Chapter 5
Near-InfraRed Technology for Access to Superficial Veins: Evidence from the Literature and Indications for Pediatric Venous Access

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The use of near-infrared light imaging has been introduced to improve the number of visible veins in pediatric patients. This technology allows the visualization of small (0.2 mm) and superficial (up to 8 mm) veins. There are different devices based on a polarized infrared light or on low power lasers. The advantage of the NIR light devices is that they are portable and enhance the peripheral vein path when compared to naked-eyes visualization or palpation. There is currently not enough evidence to support the superiority of these devices in terms of first-time successful cannulation or reduced time to cannulation due to the heterogeneity of the studies conducted. The NIR light technology is still lacking information regarding the depth of field related to the position of the peripheral veins but with an appropriate training it could improve the success during peripheral IV cannulas in pediatric patients.

Peripheral venous cannulation and phlebotomy can be challenging in neonates and pediatric patients even in expert hands. For this purpose, different technologies have been investigated to evaluate their clinical feasibility and their advantage compared with the traditional palpation or landmarks methods.

The main research has been conducted on the use of ultrasound (US), trans-illumination and near-infrared (NIR) imaging technologies. Near-infrared has been investigated in neonates and pediatric patients; different devices have been marketed with different clinical specifications and outcomes.

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5.1 Near-Infrared Technology

NIR technology is not new in the medical-devices market, and it has been introduced as a method to measure cerebral blood flow and oxygenation non-invasively.

More recently, the use of NIR has been extended to allow vein visualization and phlebotomy in difficult cases where peripheral veins were difficult to either visualize directly or to palpate.

The main devices available in the market are the VeinViewer and the Accuvein but there are other new devices that have been used in the clinical setting such as the VascuLuminator (Netherlands), the 3-light-source method Total Reticular Vision (Mexico), VeinViewer Vision2, IRIS Vascular Viewer, and Veinsite.

5.1.1 How They Work

The VeinViewer (Christie Medical Holdings, Inc.) utilizes a 760-nm polarized near-infrared light to illuminate the patient's skin. The light source is from a ring of light illuminated diodes (LEDs). The NIR light can penetrate the skin at a right angle up to 10 mm of depth from around 60 cm. The skin and subcutaneous fat are not able to absorb this light properly, so they scatter the NIR light in all directions including back to a camera that is included in the device. Blood in the veins, however, absorbs or scatters forward the NIR light. A digital video camera picks up the NIR light reflection, the device then analyses and processes this information. Another LED is used to project back to the skin an enhanced real-time image over the position of existing vessels making the veins appear black on a greenish background (Fig. 5.1). The VeinViewer has two versions: the VeinViewer Flex is handheld, and the VeinViewer Vision 2 has an articulating arm and a flexible wrist joint making it easy to maneuver to better visualize the vessels.

Fig. 5.1 Image of subcutaneous vessels obtained using the VeinViewer

The Accuvein (HF320; Avant Medical) uses NIR light from 2-low power lasers: a 642-nm wavelength red laser operating at 40 mW and a 785-nm wavelength IR laser at 25 mW. The resulting energy is reportedly 2.57 and 1.58 ohms, respectively. In this case, the resulting background on the skin is reddish and the veins will appear as black (Fig. 5.2).

The VascuLuminator (Quantivision) uses near-infrared light (~ 800 nm), which can penetrate up to several centimeters into tissue but is still absorbed by blood, which enables discrimination between blood vessels and surrounding tissues near the skin surface. Both reflected and trans illuminated NIR lights on the skin are imaged by a NIR sensitive digital camera and displayed on a LCD monitor in an ergonomic setting.

The IRIS Vascular Viewer includes the light or illumination source, the detector, and the display. The illumination source is a matrix of diodes emitting infrared light. The light source may be directed to the surface of the limb from a distance or applied directly. If applied directly, the light passes through the limb.

Veinsite (Vuetek, Grey, ME, USA), is the latest NIR vein visualizer introduced into the market. It uses a rechargeable battery and has an optional VGA cable for

Fig. 5.2 Accuvein and visualization of peripheral veins

separate monitor display. The device allows for concurrent vein inspection with normal eyesight and operates independently of ambient light conditions. When powered on, it emits a NIR light (700–900 nm) that penetrates the skin. Upon contact with tissue, the NIR light (tissue absorption coefficient between 0.02 and 0.3 cm^{-1}) scatters, travelling a depth of <5 mm before deviating from its initial direction. Conversely, hemoglobin and other vascular fluids are highly absorptive. The Veinsite's electro-optical technology detects the absorption difference between vascular structures and surrounding tissue. After converting the raw image to greyscale, it then displays it on the headset's LCD screen (Figs. 5.3 and 5.4). In this way, the operator wearing the helmet can see the veins either by direct vision or through NIR-vision.

Fig. 5.3 Veinsite

Fig. 5.4 View of veins as seen with the Veinsite

5.1.2 *Safety of the NIR Vein Visualizers*

NIR is a safe technology not harmful to patients as it does not produce ionizing radiation. The lasers emitted by Accuvein are classified as class 2 and considered safe as the blink reflex limits their exposure and prevents ocular damage. The manufacturers suggest that in cases where the blink reflex is altered, appropriate eye protection should be used.

5.2 When Should We Consider a Peripheral Venous Cannulation Difficult?

Peripheral venous cannulation can be particularly challenging in some patients when (a) the vein cannot be visualized with the naked eye and (b) the vein cannot be palpated where it should be according to the landmark anatomy. There are various patient factors making peripheral venous cannulation difficult such as darker skin, obesity, neonates and pediatric patients, previous chemotherapy, chronic illnesses, and multiple peripheral venous cannulation attempts.

A more objective peripheral venous cannulation scale has been proposed recently. Predictor variables from the DIVA (*Difficult Intra-Venous Access*) score are (1) visibility of vein after tourniquet placement, (2) palpability of vein after tourniquet placement, (3) age of the patient in months, and (4) history of prematurity. Skin shade is determined by using a Dermablend cosmetics card (Dermablend Inc., Ridgefield, NJ), which grades skin shade from 1 to 11, light to dark. For the purpose of analysis, it is dichotomized into two groups: light (shades 1, 2, 4, and 5) and dark (shade 3, and shades 6 through 11). A DIVA score greater than 4 has been recognized as the threshold to identify a patient as higher risk for predicted failure.

Table 5.1 summarizes the DIVA score.

Table 5.1 DIVA score. A score > 4 is the cut-off value for predicting peripheral venous cannulation failure

Predictor value	
Visibility	Visible = 0 Not visible = 2
Palpability	Palpable = 0 Not palpable = 2
Age	>36 months = 0 12–35 months = 1 < 12 Months = 3
Prematurity	Not premature = 0 Premature = 3
Skin shade	Light = 0 Dark = 1

5.3 Evidence from the Literature

5.3.1 NIR Light Devices' Ability to Visualize Peripheral Veins

Several studies have been conducted to study the ability of different NIR imaging devices in terms of improved visualization of peripheral veins not visible or not palpable in pediatric patients. Mihake and colleagues compared direct sight visualization with ultrasound and NIR imaging provided by a VeinViewer prototype. They found that NIR enhanced the visualization of peripheral veins by 67% compared to the naked eye alone. In the same study, NIR imaging was compared to ultrasound (by means of two different ultrasound machines: one portable and one high resolution). The authors noted that NIR can detect more superficial (up to 8.2 mm) and smaller vessels (0.2 mm) compared to ultrasound that was able to detect bigger and deeper vessels. The portable ultrasound was found to have an easier learning curve than the high resolution one.

Another paper was conducted by Chiao using the Veinsite to investigate the characteristic factors related to peripheral vein visualization on 384 subjects from different sub-cohorts including those more associated with decreased vein visibility. The study compared direct vision with NIR imaging. The authors found that an average of 3.3 additional suitable venous sites were found by using the Veinsite when compared with direct sight visualization. Veinsite increased the detection of possible peripheral venous cannulation sites in 97% of these difficult cases—including an additional 1.7 (89% increase) possible vein sites in infants and additional 3.7 (80% increase) possible vein sites in patients with dark skin. The visualization provided by NIR was also helpful in obese patients were the additional cannulations sites improved by 4.0 (82% increase) and in morbid obese patients where the visualization improved by 3 sites (83% increase).

The use of the VascuLuminator has been argued to increase the number of additional cannulation sites. The same authors conducted another study comparing VeinViewer, Accuvein and VascuLuminator in terms of visibility of suitable veins for cannulation and they found that VeinViewer was able to detect more veins suitable for cannulation (307/322 (95.3%)) than Accuvein (239/254 (94.1%)) while VascuLuminator had the lower visualization ability (229/257 (89.1%)) ($p = 0.03$).

5.3.2 Efficacy of NIR Light Devices in Successful Peripheral Vein Cannulation

A recent meta-analysis from Park and colleagues of 11 studies on pediatric patients analyzed 1994 patients in which NIR imaging was compared to a standard control group (eye alone) of 1577 patients. The failure rates were not different in the two groups: 31.9% (673/1994) in the NIR group compared to 30.9% (488/1577) in the control group. The authors of this meta-analysis concluded that the use of NIR light devices did not have any overall impact on failure of first attempt at peripheral vein cannulation (RR = 1.03, CI = 0.89–1.20, I2 = 48%) in a pediatric population. The study also concluded that there was no difference if the cannulation was performed in different settings (e.g., emergency department or operating theatres).

The synthesis of the included studies did not reveal a high heterogeneity. Different factors can contribute to an increased failure rate such as young age, the presence of dark skin color, weight less than 5 kg, obesity or increased subcutaneous fat, and previous chronic illness. A possible bias related to the non-inferiority of the NIR group compared to the traditional visualization/palpation technique can be found in the inclusion only of patients with an expected difficult peripheral venous cannulation as it happened in one study]. Other studies analyzed the results according to the operators' experience, but they were not able to find a difference related to this factor. The meta-analysis from Park found a significant positive effect of the use of NIR in terms of improved first-time successful cannulation when high power studies only were analyzed while another paper reported a higher risk of failure when NIR light devices were used even though their participants were all predicted to have difficult cannulation (DIVA score ≥ 4). In this study, the operators involved in the study belonged to an IV team to whom more than 1000 difficult cases per month were referred. Their proficiency without using cannulation assistance devices may have resulted in a higher failure risk in the NIR group; it was unknown what kind of training the operators received before starting to perform cannulation with the NIR light devices in patients.

5.3.3 Time to Successful Peripheral Vein Cannulation for NIR Light Devices

First-attempt success using a NIR light device has been considered as a secondary outcome in most of the studies conducted in this field, but it is important not to underestimate this factor, especially in emergency situations when a cannula is required for the administration of life-saving medications.

The data of first-attempt success with NIR light devices from different studies were too heterogenous and used different metrics and therefore, a meta-analysis could not be conducted. Most of the studies did not report any significant difference between the NIR light devices and the traditional methods in terms of time to obtain access while Sun et al. reported an increased time spent to insert a peripheral cannula in the NIR group. Other studies did not specifically address this aim in their analysis. This secondary aim seems to be highly related to the first-time success even if there is the need to have future studies in which the time to successful cannulation needs to be separated from the first-attempt success and it should be studied regarding the learning curve needed to obtain full competence in this technique.

5.4 How to Use NIR Light Devices in Peripheral Pediatric Venous Access

The various NIR light devices have specific characteristics that make their clinical use different.

The VeinViewer uses the reflection of the NIR light by light-emitting diodes to make sub-surface vessels visible. The veins are depicted as dark on a square green background projected on the patients' skin. The VeinViewer needs to be positioned approximately 30 cm above the puncture site until the focusing text is clearly visible. The operator can choose to adjust the size of the projection, to use the universal or fine mode, and to use normal (background green) or inverse mode (veins in green background black).

The Accuvein can be used with a second operator handling the device to optimize the veins' visualization or it can be mounted on a trolley a with a hands-free set. The AV300 is used at a height of 20–30 cm and perpendicular to the surface of the skin. The operator can freely cycle through the three different display settings (varying sensitivity) to define the best mode to locate the vein.

The VascuLuminator display/camera combination can be positioned approximately 20 cm above the puncture site, whilst NIR light source is placed underneath it. The operator can modify the focus and light intensity to optimize the image of the veins.

The Veinsite is a head-mounted system which includes a portable near-infrared (NIR) emitter, video acquisition, and display device. The device allows for concurrent vein inspection with normal eyesight and operates independently of ambient light conditions. The peripheral venous cannulation by using Veinsite can be divided in two phases: (1) visualization of the vein by NIR light and initial vein puncture, (2) once the vein is entered and flow-back flush is detected on the back of the peripheral IV cannula through direct sight the cannulation can be continued without NIR visualization. Once the cannula is in, the operator can check if there is extravasation by flushing the cannula with normal saline and with NIR visualization, assess if there is any sign of fluid outside the venous path.

5.5 Tips and Tricks

The NIR light devices can be useful as long as it is used for appropriately selected patients. First, all pediatric patients should be scored according to the DIVA score. Even in low-risk patients, the NIR devices can help in venous mapping and selecting the best vein site to be cannulated. Remember that all pediatric cannulations can be considered difficult "per se" because children are needle-phobic and require proper preparation with topical local anesthetics that. If the patient is a neonate or a toddler, it is important to involve the parents as they can help with reassuring the child and creating a calm environment.

The NIR devices should be part of the peripheral IV access tools as a dedicated peripheral IV set including tourniquet, swab gauzes, small IV cannulas (24G, 22G), needle-free connectors, and dressings.

As a rule of thumb, NIR light devices can detect peripheral veins up to 8 mm of depth. With deeper veins or those not visible even by using these devices, the next step should be to use an ultrasound device to detect bigger and deeper veins.

An important part regarding the use of NIR imaging devices is the training. There is currently no established training on how to use these devices and how steep the learning curve is. All the studies performed on these devices declared that the operators spent at least one month using the device, but it is not known when the full proficiency (100% successful cannulations) were obtained by a single operator.

The main limitation of the NIR light technology is the lack of depth perception. This can lead to puncturing the posterior wall of the vein causing extravasation once the cannula is inserted.

5.6 Conclusions

Pediatric patients are potentially at higher risk for difficult peripheral venous cannulation. A proper evaluation of potential sites and potential difficulty during the cannulation is mandatory. This procedure should be performed by expert operators and with specific tools including NIR light devices and ultrasound machines. The visualization of the veins by using NIR imaging is enhanced but the results related to first-time successful cannulation and time to cannulation are still not significantly different from the traditional palpation and direct visualization. Further studies are needed to understand if the lack of efficacy is due to technical reasons or by lack of training in these new devices.

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