CHAPTER **50**

UPDATE ON NON-INVASIVE VASCULAR STUDIES

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Peripheral vascular disease and the resultant decrease in arterial blood flow to the lower extremities presents a challenge to the clinical team. The patient history and clinical evaluation remain the main diagnostic indicators. While an appropriate vascular consult can be helpful, the podiatric physician must understand the benefits and limitations of non-invasive vascular studies.

The evaluation of lower extremity arterial blood flow can be categorized according to the identified vasculature. Macroangiographic evaluation, including Doppler exam, ankle/brachial index, and segmental pressures, may be helpful in determining the extent of arterial occlusion and in the identification of the site of blockage or stenosis. Perfusion of the cutaneous blood flow is dependent on patent proximal flow but is specifically assessed through microangiographic evaluation, including transcutaneous oxygen measurements, laser Doppler flowmetry, and photoplethysmography. Examination at both levels enhances the ability of the physician to accurately identify the patient's prognosis for healing, and the success of, or need for revascularization.

MACROANGIOGRAPHIC EVALUATION

Peripheral vascular disease is commonly assessed in the podiatric physician's office through the use of macroangiographic evaluation. The techniques utilized provide an excellent primary screening for vascular disease and can indicate the degree of progression.

Doppler Exams

The use of a Doppler probe to assess blood flow and correlate with the clinical exam findings has expanded the physician's ability to identify the level of disease within the arterial tree. The frequency emitted by the Doppler probe is altered by velocities greater than 6 cm/sec. The reflected frequency is then compared to the emitted frequency, producing a signal proportional to the velocity of flow in the vessel. This signal can be reproduced graphically, digitally, or audibly to allow the physician to assess velocity within an isolated vessel. The evaluation of the Doppler signal includes the amplitude and waveform produced. An increase in amplitude is directly proportional to an increase in velocity in the vessel. With the patient in a supine position, the waveform in a normal vessel will produce three sounds: systolic forward flow, diastolic reverse flow, and forward flow secondary to elastic vessel recoil. The clarity and definition of the signal diminishes as disease progression reduces vessel compliance and patency. Evaluation of arteries of the lower extremity can be compared with the proximal and contralateral vessels to identify the presence of occlusion or stenosis.

There are separate parameters for digital Doppler examination due to the decreased diameter and increased resistance of the digital vessels. The digital probe is oriented approximately 90 degrees to the toe, lightly abutting the medial and lateral bases of the digits at the dorsal and plantar aspects. The presence and pitch of a monophasic signal is indicative of the velocity of flow.

Ankle/Brachial Index

The Ankle/Brachial Index (ABI) is used to produce a quantitative value comparing the systolic pressure at the ankle and brachial levels. The examination is performed with the patient in a supine position. Pneumatic cuffs are placed alternately at the ankle and arm levels and the return of systolic flow following occlusion of the respective arteries is recorded. Normal values are equal to or greater than 1.0. Severe occlusive disease is identified by ABI less than 0.5. Values greater than 1.0 must be verified by Doppler exams, because calcification of the media of the vessel (medial calcinosis or Monckeberg's sclerosis) may produce a falsely-elevated result. ABI is a simple exam that provides a standard of comparison to be used in the classification of peripheral vascular disease.

Segmental Pressures

The use of segmental pressures enables the physician to identify the level of occlusion. Results must be correlated with Doppler studies because collateral blood flow may produce falsely-elevated segmental pressures, and disguise the presence of a significant occlusion. Segmental pressures are determined using pneumatic cuffs, 1 to 1.25 times the girth of the part being examined. The cuffs are placed high on the thigh, above the knee, below the knee, and at the ankle level. The most prominent pedal pulse is identified using a Doppler probe, followed by the inflation of each cuff until occlusion of systolic flow is achieved. The pressure at which flow returns is recorded and compared to the proximal sections and contralateral extremity to determine the level and presence of occlusion. Occlusive pathology is identified by a pressure decrease of greater than 20 mm Hg between adjacent cuff levels, or compared to the corresponding level on the contralateral extremity. As with the ABI, calcification of vessels can produce elevated pressures and must be considered when the results do not correlate with the clinical setting.

MICROANGIOGRAPHIC EVALUATION

The use of microangiographic studies in the evaluation of cutaneous blood flow provides a more accurate means of determining the patient's ability to heal. The information provided by these non-invasive methods is also helpful in the assessment of revascularization attempts in the lower extremity. Microangiographic variations occur between subjects and within individuals themselves based upon factors such as skin thickness, cutaneous blood flow, and daily metabolic activity, therefore one must establish controlled conditions prior to evaluation.

Transcutaneous Oxygen Measurements

Transcutaneous oxygen measurements have been popular in assessing wound viability and healing potential via the evaluation of oxygen tension at the measurement site. This technique is dependent on the creation of a cutaneous oxygen tension by the diffusion of oxygen from capillaries to the skin surface with minimal skin metabolic consumption. An oxygen-sensing electrode containing an electric heating device detects this tension and records it graphically. The skin is warmed to 43°C to eliminate the effect of local vasomotor effects producing maximal vasodilation of the underlying vasculature. Values are recorded continuously for 10 to 30 minutes to achieve an accurate value. There is little variation between adjacent skin site evaluations. The ability to reproduce consistent results allows for the monitoring of the progression of peripheral vascular disease.

Positive predictive levels of oxygen tension above which healing occurs vary from 20 to 40 mm Hg. High sensitivities for healing potential are noted with values greater than 40 mm Hg. The change in oxygen tension with oxygen inhalation also aids in determining wound healing potential. Conlon et al. noted that a rate of change in transcutaneous oxygen tensions greater than 9 mm Hg/minute relative to baseline, after 5 minutes of oxygen inhalation, accurately indicates that wound healing will occur. Healing has still been shown to occur with 0 to 1 mm Hg tensions, indicating that there is no transcutaneous oxygen level below which all wounds will fail to heal. The high sensitivity and low specificity for healing has made it difficult to create baseline standards for general applications. The evaluation of transcutaneous oxygen tensions is directly influenced by the inhalation of oxygen, hemoglobin saturation and lung function. The Regional Perfusion Index attempts to reduce this variability in a manner similar to the ABI indices by comparing the recorded limb value with a recording from the chest. A Regional Perfusion Index (RPI) above 0.6 have been established as being likely to heal, while wounds with indices less than 0.4 are unlikely to heal. Difficulty arises in attempting to exclude wounds that will not heal, since revascularization measures potentially place patients at risk, who otherwise would have healed. Therefore, transcutaneous oxygen evaluation is beneficial in the determination of wound healing potential, but is ineffective in determining which wounds will not heal.

Laser Doppler Flowmetry

The laser Doppler flowmetry uses the same principles as ultrasound Doppler to determine flow velocity. Red blood cells scatter the light which is emitted resulting in a frequency drift. This frequency drift (change in emitted versus detected frequencies) is recorded in millivolts (mv) as a voltage output which has a linear relationship with cutaneous blood flow. The penetration depth of the light source is approximately 1 mm and the output signal produces a relative red blood cell velocity which is allowed to reach a baseline prior to any measurements being recorded.

Criteria for successful healing, as presented by Karanfilian et al. are a laser Doppler skin blood flow velocity greater than 40 mv and a pulse wave amplitude (velocity changes corresponding to the cardiac cycle) of more than 4 mv. The sensitivity of laser Doppler is 87%, compared to a 100% sensitivity with transcutaneous oximetry in Karanfilian's study. Padberg et al. attempted to eliminate the variable of skin temperature by incorporating a heated probe with the laser Doppler. They concluded that transcutaneous oximetry and the laser Doppler with a heated probe predict healing potential with similar accuracy. Laser Doppler flow has been more reliable in predicting wound failure, although its ability to predict wound healing is not as sensitive as the transcutaneous oxygen evaluation. The use of laser Doppler with a heated probe is beneficial in that it provides a direct measure of blood flow in the skin and is not dependent on the oxygen tension at the skin surface. Furthermore, this test enhances the ability to accurately identify non-healing wounds which may then be considered for alternative treatment protocols.

Photoplethysmography and Digital Toe Pressures

Photoplethysmography measures the flow of blood in the subpapillary venous plexus which is useful in identifying circulation to isolated regions. An infrared beam released from the probe reflects off the hemoglobin molecule, is detected, and is recorded as a waveform. A normal capillary plexus will produce a narrow high amplitude waveform which will diminish to a flat line with the application of a digital cuff or in the presence of significant occlusive disease. The placement of the probe at the distal tuft of the digit with a pneumatic cuff 1 to 1.25 times the width of the digit enables the digital pressure to be recorded. Normal digital pressures range from 70 to 110 mm Hg, with values less than 50 indicating occlusive or vasospastic disease. Photoplethysmography is useful in the objective determination of cutaneous blood flow, but does not provide a quantitative assessment of healing.

CONCLUSION

Advances in the evaluation of peripheral blood flow can play a role in determining treatment options and predicted outcomes. Both macroangiographic and microangiographic evaluation are beneficial in determining the source of a patient's pathology and identifying the progression of peripheral vascular disease. An understanding of the available examinations and their clinical applications can enhance the physician's treatment plan and allow the clinical team to better collaborate and determine the disease prognosis.

BIBLIOGRAPHY

Chang TJ, Poindexter J: Role of non-invasive vascular studies. In Ruch JA, Vickers NS, eds. *Reconstructive Surgery of the Foot and Leg, Update 92* Tucker, GA: Podiatry Institute; 1992: 5-8.

Conlon K, Sclafani L, DiResta GR, Brennan MF: Comparison of transcutaneous oximetry and laser Doppler flowmetry as non-invasive predictors of wound healing after excision of extremity soft-tissue sarcomas. *Surgery* 115(3):335-340, 1994.

Karanfilian R, Lynch T, Zirul V, Padberg F, Jamil Z, Hobson RW: The value of laser Doppler velocimetry and transcutaneous oxygen tension determination in predicting healing of ischemic forefoot ulcerations and amputations in diabetic and nondiabetic patients. *J Vasc Surg* 4(5):511-516, 1986.

Levin J, Zier BG, Grandinetti GM, Hoffman AF: Peripheral Vascular Disease. In Zier BG, ed. *Essentials of Internal Medicine in Clinical Podiatry* Philadelphia, PA: WB Saunders; 1990: 45-98.

Oishi CS, Fronek A, Golbranson F: The role of non-invasive vascular studies in determining levels of amputation. *J Bone Joint Surg* 70A(10):1520-1530, 1988.

Padberg FT, Back T, Hart L, Franco C: Comparison of heated-probe laser Doppler and transcutaneous oxygen measurements for predicting outcome of ischemic wounds. *J Cardiovasc Surg* 33:715-722, 1992.

Rooke TW: The use of transcutaneous oximetry in the non-invasive vascular laboratory. *Int Angiol* 11(1):36-40, 1992.

Sidawy AN, Curry KM: Noninvasive Evaluation of the Lower Extremity Arterial System. In Frykberg RG, ed. *The High Risk Foot in Diabetes Mellitus* New York, NY: Churchill Livingstone; 1991: 241-254.

Winsor T, Haumschild DJ, Winsor D, Wang Y, Luong T: Clinical application of laser Doppler flowmetry for measurement of cutaneous circulation in health and disease. *Angiology* 38(10):727-736, 1987.