Near-Infrared Spectroscopy Imaging for Assessing Skin and Wound Oxygen Perfusion

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KEYWORDS

• Near-infrared spectroscopy • NIRS • Wound perfusion • Healing rate
• Oxygenated hemoglobin • Tissue oxygenation • Tissue oxygen perfusion

KEY POINTS

- One of the most important aspects in assessment of wound closure and skin viability is blood supply.
- Measurement of blood supply has continually evolved over the last 30 years, from simply palpating pulses to angiography to peripheral circulatory measurements based on skin perfusion.
- Light-based systems have provided a new way to evaluate the delicate peripheral oxygenation of superficial tissues.

INTRODUCTION

Without a doubt, among the most important aspects in assessment of wound closure and skin viability is blood supply. Blood carries nutrients to the site and removes waste. It plays a role in every aspect of tissue life. Measurement of blood supply has continually evolved over the last 30 years, from simply palpating pulses to angiography to peripheral circulatory measurements based on skin perfusion. The evaluation of skin perfusion becomes much more complex due to the tiny and diffuse nature of the capillary beds.

The Ankle-Brachial Index and angiography give little useful information when it comes to evaluating blood flow to the skin. Historically, patients may have good macroscopic blood flow and yet still may have poor skin perfusion, which can be

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attributed to basement membrane thickening in patients with diabetes and to issues such as microembolism in patients with a history of atherosclerotic disease.

Light-based systems have provided a new way to evaluate the delicate peripheral oxygenation of superficial tissues. Pulse oximetry (S_pO2) systems are routinely found in operating rooms and are a staple for monitoring oxygenation levels during anesthesia. This simple diode-receptor combination attaches to a finger and measures changes in oxygenation levels in the larger arteries. Similarly, plastic surgeons have relied on local probes that can be attached directly to a skin flap to monitor flow to 1 point within the flap. Flow is calculated using an algorithm and is expressed in tissue perfusion units, which does not actually relate to a volumetric measure but rather a relative assessment of perfusion. Both modalities have 2 significant limitations. The first is that they require direct contact with the tissues. This may be problematic in cases in which there is concern about an infection. The second issue is that they provide information from only a single point, without providing any information about adjacent areas.

To measure greater areas of tissue, an intravenous dye, indocyanine green (ICG) can be administered. It has a peak spectral absorption of around 800 nm, and can be viewed when a specialized light source and camera are used to view the tissues shortly after administration. Typically, this process is done within the operating room suite, allowing real-time viewing of the tissues as they are being perfused. Although this system is highly capable of providing a detailed image of the superficial tissue circulation, it has significant limitations. The test must be conducted in an operating room suite, adding significant costs. The test cannot be immediately repeated, which is problematic if taking an image, adjusting some aspect influencing perfusion, and then repeating the image to determine if the adjustment had any effect. For example, if a patient had reflex sympathetic dystrophy with autonomically controlled vasoconstriction, the image would show reduced perfusion. Then, if a nerve block is performed, one would expect to see resultant vasodilation but this would not be possible with an ICG system. A second limitation is the physical size of the device. A typical ICG-based system is on a large cart that requires a significant amount of space and coordination to operate.

Thermography is another alternative that may give some indication about the level of peripheral circulation. Historically, warm tissues are well-perfused, whereas colder tissues are not. Although thermography can be used to assess peripheral circulation indirectly, the images typically lack detail, and are highly susceptible to changes in room temperature and the patient's level of comfort. Consequently, thermographic images are highly irreproducible.

More recently, near-infrared spectroscopy (NIRS) has become available. This technique is based on the transmission of near-infrared light onto the skin surface. Some portions of the light are absorbed, whereas other portions are reflected. The device used in this study is an imaging NIRS device (Kent KD203, Kent Imaging, Calgary, AB, Canada), emitting a series of illuminating flashes of near-infrared light between 600 and 1000 nm. Light around 750 nm is predominantly absorbed by unbound hemoglobin, whereas light around 850 nm is predominantly absorbed by hemoglobin bound to oxygen. By measuring the relative absorption of near-infrared light around those key wavelengths, the ratio of oxygenated to oxygenation plus deoxygenated hemoglobin can be determined. Well-perfused tissues will have a higher percent of oxygenated hemoglobin than poorly perfused skin (**Fig. 1**).

Spectroscopy systems that use near-infrared light to determine hemoglobin oxygenation have the benefit of sampling tissue more deeply compared with their visible light counterparts. This is particularly the case in the presence of higher