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The use of near-infrared light for safe and effective visualization of subsurface blood vessels to facilitate blood withdrawal in children

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ABSTRACT

Obtaining access to blood vessels can be difficult, especially in children. Visualization of subsurface blood vessels might be a solution. Ultrasound and visible light have been used to this purpose, but have some drawbacks. Near-infrared light might be a better option since subsurface blood vessels can be visualized in high contrast due to less absorption and scattering in tissue as compared to visible light. Our findings with a multispectral imaging system support this theory.

A device, the VascuLuminator, was developed, based on transillumination of the puncture site with near-infrared light. The VascuLuminator was designed to meet the requirements of compact and safe use. A phantom study showed that the maximum depth of visibility (5.5 mm for a 3.6 mm blood vessel) is sufficient to visualize blood vessels in typical locations for peripheral venous and arterial access. A quantitative comparison of the VascuLuminator and to two other vessel imaging devices, using reflection of near-infrared light instead of transillumination, was conducted. The VascuLuminator is able to decrease failure at first attempt in blood withdrawal in pediatric patients from 10/80 (13%) to 1/45 (2%; P = .05).

1. Introduction

1.1. Peripheral venous and arterial access

Peripheral venous and arterial access are commonly required in hospital [1]. Although the procedure is frequently performed, it can be difficult, especially in children. Subcutaneous fat or a dark skin color hamper visualization of blood vessels underneath the skin [2]. When no blood vessel can be located, the physician or nurse has to perform a blind stick based on anatomical knowledge. A possible solution to this problem is enhancement of localization by visualization of subsurface blood vessels. Ultrasound has been used for this purpose, but requires skill, extra assistance and is expensive [3]. Another option is the use of white or red light sources transmitting through thin body parts such as the hands or wrists of neonates [4]. However, penetration depth and quality of visibility are limited. In addition, these light sources might cause skin burns as a result of excessive heat production [5]. The use of near-infrared (NIR) light might be a better solution. Therefore, a device was developed at our department based on transillumination with NIR light: the VascuLuminator.

1.2. Development of the VascuLuminator

The VascuLuminator is based on the principle of transillumination; a NIR light source is placed underneath the puncture site and the image is captured by a camera and presented on a display (Fig. 1). In more detail, the VascuLuminator consists of a compact infrared sensitive CCD camera with VGA resolution (640 × 480) and adjustable focus lens. A filter is used to block all visible light below 850 nm. The camera can be positioned single-handedly above the puncture site. After releasing the grip, the camera remains on this location by itself, due to a spring-balanced articulated arm. The camera is connected to an 8 in. LCD display. Display and camera are aligned to each other, so that the orientation of the puncture site on the display is similar to the orientation of the puncture site itself. Due to the position of the display and the magnification of the lens at working distance (~20 cm), the size of the image of the puncture site and the distance of this image to the eyes of the observer is similar to the size and distance of the puncture site.

This allows effortless switching between puncture site and display without re-focusing or large movements of the eyes (Fig. 2).

Abbreviation: NIR, near-infrared.

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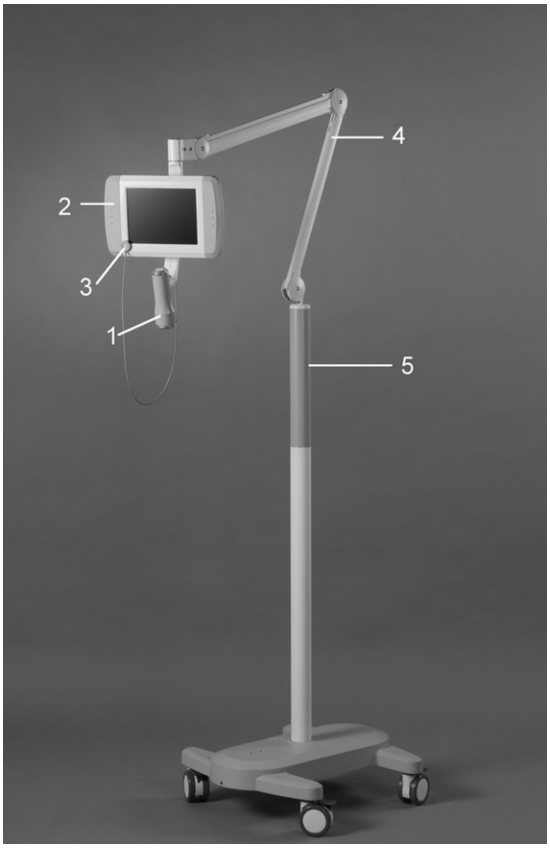

Fig. 1. The VascuLuminator. (1) The camera inside a handgrip. (2) The display. (3) The LED light source, emitting NIR light. It is attached to the display by a magnet and should be placed underneath the puncture site during use. (4) The camera/display unit is mounted on a flexible arm with three translational degrees of freedom. (5) The VascuLuminator is stand-alone and has its own power source.

Fig. 2. Close-up of the display and camera in use. The display and the puncture site are at the same distance to the eye of the user. The puncture site is shown approximately life-sized on the display.

A high power NIR Light Emitting Diode (LED, SFH 4235, Osram, Munich, Germany) of 850 nm is used as the light source. The NIR light transilluminates the puncture site from underneath and is scattered by the tissue, providing a diffuse background of light. The subsurface blood vessels become visible as dark lines on the display (Fig. 2). There are two concepts of transillumination with a near-infrared light source possible; the LED, housed inside an aluminum socket, can either be placed directly underneath the puncture site, or it can be attached to the device in connection with a light guide to transport the light to the puncture site. A prism is then used to render the light beam perpendicular to the light guide into the tissue.

The basic concept of the VascuLuminator aimed to establish an easy, compact, safe and reliable device with minimal interference in the usual routine of vessel puncturing. This is necessary to provide a good acceptance and a successful implementation in a clinical setting. Easy use is realized by allowing single-handed control and manipulation. Also, switching sights between the image on the display and the puncture site is optimized. Camera and display are mounted on a flexible arm, which can rotate along its vertical axis and has one elbow joint. Therefore, the arm accommodates three translational degrees of freedom for the display/camera combination. Both the camera and the display can also rotate along their horizontal axis, thus adding another two degrees of freedom. Because of those five degrees of freedom, the VascuLuminator can be placed in different positions and orientations when used, such as opposite the chair or bed of the patient or behind the back of the user. Safety is guaranteed by preventing heat production of parts in contact with the patient. Reliability is guaranteed by a long duration of functioning on the battery operated power source (±14 h) and by omitting image processing, which can be sensitive to artifacts.

During the development of the VascuLuminator, various design, safety and optimization features had to be investigated, as well as clinical effectivity of the final concept. In this paper, we will discuss these steps that have resulted in the device that has recently obtained CE approval partly based on the results of our experiments.

2. Materials

2.1. Optimal wavelength for subsurface visualization of blood vessels

Blood vessels that are used for peripheral venous and arterial access are typically located up to a few millimeters below the skin surface. The blood vessels are embedded in a layer of subcutaneous adipose tissue, at a depth of 1 mm to several millimeters. On top, the epidermis (∼0.1 mm) is situated, followed by the dermis (∼1 mm). The main chromophores in epidermis, dermis and subcutaneous adipose tissue are melanin, blood (mostly hemoglobin), lipids and water. In the visible part of the spectrum, melanin and hemoglobin are highly absorptive, counteracting deep tissue penetration. In the NIR part of the spectrum (700–1400 nm), there is much less absorption by melanin and hemoglobin. However, above 900 nm, absorption of water is increasing, again preventing deep tissue penetration. This creates a so-called “near-infrared window” between 700 and 1000 nm, where deep tissue penetration with light is possible [6].

Scattering of light by tissue is also an important factor in characterizing the depth of tissue penetration. In the NIR region scattering