Chronic symptomatic ischemia in the upper extremity is the result of blood flow that is nutritionally inadequate to fulfill metabolic requirements. Symptoms may also result from inappropriate thermoregulatory function. Ischemia may be secondary to inappropriate vessel response when vessels are unable to vasodilate in response to stress or inappropriate vasoconstriction (ie, vasospastic disease); intima/media injury resulting in aneurysm, embolism, and thrombosis (occlusive disease); or a combination of both (vaso-occlusive disease). Occlusive events may occur secondary to low-flow states in vasospastic disease that precipitate thrombosis development (ie, secondary occlusion) or secondary to ischemia from occlusive disease that may produce autonomic dysfunction and secondary vasospasm. This cross-over phenomenon creates difficulty in evaluation and management. The goal of this article is to assess contemporary methods of evaluation, classification, and management of upper extremity ischemia.

ANATOMY

Significant variations of the vascular anatomy of the hand exist.1,2 Classically, the arterial supply of the hand occurs through the superficial palmar arch (a continuation of the ulnar artery) and the deep palmar arch (a continuation of the radial artery). A persistent median vessel or interosseous vessel is present in 5% of hands.3,4 The ulnar artery and superficial arch typically provide (1) 1 or 2 branches to the deep arch, (2) the proper digital artery to the little finger, (3) a common digital artery to the little and ring fingers, (4) a common digital artery to the ring and long fingers, and (5) a common digital artery to the long and index fingers. The terminal branch anastomoses with the deep arch at the level of the princeps pollicis. Clinically significant variations occur in 2 major sites: (1) the superior and inferior deep branches of the ulnar artery, which are continuous with the deep arch, and (2) the termination of the superficial arch, which may be continuous with either the princeps pollicis (39%), the radial artery (34.5%), or the median artery (5%).1

Less variation exists at the level of the deep arch. The radial artery and deep arch typically provide (1) a superficial branch, which continues with the superfi-
cial arch in 34.5%; (2) a first dorsal metacarpal artery; (3) the proper digital artery to the index; (4) the princeps pollicis artery; (5) the common digital vessels to the index/long, long/ring, and ring/little fingers; (6) a proper digital vessel to the little finger; and (7) a connection to the superficial arch via the superior and/or inferior branches of the ulnar artery.

The superficial or deep palmar arches are defined as completed if there is a significant connection to a branch from a parallel artery or arch. The superficial arch may be completed by a branch from the deep arch (39%), the radial artery (34.5%), or the median artery (5%). The deep arch is less variable and is completed by the superior or inferior ulnar recurrent in 95.5% of cases (Fig 1). In a Doppler study of 120 normal subjects, 57% of radial arteries provided dominant flow to 3 or more digits. The ulnar artery supplied 3 or more digits in only 21.5% of hands, and the radial and ulnar arteries were equal in flow in 21.5% of hands.

Despite the number and variety of vascular patterns, the existing anatomy texts report at least 3 palmar common digital vessels at the level of the metacarpophalangeal joint in all patients.

**EVALUATION**

The first step in managing ischemia in the hand is to establish if the process is primarily vasospastic or occlusive disease. Because combined vaso-occlusive processes can occur from either process, it is critical to establish the predominant pathophysiology. Primary vasospastic disease is often secondary to a collagen vascular disorder (eg, scleroderma, CREST syndrome [calcinosis, Raynaud’s disease, esophageal dysmotility, sclerodactyly, and telangiectasia], or rheumatoid arthritis). Occlusive disease occurs, in general, after trauma (eg, hypothenar hammer syndrome, penetrating trauma [pseudoaneurysm], and tobacco use [Buerger’s disease]). Symptoms of upper extremity ischemia typically include pain, cold sensitivity (intolerance), numbness, and paresthesias, and signs include pallor, abnormal Allen test results, ulceration, and/or gangrene. Medical history may be therefore augmented by health-related quality of life scales including the Levine Carpal Tunnel Instrument, the McCabe Cold Sensitivity Severity Scale, the McGill Pain Questionnaire, and the DASH (Disabilities of the Arm, Shoulder, and Hand) Outcome Scale.

**DIAGNOSTIC EVALUATION**

Diagnostic modalities may be divided into tests that image vascular anatomy and those that assess adequacy of functional blood flow (both thermoregulatory and nutritional).

Imaging studies include ultrasonography (both Doppler and pulse echo), contrast arteriography, and magnetic resonance angiography. Ultrasonography has the advantages of being noninvasive and inexpensive, and it allows the real time assessment of the wall, lumen, and intraluminal changes. The combination of ultrasonographic imaging with quantitative color-coded Doppler assessment (color duplex imaging) provides high resolution of intraluminal events, an evaluation of mural activity, and quantitative-flow data flow across injured segments. Arteriography provides the optimal anatomic detail and can identify...
arterial variants, thrombosed segments, and distal emboli. Arteriographic imaging is enhanced by intravascular vasodilators, careful assessment of antegrade versus retrograde flow, and analysis of segment reconstruction. Magnetic resonance arteriography with or without intravenous gadolinium contrast permits visualization and mapping of arterial and venous structures and has been used to verify normal vascular anatomy before free tissue transfers, to visualize vascular tumors, and to show the relationship of neoplasms to vascular structures.14-16

Physiologic Assessment of Flow

Despite advances in imaging modalities, symptoms do not necessarily correlate with arteriographic findings. In a recent study of 23 patients with symptomatic multiple-level occlusive disease, arteriography proved a poor predictor of the presence and magnitude of the symptoms.17 This disparity between symptoms and arteriographic findings supports the use of physiologic control mechanisms and highlights the importance of quantitating both macrovascular and microvascular flow. Digital temperature, digital plethysmography, laser Doppler fluxmetry, vital capillaroscopy, and digital blood pressure allow the assessment of both macrovascular and microvascular elements of digital blood flow.4 These studies (eg, laser Doppler fluxmetry) are more reliable than arteriography at predicting patients’ symptoms.17 The digital brachial index (DBI) is an inexpensive and reliable means of quantitating total blood flow.18 DBI is equal to digital blood pressure divided by brachial blood pressure. A DBI greater than 0.7 suggests sufficient blood flow to prevent tissue necrosis, whereas a value of 0.7 or less suggests a need for intervention.18 In the absence of reproducible stress, digital temperature measurements (including thermography) must be interpreted carefully. Normally, digital temperature responds to cold stress with cooling followed by rapid rewarming. Low digital temperatures may represent upper extremity ischemia, vasospasm secondary to peripheral nerve injury, or vasospasm making clinical correlation mandatory.19 Laser Doppler fluxmetry is an excellent indicator of cutaneous hand perfusion; it measures motion of red blood cells and can be numerically quantified after stress. The technique provides reproducible, real-time, noninvasive microvascular data that correlate closely with symptoms and function.17

Symptoms of upper extremity ischemia may be altered significantly by the presence of environmental stress. The use of cold as a stressor may be done in conjunction with any of the previously mentioned modalities to document adequate blood flow in response to physiologic stress. Patterns of digital temperature fluctuation and laser Doppler fluxmetry have been observed and characterized for a variety of occlusive and vasospastic disorders.20,21

Nonoperative Treatment

The nonoperative management of upper extremity vascular disease has focused on lifestyle changes, the use of thrombolytic agents to reconstruct the vessels, and the use of pharmacologic agents to alter autonomic dysfunction.

Thrombolytic agents have been used to recanalize medium- and small-vessel occlusions with variable success.22 An arterial catheter is advanced to or into the thrombus, and the thrombolytic agent is infused. Intermittent repeat arteriograms at 6- to 12-hour intervals document progress or failure of the technique. The technique, although less invasive than surgical options, requires close observation because of local or distant hemorrhage, autoimmune complex formation, and long-term anticoagulation. The risk of repeat thrombosis and the conversion of a thrombosed aneurysm to an aneurysm are the significant concerns regarding the use of thrombolytic agents. The risks and benefits of this procedure are not well defined, and the risk of repeat thrombosis may preclude its use in otherwise healthy patients.

Pharmacologic intervention primarily relies on vasodilators or sympatholytics. Oral vasodilators including nifedipine (a calcium-channel blocker) increase collateral and nutritional blood flow, thereby decreasing ischemic symptoms from vasospasm and inappropriate shunting. In addition, topical vasodilators such as nitroglycerine ointment may provide some end-organ vasodilation with subsequent symptomatic relief. Sympatholytic agents (eg, tricyclic antidepressants, epidural or brachial plexus blockade) alter autonomic function and improve thermoregulatory and nutritional blood flow. The long-term efficacy of these measures remains undocumented. Lifestyle alterations including cessation of smoking, biofeedback,
discontinuation of caffeine, and minimization of cold exposure use may reduce sympathetic tone and result in improved vascular perfusion.6,23

OPERATIVE MANAGEMENT—OCCLUSIVE DISEASE

Oclusive disease of the hand includes (1) adventitial, medial, or intimal changes (secondary to either trauma or plaque/mural thrombus formation that compromise flow); (2) thrombus formation (with or without aneurysm); and (3) embolism with distant thrombosis. Ischemia may result from inadequate collateral vessels or inadequate flow through collateral vessels secondary to vasospasm. Surgical treatment may restore flow through compromised vessels, increase effective collateral flow, or both.24 Historically, ligation of the thrombosed segment (Leriche sympathectomy) with resultant interruption of the sympathetic nerve fibers in the adventitia was the primary surgical option.25 Subsequently, the use of microsurgical techniques to reconstruct thrombosed segments of the radial artery, ulnar artery, and superficial arches was described.26 There currently exists a dilemma concerning the need for arterial reconstruction versus ligation of the thrombosed segment.4 The ligation of the thrombosed segment results in a Leriche sympathectomy, which may be supplemented by additional adventitial stripping at the level of the common digital arteries. If symptoms are related to secondary vasospasm and the patient has adequate collateral circulation to prevent ischemia symptoms during rest and stress (ie, cold weather), excision and ligation provide safe and effective palliation. However, if collateral flow is inadequate, arterial reconstruction is crucial for optimal outcome. A variety of sophisticated modalities permit an assessment of adequate collateral flow; however, the decision is primarily clinical. Useful data supporting sympathectomy alone include a DBI greater than 0.7, pulsatile Doppler readings after pharmacologic sympathectomy intervention, and pulsevolume recordings approaching the asymptomatic contralateral limb after sympathetic blockade or intra-arterial vasodilators.

Arterial reconstruction is suggested by a DBI of less than 0.7, evidence of inadequate potential collateral flow (eg, injury to parallel vessels, thrombosis past collateral inflow, or distal emboli), or diffuse disease. There are currently no randomized studies that compare the results of sympathectomy alone with the results of arterial reconstruction for chronic occlusive disease. The preoperative assessment of flow adequacy is confounded by the presence of distal occlusions at or distal to the level of the proximal interphalangeal (PIP) joint and the effect of abnormal tone on resistance vessels. In a study of 37 patients with chronic vaso-occlusive disease, 76% of hands had multilevel occlusions. Thirteen of 25 hands (52%) had occlusion of the ulnar artery or superficial arch with a second occlusion in the proper digital vessel at or distal to the PIP joint. Distal occlusion at the level of the PIP joint makes it difficult to anatomically verify the presence of adequate collateral vessels by arteriography alone and is presumptive evidence of inadequate collateral flow.17,21 In this group of patients, successful proximal arterial reconstruction improved total flow, digital flow, symptoms, and quality of life. Our current protocol involves appropriate medical management and lifestyle alterations. If symptoms persist, exploration is performed. If the occluded vessel is reconstructable, then reconstruction, generally with a reversed interposition vein graft, is attempted. The presence of an unreconstructable distal occlusion at or distal to the level of the PIP joint is an indication for reconstruction.27 If the vessel is not reconstructable, a Leriche or periarterial sympathectomy is performed27 (See Table 1).

<table>
<thead>
<tr>
<th>Level of Injury</th>
<th>Finding</th>
<th>DBI</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Internal elastic lamina</td>
<td>Aneurysm</td>
<td>Usually &gt; 0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thrombosis</td>
<td>Usually &gt; 0.7</td>
</tr>
<tr>
<td>II</td>
<td>Media</td>
<td>Buerger’s disease</td>
<td>Usually &lt; 0.7</td>
</tr>
<tr>
<td>III</td>
<td>Adventitial</td>
<td>External constriction</td>
<td>Usually = 0.7</td>
</tr>
</tbody>
</table>

Abbreviation: DBI, digital brachial index.
OPERATIVE TECHNIQUES

Under an adequate level of anesthesia, the upper extremity is exsanguinated, and a tourniquet is inflated, and a longitudinal and extensile incision is made to expose the ulnar artery and superficial arch. The choice of anesthesia depends on whether the saphenous veins of the foot will be used as a graft site. Exploration is performed under magnification, and the thrombosed segment of the ulnar artery is identified. If there is any history of carpal tunnel symptoms, the transverse carpal ligament is released to avoid repeat exploration in the future. Proximal and distal resection points are identified. Vessel damage is often extensive, with average compromised segment measurements of 5 to 7 cm. The existence of a patent side branch proximal and distal to the thrombus is the best indicator of an adequate inflow and outflow. The dissection should include the origin of the superior and inferior collateral vessels, the proper digital vessel to the little finger, and the superficial arch. The damaged segment typically involves the origin of the proper digital vessel to the little finger and the origin of the superficial arch. A branched vein is selected from either the patients’ ipsilateral cephalic system, saphenous vein at the foot, or saphenous vein at the knee. In the majority of cases, the caliber of the vessels is best approximated by the venous system at the foot. The vein graft is reversed and the vessel dilated, and flow is confirmed by using heparinized saline under pressure, with leaks being repaired. The graft is sutured in distally by using the operating microscopic with 9-0 or 10-0 nylon. End-to-end repairs are performed to the proper digital vessel of the ring/little fingers and/or proximal arch. Antegrade flow is verified, and proper rotation of the graft is checked. The proximal anastomosis is then performed. In the case of more extensive thrombosis, complex reconstructions may be necessary (Fig 2). Alternative methods of reconstruction include end-to-end repair, nonreversed veins (with valvulotomes), or arterial grafts.4,13,28

Occlusive disease of the radial artery occurs as the artery passes from volar to dorsal under the first dorsal compartment. In a series of 13 radial artery occlusions,

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Clinical Finding</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Primary Raynaud’s disease</td>
<td>Adequate collateral flow</td>
<td>Nonoperative management</td>
</tr>
<tr>
<td></td>
<td>Inadequate collateral flow</td>
<td>Sympathectomy</td>
</tr>
<tr>
<td>II Secondary Raynaud’s disease</td>
<td>Adequate collateral flow</td>
<td>Sympathectomy</td>
</tr>
<tr>
<td></td>
<td>Inadequate collateral flow</td>
<td>Consider bypass graft</td>
</tr>
<tr>
<td>III Thromboangiitis obliterans</td>
<td>Inadequate collateral flow</td>
<td>Bypass graft; consider salvage procedures</td>
</tr>
</tbody>
</table>
reconstruction was performed end to end into the deep arch in 5 cases. In the remaining 8 cases, a branched reversed ipsilateral cephalic or saphenous vein was used with distal end-to-end repairs to the deep arch and princeps pollis and with proximal anastomosis to the radial artery. Postoperatively, the patients are maintained on low–molecular-weight dextran for 2 to 4 days and subsequently discharged on a regimen of enteric-coated aspirin and ibuprofen.

Results of reconstruction of occlusive disease vary depending on the cause and the extent of the disease. Patency rates for ulnar-sided reconstruction showed that 2 of 16 patients had an acute thrombosis and that 1 of 16 had a late thrombosis (more than 6 months after surgery). Radial-sided occlusion tended to be more localized and had a 100% patency rate at a mean 22-month follow-up. Both radial and ulnar artery reconstruction showed improved microvascular perfusion by laser Doppler and temperature (with and without a cold stress), which correlated with improved symptom and function. Cold sensitivity, as measured by the McCabe Sensitivity Severity Scores, did not improve.

**VASOSPASTIC DISEASE**

Primary Raynaud’s disease typically presents in young women without significant ischemic changes or necrosis. When Raynaud’s phenomenon is present in conjunction with a collagen vascular disease, the diagnosis of secondary Raynaud’s disease is made. The presence of ulcerations and/or gangrene, in general, suggests an occlusive component. Typically, Raynaud’s disease is present only with thermal stress, rarely results in necrosis, and responds to nonoperative measures. Secondary Raynaud’s phenomenon may be complicated by occlusive events and may be grouped based on the presence or absence of adequate collateral circulation. Optimal management of refractory vasospastic disease is controversial because of the significant number of comorbidities. In a series of 70 periarterial sympathectomies, scleroderma was identified as the primary diagnosis in only 21 patients. The remaining patients had significant other comorbidities (eg, insulin-dependent diabetes mellitus, atherosclerotic coronary artery disease, and Buerger’s disease), all of which predispose the patient to additional vascular events. In the presence of vasospastic disease and secondary occlusion, the treatment options in-
clude interposition grafting, Leriche sympathectomy, periarterial sympathectomy, or a combination of 2 or more of these. The clinical decision is based on the adequacy of collateral vessels and the feasibility of arterial reconstruction.

Inadequate collateral flow is suggested by the presence of significant tissue loss or frank gangrene, the existence of segmental occlusions on arteriography, a DBI of less than 0.7, failure to respond to intraarterial vasodilators at arteriography, and clinical failure after sympathetic blockade.

When one of more of these factors are present, arterial reconstruction is recommended if technically possible. Excision of the thrombosed segments and interposition graft combined with periarterial sympathectomy is used. In the absence of occlusions or if the occlusion is unreconstructable, periarterial sympathectomy alone provides moderate relief of ischemic symptoms (Table 2).

**PERIARTERIAL TECHNIQUE**

**Periarterial Sympathectomy**

The procedure is performed through 3 extensile incisions. First, the radial and ulnar arteries are exposed at the level of the distal wrist crease. The incision on the ulnar artery is carried distally across the palm just distal to the distal palmar crease. The third incision is dorsal-radial, immediately distal to the anatomic snuffbox (Fig 3). The operating microscope is used after initial dissection and a 1- to 2-cm segment of adventitia is stripped from the (1) ulnar artery, (2) superficial arch, (3) common digital vessels, (4) proper digital artery to the little finger, (5) radial artery, and (6) origin of the deep arch between the 2 heads of the first dorsal interosseous.

The results of sympathectomy remain variable. In the acute setting, sympathectomy improves microvascular perfusion (as measured by laser Doppler), correlates with healing of digital ulceration in the majority of patients, and improves health-related quality-of-life indicators. Long-term results suggest sustained improvement in microvascular perfusion and health-related quality-of-life indicators, but very few patients (17%) had no further ulceration, and 13% eventually required further finger tip amputations.

**SUMMARY**

The management of chronic occlusive and vasospastic disorders of the upper extremity is difficult and requires an assessment of vascular structure and function. In vasospastic disease, secondary occlusion is often the harbinger of dysfunction. Both the degree of symptoms and the optimal intervention technique depend on the degree of arterial damage, the location of the vascular insult, and the adequacy of collateral vessels. Treatment is directed by clinical considerations that include severity of symptoms, degree and severity of ulcerations, and an assessment of vascular distribution. Arterial reconstruction is performed in the face of tissue necrosis whenever possible, regardless of whether the cause is primary or secondary vasospasm. Periarterial sympathectomy alone is reserved as a salvage procedure for ischemic extremities in which arterial reconstruction is not feasible or for refractory vasospastic patients without occlusion. The role of sympathectomy alone in a reconstructable artery may be indicated in patients with marginally adequate flow that is compromised by abnormal sympathetic tone, no tissue necrosis, and potentially adequate collateral circulation.

**REFERENCES**