REVIEW ARTICLE

Noninvasive Evaluation of Upper-Extremity Vascular Perfusion

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Evaluation of vascular disorders of the upper extremity requires an anatomic and functional approach. The combination of a good history and physical examination, laboratory testing, and specialized vascular laboratory studies will help detect any underlying collagen vascular disease or coagulopathy and provide physiologic-specific and patient-oriented management. This paper reviews the currently available noninvasive modalities for the evaluation of upper-extremity perfusion. *(J Hand Surg 2008;33A:591–600. Copyright © 2008 by the American Society for Surgery of the Hand.)*

Key words Disorders, evaluation, hand, upper extremity, vascular.

Vascular disorders of the upper extremity are rare and far less frequently encountered than are those of the lower limb; nevertheless, they may cause marked morbidity.[1,2] Upper-extremity flow is both thermoregulatory and nutritional with symptoms of pain, cold sensitivity, numbness, and signs of ulceration and/or gangrene correlating with inadequate nutritional flow sufficient to respond to the metabolic requirements of the tissues. The causes may involve (1) structural abnormalities (occlusive disease), (2) inappropriate control of the vascular system (vasospastic disease), or (3) a combination of both (vaso-occlusive disease). Because the primary goal of treatment is to restore pulsatile blow flow to nutritional beds, information regarding both structure and function should be obtained (Table 1). The purpose of this article is to present the currently available noninvasive techniques for the evaluation of the components of upper-extremity perfusion to help guide treatment algorithms.

ANATOMY

In the hand, the ulnar artery continues as the superficial palmar arch, and the radial artery continues as the deep palmar arch. In approximately 5% of patients, an interosseous median artery is a major contributing vessel. If the arch connects with a branch from another independent artery, that arch is defined as *complete*. In approximately 78.5% of extremities, the superficial palmar arch is complete, whereas the deep palmar arch is complete in 97% of extremities[3] (Fig. 1). Although the patterns of collateral flow may vary tremendously,[3] the presence of 3 palmar common digital arteries at the level of the metacarpophalangeal joints is a consistent finding.[4] Common digital vessels branch into radial and ulnar proper digital arteries. The thumb is variably supplied by either the radial artery or superficial or deep arches, through the *princeps pollicis* artery (the first palmar metacarpal artery).[3,5,6]

Distally, within the digital pulp, a large number of vessels cluster with most of the interconnections located superficially near the skin surface.[7] The superficial vessels of less than 100 μm in diameter comprise the microvascular nutritional and thermoregulatory (nonnutritional) vessels (*beds*)[8] (Fig. 2). Total blood flow equals nutritional flow (providing material for cellular metabolism) and thermoregulatory flow (does not support cellular metabolism). Under normal conditions, 80% to 95% of the total flow is thermoregulatory, whereas 5% to 20% is nutritional.[9] The relative contributions of each are controlled by complex factors regulating arteriovenous shunting.[10–12] In cases of decreased total flow and/or inappropriately decreased flow into nutritional beds, cellular ischemia will ensue, resulting in symptoms and/or permanent injury. Ironically, in vasospastic disease states, inappropriate arteriovenous shunting exists in the presence of pathologically reduced total flow.

HISTORY AND PHYSICAL EXAMINATION

The value of focused history cannot be overemphasized. Pertinent points to include are the presence of penetrating or nonpenetrating trauma, repetitive insults, use of the hand as a hammer, drug and tobacco use, history of myocardial

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TABLE 1: Most Common Etiologies of Vascular Disorders

Structural Abnormalities	Combined	Functional Abnormalities
1. Acute vascular injury (including iatrogenic injuries)	1. Vaso-occlusive disease	1. Vasospastic disease (inappropriate control of the vascular system)
2. Occlusive disease		
Thrombosis		
Aneurysm		
Embolism		
3. Genetic/congenital factors		
Arteriovenous malformations		
Coagulopathies		
Connective tissue diseases		

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infarction or atrial fibrillation, weakness, numbness, and color change. Arm claudication may be described as effort-induced "heaviness" or "tiredness" that is relieved by rest. Pallor and cold (intolerance) sensitivity are reported commonly. Family history should include queries regarding blood dyscrasias, pulmonary emboli, collagen vascular diseases, and stillbirths. The presence of a unilateral Raynaud phenomenon is suggestive of occlusive disease. When associated with nonhealing ulcerations, necrosis, and/or gangrene, it is pathognomonic for the diagnosis of thrombosis/embolism.

The entire upper extremity and the neck should be evaluated including inspection, palpation, range of motion, joint stability, nerve irritability, vascular integrity, and sensibility. Examination should assess capillary refill, turgor, skin integrity and temperature, swelling, presence of punctuate violaceous lesions, splinter hemorrhages, ulcerations (Fig. 3), gangrene, a mass or bruits, and quality of peripheral pulses.

Allen Test, Timed Allen Test, and Digital Allen Test

Allen originally described this test in 1929 to diagnose occlusive disease of ulnar circulation in thromboangiitis obliterans.[13] During the test, the patient closes the hand tightly for 1 minute or until blanching of all digits occurs while the examiner occludes both arteries. The patient then extends the fingers partially, and the ulnar artery is released while compression on the radial artery is maintained. The return of color to the hand indicates an intact ulnar circulation. The radial circulation is similarly evaluated by occluding the ulnar artery. In 1981, Gelberman presented a technique for timing hand revascularization using the Allen test (timed Allen test).[14] The evaluation of 800 hands in 400 control subjects showed the average timed radial artery fill was 2.4 seconds ± 1.2 and average ulnar artery fill was 2.3 seconds ± 1.0. Ninety-one percent of the hands tested were considered "normal" with uniform brisk refill under 6 seconds. Reduced digital blood pressure correlated with the clinical observation of inadequate or absent revascularization. Distally, evaluations for occlusion of a digital artery at or distal to the metacarpophalangeal joint used the digital Allen test. The test is performed by compressing both digital arteries at the base of the finger. The patient then elevates the hand and fully flexes the finger several times to blanch the finger. If the finger remains blanched after lowering the hand and releasing the compression on 1 digital artery, then the released digital artery is considered compromised. On the contrary, the digital artery must be patent if color returns promptly.

DIAGNOSTIC EVALUATION

Initial laboratory evaluation probes for an underlying autoimmune disorder or hypercoagulable state contributing to an abnormality in upper-extremity perfusion. Recommended testing includes a comprehensive metabolic panel and complete blood count with differential. Further laboratory studies indicated for the evaluation of a patient with an upper-extremity vascular disorder are presented in Table 2. Testing of upper-extremity perfusion should evaluate vascular structure and function under resting conditions and under the application of a stressor.[15] The techniques or tests described herein may be further categorized into those that provide structural information (anatomy) versus those that provide functional information, that is evaluate the adequacy of blood flow (thermoregulatory and nutritional) (Table 1). Evaluation of extremity perfusion capability and capacity and its effects on the components of blood flow requires stress. Measurements without stress may be misleading and misinterpreted. For