoral, confirms refilling of the P1 popliteal segment without major obstruction. In these cases, TEA at the inguinal level is indicated with subsequent evaluation of the clinical improvement. Vessel mapping, in particular with evaluation of the lower leg arteries, does not affect therapeutic decision making, and the benefit of determining collateral flow in the thigh by preoperative anteroposterior

<table>
<thead>
<tr>
<th>Vascular disease</th>
<th>Therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral AOD</td>
<td>Symptom-oriented</td>
</tr>
<tr>
<td>Nonatherosclerotic peripheral vessel disease</td>
<td>Prevention-oriented</td>
</tr>
<tr>
<td>Carotid artery stenosis</td>
<td>Prevention-oriented</td>
</tr>
<tr>
<td>Aneurysm</td>
<td>Prevention-oriented</td>
</tr>
<tr>
<td>Diagnostic procedure prior to: Symptom-oriented therapy:</td>
<td>Levelwise duplex scanning guided by therapeutic options contemplated/step-by-step diagnostic management</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prevention-oriented</td>
</tr>
<tr>
<td></td>
<td>Duplex sonographic vessel mapping of predilection sites based on clinical suspicion or in high-risk patients</td>
</tr>
</tbody>
</table>
angiography in occlusion of the superficial femoral artery is disputed. This is confirmed in a study by our group including 38 patients with clinical stage II and III AOD in whom duplex scanning performed in the framework of step-by-step diagnostic workup demonstrated high-grade stenosis or occlusion of the common femoral artery (14 patients) or high-grade stenosis of the profund femoris artery in occlusion of the superficial femoral (24 patients). Angiography identified plaque with mild to moderate luminal narrowing in some of these patients and confirmed high-grade stenoses in 86 % of the cases. Intraoperatively, high-grade stenosis was confirmed in all cases. The popliteal artery was included in the duplex evaluation, which excluded pelvic stenosis, while dilation with stenting was performed before or during surgery in 4 cases. The crucial question to be answered by this study was whether preoperative angiography can be done without in patients with stenosis of the common femoral or profund femoris. In no case did the preoperative angiography findings alter the therapeutic procedure determined on the basis of duplex ultrasonography. However, 3 patients had to be excluded from the analysis due to a poor insonation window that prevented reliable exclusion of pelvic artery stenosis, which is the crucial prerequisite for dispensing with angiography.

An exception to the restrictive use of diagnostic angiography are patients with longstanding diabetes and secondary macro- and microangiopathy. Medial sclerosis in these patients may preclude continuous scanning of the lower leg arteries and peripheral outflow tract. Possible sequential stenoses may thus be overlooked. Still, identification of all macro- and microangiopathic lesions is necessary for initiation of appropriate therapeutic measures.

The hemodynamic effect of arterial stenoses is evaluated using hemodynamic parameters. Flow models and studies indicate that a reduction in vessel diameter of 50 % or more becomes hemodynamically significant and is associated with an increase in peak systolic velocity and, in higher-grade stenosis, an increase in peak end-diastolic velocity as well. The increase in peak velocity correlates with the grade of stenosis (cf. also Fig. 5.5).

In contrast to the evaluation of the carotid artery system, evaluation of plaque morphology in the B-mode for estimating the risk of embolism has no role in examining the peripheral arteries. This is obvious given the difficulties one faces in assessing the risk of embolism associated with carotid artery stenoses in B-mode sonography and the rare occurrence of interdigital artery embolism (blue toe). Nevertheless, one must be aware that, as in the carotid territory, the risk of embolism increases with the degree of stenosis and plaque thickness.

Determining the degree of stenosis from the vessel diameter and the residual perfused lumen on transverse color duplex scans is less accurate than the hemodynamic estimation from the Doppler waveform. The former is done only for preliminary orientation and is susceptible to artifacts due to calcified plaques. Moreover, the interpolation necessary
Common iliac artery stenosis (PTA and stent)
Internal iliac artery stenosis
External iliac artery stenosis (PTA)
Common femoral artery stenosis (TEA)
Stenosis at profunda femoris origin (TEA for stages II, III/no preop. angiography necessary)
Profunda femoris artery
Superficial femoral artery occlusion (bypass for stages IIb, III, IV)
Superficial femoral artery stenosis (conservative/(PTA))
Stenosis at opening
Popliteal artery stenosis/occlusion (PTA, bypass)
Lower leg artery occlusion (cons.)

Fig. 2.6. Schematic representation of stenotic and atherosclerotic processes diagnosed by duplex ultrasound and primary therapeutic procedures that can be initiated on the basis of the duplex ultrasound findings (alternative therapeutic strategies may be required according to the clinical stage or in patients with multilevel involvement)

because of the wider spacing of the color scan lines due to physical and technical limitations often leads to overestimation of the patent lumen and underestimation of the stenosis.

2.1.4 Interpretation and Documentation

Reporting and documentation of the duplex ultrasound findings of the leg arteries is guided by the assessment of the key sites. These are the common femoral artery, the origins of the deep and superficial femoral arteries, and the popliteal artery in longitudinal B-mode views and the corresponding Doppler spectra obtained with proper angles of incidence. If the findings at these levels are inconclusive or a specific clinical question has to be answered, angle-corrected time-velocity spectra are sampled in longitudinal orientation from the common and external iliac arteries, possibly the lower leg arteries as well, and documented together with longitudinal scans from these vessels. In addition, all abnormal findings (stenosis or occlusion) are documented on a longitudinal view with a corresponding angle-corrected spectral waveform. The intrastenotic and poststenotic Doppler waveforms are analyzed (see also Table 2.9) to quantify the stenosis (magnitude of peak systolic flow velocity, extent to which triphasic flow profile is lost poststenotically). An aneurysm must be documented in two planes and its diameter measured on the transverse scan. Partial thrombosis, if present, should be documented as well. Optional documentation of corresponding color duplex scans (transverse view of aneurysm, longitudinal view of stenosis) is useful.

The report should describe the morphologic and Doppler ultrasound appearance of the abnormal vascular findings that led to the diagnosis (Table 2.2).

2.1.5 Normal Duplex Ultrasound of Pelvic and Leg Arteries

Flow in the limb arteries is pulsatile and nearly laminar, due to the high peripheral resistance, which is reflected in the Doppler waveform by a narrow bandwidth with a clear systolic window. The typical triphasic waveform is characterized by a steep systolic upslope and rapid return to the baseline, followed by a short early diastolic reversal of flow and subsequent diastolic forward flow depending in magnitude and duration on the vessel area supplied (see also Fig. 1.22). The early diastolic backward flow component is due to the high peripheral resistance. The slight but variable forward flow in late diastole depends in magnitude not only on peripheral resistance (which in turn is dependent on sympathetic tone) but above all also on aortic compliance (windkessel effect).

The character of the Doppler waveform varies with the elasticity of the vessel wall and peripheral resistance (Table 2.3) and is influenced by systemic or local hypercirculatory effects (fever, hyperthyroidism, phlegmon). The more or less pronounced flow persisting during diastole is affected by physiologic parameters such as sympathetic tone and heart rate. In addition, the flow pattern is influenced by the ratio of skin to muscle supply, which is why diastolic flow is higher in the profunda femoris than in the superficial femoral artery (Fig. A 2.2). The vessel diameter and peak systolic velocity show wide interindividual variation and decrease toward the
Peripheral Arteries

and the extent of this change correlates with the decrease in peripheral resistance, triphasic flow becomes monophasic dilatation of the arterioles and the resulting decrease in end-diastolic velocity become more pronounced through poststenotic decrease in peak systolic velocity and increase in pulsatility of flow (for its calculation cf. Fig. 1.12). As the systole to the first peak.

The acceleration time is the quotient of decrease in peak systolic velocity and a lengthened systolic stenoses and occlusions are associated with a postocclusive changes in blood flow. Higher-grade stenoses and occlusions are associated with a postocclusive decrease in peak systolic velocity and a lengthened systolic acceleration time. The acceleration time is the quotient of peak systolic velocity and the pulse rise time from the onset of systole to the first peak.

Moreover, the pulsatility index (PI) is used to describe the pulsatility of flow (for its calculation cf. Fig. 1.12). As the poststenotic decrease in peak systolic velocity and increase in end-diastolic velocity become more pronounced through dilatation of the arterioles and the resulting decrease in peripheral resistance, triphasic flow becomes monophasic and the extent of this change correlates with the decrease in PI (cf. Figs. 1.12, A 2.2, and A 2.3).

Investigations of normal flow velocity in the pelvic and leg arteries (Jäger et al. 1985; Kohler 1990; Karasch et al. 1990; Polak et al. 1992) show wide variation between different study populations as well as between individual subjects within a study population. These observations make it somewhat difficult to determine an absolute systolic velocity threshold above which a hemodynamically significant stenosis should be assumed, as is the case for the diagnosis of carotid and renal artery stenosis. Alternatively, a hemodynamically significant stenosis is assumed when there is doubling of the mean normal velocity of the respective artery. The normal values determined by our group are presented in Table 2.4 and are comparable to those reported by others (Jäger et al. 1985; Kohler 1990; Karasch et al. 1990; Polak et al. 1992).

In addition to peak systolic velocity and changes in the normal triphasic flow profile, the acceleration index has established itself as a further parameter for describing occlusive and postocclusive changes in blood flow. Higher-grade stenoses and occlusions are associated with a postocclusive decrease in peak systolic velocity and a lengthened systolic acceleration time. The acceleration time is the quotient of peak systolic velocity and the pulse rise time from the onset of systole to the first peak.

Moreover, the pulsatility index (PI) is used to describe the pulsatility of flow (for its calculation cf. Fig. 1.12). As the poststenotic decrease in peak systolic velocity and increase in end-diastolic velocity become more pronounced through dilatation of the arterioles and the resulting decrease in peripheral resistance, triphasic flow becomes monophasic and the extent of this change correlates with the decrease in PI (cf. Figs. 1.12, A 2.2, and A 2.3).

### Table 2.3. Factors influencing the flow profile (Doppler waveform)

<table>
<thead>
<tr>
<th>Elasticity of the vessel wall (atherosclerosis, medial sclerosis)</th>
<th>Normal: Muscle activity</th>
<th>Abnormal: Inflammation (stage IV AOD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral resistance</td>
<td></td>
<td>Hypercirculation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pharmacologic therapy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Postocclusive vasodilatation (AOD)</td>
</tr>
</tbody>
</table>

### Table 2.4. Normal diameters (D) and peak systolic velocities (V\text{max} and standard deviation) of the pelvic and leg arteries determined in 30 healthy subjects

<table>
<thead>
<tr>
<th>Artery</th>
<th>D [cm]</th>
<th>V\text{max} [cm/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>External iliac artery</td>
<td>0.85 ± 0.11</td>
<td>116 ± 29.7</td>
</tr>
<tr>
<td>Common femoral artery</td>
<td>0.81 ± 0.17</td>
<td>112.2 ± 22.7</td>
</tr>
<tr>
<td>Proximal superficial femoral artery</td>
<td>0.65 ± 0.14</td>
<td>93.95 ± 15.9</td>
</tr>
<tr>
<td>Profunda femoris artery</td>
<td>0.55 ± 0.14</td>
<td>95.1 ± 21.5</td>
</tr>
<tr>
<td>Popliteal artery</td>
<td>0.58 ± 0.12</td>
<td>71.6 ± 12.4</td>
</tr>
</tbody>
</table>

### Table 2.5. Indications for (color) duplex ultrasound of the peripheral arteries

**Step-by-step diagnostic workup of AOD**
- Localization of flow obstruction (upper leg, lower leg, pelvis, vessel origin)
- Identification of type of flow obstacle (stenosis, occlusion)
- Length of flow obstacle (length of occlusion, sequential stenoses)
- Grading of stenosis (high-grade, low-grade)
- Cause of occlusion (embolism, atherosclerosis, trauma, compression, dissection)
- Evaluation of postocclusive outflow tract
- Therapeutic decision making: medical treatment, radiologic intervention, surgery

**Diagnostic evaluation of aneurysm**
- Localization
- Characterization (saccular, spindle-shaped, false)
- Extension (infra renal, aortoiliac, popliteal)
- Thrombosis (partial, complete)
- Therapy: compression therapy of false aneurysm, thrombin injection

**Arterial compression**
- Entrapment syndrome
- Cystic adventitial disease
- Thoracic outlet syndrome
- Tumor compression

**AV fistula**
- Localization
- Flow volume in fistula

**Follow-up after vessel reconstruction**
- Bypass procedure (anastomotic stenosis, suture aneurysm, infection, occlusion, flow velocity inside bypass: prognosis)
- PTA (residual stenosis, restenosis, puncture aneurysm, hematoma)
- Endoluminal stents (patency, stenosis)
Fig. A 2.2 a–f
Femoral bifurcation – normal perfusion

a Gray-scale scan and color flow information supplement each other: Along the course of an artery, some segments may be better appreciated in the B-mode scan, others in the color Doppler mode. In the example, the superficial femoral artery (A.F.S) and profunda femoris artery (A.P.F) are insonated with a smaller angle and are thus seen better in the color mode whereas wall structures perpendicular to the ultrasound beam (here: common femoral artery, A.F.C, left side of scan) are seen more clearly in the B-scan. Echo pulses striking the vessel wall at a perpendicular angle produce a detailed image of wall structures as the wall is a strong reflector. In contrast, only a shallow angle between the direction of flowing blood and the beam enables adequate sampling of Doppler information for reliable evaluation of flow

Although all extremity arteries have a triphasic pulsatile flow profile under normal conditions resulting from the high peripheral resistance at rest, different spectral waveforms may be obtained, depending on the territory supplied by the vessel interrogated. A vessel with high-resistance flow like the superficial femoral artery, which mostly supplies skin and subcutaneous tissue but only a small proportion of muscle, has a triphasic waveform with pronounced pulsatility and zero flow in end-diastole

The example shows the femoral bifurcation with the Doppler sample volume placed in the superficial femoral artery (A.F.S). Blue indicates arterial flow away from the transducer, red the flow in the superficial femoral vein toward the transducer. The corresponding Doppler tracings illustrate the hemodynamic situation at rest (left waveform) and after exercise (right waveform). Peak systolic velocity increases from 90 cm/s at rest to 141 cm/s after exercise (10 tiptoe movements)

The increased muscular blood demand during exercise is met by a decrease in peripheral resistance and is reflected in the Doppler waveform by an increase in peak end-diastolic flow velocity from 0 (left waveform) to 16 cm/s (right waveform)

b Femoral bifurcation (longitudinal scan): The profunda femoris (A.P.F) supplying more muscle tissue has a slightly less pulsatile flow but the profile is still triphasic. Peak velocity at rest (left waveform) is 77 cm/s in systole and 7 cm/s at end-diastole

After exercise (right waveform) peak systolic flow increases to 90 cm/s with end-diastolic velocity doubling to 15 cm/s. The color change in the color duplex image from red, through black, to blue reflects the change in flow direction relative to the ultrasound beam (toward transducer: red; away from transducer: blue). (A.F.S superficial femoral artery, A.F.C common femoral artery)

c When there is occlusion of the superficial femoral artery (A.F.S), the profunda femoris is the main collateral vessel to compensate for this loss. The increased blood flow in the profunda femoris circulation is reflected by a higher flow velocity, which may increase by 50 – 80% even if there is no stenosis at the origin of the profunda femoris

The Doppler waveform from the profunda femoris artery (A.P.F) illustrates peak velocity in case of occlusion of the superficial femoral, which is 145 cm/s in systole and 18 cm/s in diastole. Reversed flow due to eddy currents at the origin of the occluded superficial femoral is displayed in red
The leg arteries have a triphasic waveform down into the periphery as illustrated here by the normal fibular artery. The artery has a diameter of 2.7 mm.

**Sonoanatomy of the origin of the anterior tibial artery**

The popliteal artery gives off the anterior tibial artery, which courses anteriorly to pierce the interosseous membrane in front of which it descends, initially taking a course close to the fibula. The scan depicts the anterior tibial artery insonated from a posterior transducer position (popliteal fossa) in blue (flow away from transducer) downstream of its origin from the popliteal artery (A.POP) as it pierces the interosseous membrane (hyperechoic structure between tibia and fibula). With the transducer slightly angled, the anterior tibial vein is depicted in blue (flow toward transducer) along its course parallel to the artery and as it empties into the popliteal vein.

**Hyperemia**

Peripheral inflammation is another factor affecting the character of the Doppler waveform besides an increased flow resulting from exercise-induced hyperemia or collateral function of a vessel. In the case depicted here, a phlegmon of the foot results in a monophasic waveform with reduced pulsatility and a rather high end-diastolic flow velocity of 22 cm/s. The fact that the steep systolic upslope is preserved excludes an upstream stenosis. In contrast, the normal anterior tibial artery has a triphasic flow profile with short diastolic forward flow after the incisure and zero end-diastolic flow (cf. Fig. A 2.2 d).
In evaluating a patient with suspected pelvic artery obstruction, the examiner first obtains Doppler tracings from both common femoral arteries to compare these in terms of triphasic flow, steep systolic upslope, and magnitude of peak systolic velocity. Reliable Doppler shift analysis requires an insonation angle below 60°. In this example, the angle is 50° on the right and 54° on the left. The waveform from the right groin shows triphasic flow with a systolic upslope and a peak systolic velocity of over 80 cm/s.

The Doppler waveform from the left common femoral artery illustrates postocclusive flow with a monophasic profile, reduced peak systolic velocity (57 cm/s), and delayed systolic rise.

Monophasic flow profile caused by a high-grade stenosis of the common iliac artery (A.I.C) due to plaque, mainly of the posterior wall. Criteria for a stenosis are aliasing in the color duplex image and a peak systolic flow velocity of over 5 m/s in the Doppler frequency spectrum.

Angiography demonstrates the high-grade iliac stenosis as a filling defect in the lumen.
Fig. A 2.4 a–f
External iliac artery stenosis — diagnosis by distal Doppler tracing

a Under good insonation conditions, the B-scan demonstrates stenosing plaques (P) in the pelvic artery territory by an irregular vessel contour, acoustic shadowing due to calcification, and protrusion of hyperechoic structures into the lumen.

b Only color duplex scanning enables qualitative estimation of the degree of a stenosis on the basis of aliasing and the Doppler waveform its quantitative hemodynamic grading. The example shows a stenosis in the external iliac artery (A.I.E) immediately distal to the bifurcation. The internal iliac artery (A.I.I) is depicted farther away from the transducer. The high peak systolic flow velocity suggests a higher-grade narrowing with the pulsatile flow profile (early diastolic dip) indicating only little impairment of peripheral hemodynamics at rest. Taken together, these findings suggest good collateralization and/or a stenosis grade of less than 75%.

c Such stenoses will be noted in the Doppler waveforms from the groin and a more peripheral site only if the examination is performed carefully and the Doppler information is acquired with an angle as small as possible and a meticulous spectrum analysis is done with comparison of both sides. In this case, the waveform from the stenotic side shows an early diastolic retrograde flow component, indicating that high peripheral resistance is preserved, while peak systolic velocity is markedly decreased compared to the unaffected side (80 cm/s versus 150 cm/s). Moreover, the waveform from the unaffected side displays the preserved diastolic flow resulting from the windkessel effect of the aorta.
Collateral pathway
1 lumbar
2 epigastric
3 mesenteric
4 iliofemoral
5 profunda femoris territory

(Fig. A 2.4 cont.)

The upstream stenosis on the left is likewise apparent in the popliteal waveform as a dampened flow signal that is also audible and a postocclusive peak systolic velocity of 29 cm/s versus 45 cm/s on the nonstenotic side.

Another way of demonstrating a stenosis is to sample the Doppler information after exercise: After 10 knee bends, the Doppler waveforms from the groin and popliteal artery are monophasic on both sides (due to exercise-induced peripheral widening). On the unaffected side, the waveform returns to its normal triphasic shape within a minute. A delayed return to this normal profile indicates a stenosis, which prevents an adequate blood supply during and after exercise. The length of the delay varies with the stenosis grade and collateralization.

Status after dilatation and stenting of a proximal external iliac artery stenosis with a high-grade stenosis at the proximal end of the stent (aliasing, peak systolic flow above 4 m/s). The meshlike structure enables good estimation of the extent of the stent.

Collateral pathways in stenosis and occlusion of the aortoiliac and iliofemoral territories

The better the collateralization, the less pronounced the postocclusive changes of the Doppler waveform.
Fig. A 2.5 a–h

iliac artery – stenosis – occlusion – collateral pathways

a The iliac bifurcation with the origin of the internal iliac artery (A.I.I) is situated at the deepest point of the true pelvis. The internal iliac courses posteriorly (blue, away from transducer, toward periphery). The waveform shows a pulsatile profile but with diastolic flow because the internal iliac empties into the pelvic vessels. The color change from red to blue in the bifurcation is due to the changed flow direction relative to the ultrasound beam. With the high pulse repetition frequency selected to depict fast arterial flow, no flow signals are obtained from the iliac vein (V) posterior to the artery. (A.I.E external iliac artery, A.I.C common iliac artery)

b Exact localization of an occlusion is crucial for planning a bypass procedure. In case of external iliac artery occlusion (A.I.E), the internal iliac artery (A.I.I; blue, away from transducer) is an important collateral pathway.

c, d 54-year-old patient with intermittent claudication with a short walking distance and impotence (see also Ch. 7) due to external iliac artery occlusion (Doppler waveform with wall pulsation but no flow signals) and concomitant high-grade internal iliac stenosis (aliasing and peak systolic velocity of 4 m/s)

e Oblique angiographic projection depicting right-sided occlusion of the external iliac artery and internal iliac stenosis. The internal iliac artery stenosis on the left is obscured by superimposed structures.
In common iliac artery occlusion, the internal iliac fills the external iliac and shows retrograde flow (red, toward transducer). No flow signal in the common iliac artery (A.I.C).

The refilled external iliac artery (A.I.E) is depicted with normal flow toward the periphery (red). The waveform is monophasic, corresponding to postocclusive flow.

Angiography showing common iliac artery occlusion.
Fig. A 2.6 a–d
**Common iliac artery stenosis**

a Morphologic evaluation of the pelvic territory is frequently precluded by scattering structures and the great scanning depth necessitating the use of low-frequency transducers with a poor resolution. Therefore, only hemodynamic parameters can be determined to diagnose a stenosis. In the case presented, a stenosis of about 60% in the mid-portion of the common iliac artery produces aliasing in the color flow image. In the Doppler tracing, peak systolic velocity is increased to 330 cm/s while pulsatility is preserved. The early diastolic incisure (arrows) is obscured by retrograde flow during systole (turbulence).

b The decreased peripheral resistance shortly after exercise induces an increase in flow velocity (440 cm/s in systole and 30 cm/s at end diastole). The waveform and the reduced pulsatility suggest a high-grade stenosis. The increased arterial blood flow resulting from the higher peripheral demand leads to overestimation of the degree of stenosis. The rather low overall diastolic flow is, in this case, due to diabetes-related vascular damage. This example underlines the importance of 3 to 5 minutes of rest prior to stenosis grading in order to prevent overestimation.

c Stenoses of the iliac and common femoral arteries are often more difficult to assess by angiography in anteroposterior projection because plaques of the posterior wall may impair evaluation of the hemodynamic significance. The gray-scale scan depicts the posterior wall plaque with acoustic shadowing. Aliasing in the color duplex image and the Doppler tracing with a peak systolic velocity of 250 cm/s but preserved triphasic flow suggest a stenosis becoming hemodynamically significant.

d Angiography demonstrating wall irregularities of the common iliac artery and luminal narrowing at its origin.
Iliac artery aneurysm

a The common iliac artery (left side of scan) shows circumscribed dilatation at its origin from the aorta (red, flow toward transducer). The aneurysm (AN) has a diameter of 2.5 cm and contains no thrombus. There is aliasing in the color duplex scan distal to the aneurysm. Along its further course, the common iliac artery is depicted in blue indicating flow away from the transducer. The peak velocity is 590 cm/s during systole and 45 cm/s at end-diastole. These velocities, together with the monophasic flow profile, indicate a high-grade stenosis at the distal end of the aneurysm.

b Angiography: Aortic aneurysm and stenosis at the origin of the common iliac artery (arrow)

Common femoral artery stenosis

a In the common femoral artery, stenosing plaques chiefly affect the posterior wall. The B-scan depicts the extent and morphology of the plaque with acoustic shadowing (SS). The transverse scans (B-scan in the middle, color duplex scan on the right) illustrate the problem of estimating the degree of stenosis on the basis of cross-sectional area reduction (vessel cross-section/plaque cross-section; planimetric measurement: 69.9%). Acoustic shadowing impairs visualization of the vessel and plaque contour in the B-mode and thus makes it difficult to precisely differentiate the atherosclerotic wall thickening from the patent lumen. In the color duplex mode, perivascular vibration artifacts and poor color resolution with interpolation lead to “color overflow” beyond the patent lumen.
Perivascular vibration artifacts may prohibit the differentiation of the patent lumen from plaque by color duplex scanning in large vessels with high-grade stenosis (left section: longitudinal color scan; middle section: corresponding B-scan). The combination of plaque localization in the B-scan and color duplex visualization of the stenosis jet facilitates placement of the sample volume in the jet for recording of a representative Doppler spectrum. Here, peak systolic flow over 3.5 m/s, pronounced turbulence, and monophasic flow suggest high-grade stenosis.

B-scan on the left and color duplex scan in the middle demonstrate a similar situation in the common femoral artery on the contralateral side with plaques protruding into the vessel lumen. However, the Doppler tracing fails to demonstrate a hemodynamic effect (triphasic flow with normal waveform and no increase in peak systolic velocity).

Angiography depicting plaques with luminal narrowing of the common femoral artery, which is more pronounced on the right side.
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