

Objective Burn Assessment Using Laser Doppler Imaging and Indocyanine Green Videoangiography to Evaluate the Effect of Hyperbaric Oxygen Treatment: A Case Report

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Abstract

Introduction: Several relatively new technologies have served as valuable adjuncts to clinical judgment in burn wound depth assessment. Among these technologies, laser Doppler imaging and indocyanine green videoangiography have improved accuracy of burn depth assessment. However, an objective way to monitor improvement and changes in blood flow after hyperbaric oxygen treatment is not well documented.

Methods: We present a case of a 43 year-old African American female patient whose burns we evaluated with laser Doppler imaging and indocyanine green videoangiography prior to and after hyperbaric oxygen therapy (HBOT).

Results: These imaging modalities documented an improvement in perfusion of the burned tissues in our patient.

Conclusions: Though we need more comparative data in the form of prospective studies with large cohorts to make concrete recommendations, we suggest with our case report that laser Doppler imaging and indocyanine green videoangiography can be used to monitor improvement and document blood flow after HBOT.

Keywords: Indocyanine green angiography, Hyperbaric oxygen therapy, Laser Doppler imaging, Burn depth assessment, Burn treatment

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Citation: English C, Williams JF, King BT. Objective Burn Assessment Using Laser Doppler Imaging and Indocyanine Green Videoangiography to Evaluate the Effect of Hyperbaric Oxygen Treatment: A Case Report. *Ann Clin Lab Res.* 2015, 3:4.

Received: December 16, 2015; **Accepted:** December 24, 2015; **Published:** December 31, 2016

Introduction

Several technologies have aided the clinician in burn wound depth determination for treatment purposes; among these are laser Doppler imaging (LDI) and indocyanine green videoangiography (ICG-VA) [1-3].

LDI enables the study of perfusion of tissue by detecting movement of red blood cells in the microcirculation and thus reporting the integrity of dermal capillaries. When laser light is directed at the tissue, some is reflected off moving structures (e.g. red blood cells), undergoes a frequency shift from the Doppler effect, is detected by the photodetector, and is used to create a two dimensional image which is usually color coded for ease and speed of interpretation [4]. Clinical judgment of surgeons using indicators including appearance, blanching, and pin-prick testing has historically shown to be 60-80% accurate [2,5-7], but LDI has

demonstrated the ability to determine the need for excision with accuracy approaching 100% several days in advance of clinical decision [8].

Indocyanine green (ICG) is a heavily protein-bound molecule which undergoes rapid plasma clearance by the liver with excretion into bile [9]. ICG is useful in videoangiography (VA) due to the observation that ICG absorbs and emits near-infrared light [9]. ICG-VA has been used extensively to assess tissue perfusion, especially in plastic surgery [10-12]. Recently, some authors have suggested refining it as a method to determine burn depth [1]. Since burn wound depth and severity is dependent on damage to microvascular dermal circulation, ICG-VA proves useful for determining depth and monitoring improvement.

Hyperbaric oxygen therapy (HBOT) has served as an adjunct to

excision and grafting in promoting the healing of burn wounds. HBOT has a long history in wound care, especially chronic, complex wounds [13,14]. In 2012, the Undersea and Hyperbaric Medical Society HBOT indications included, among others, acute thermal burn injury [14]. Some burn centers, including our own, use HBOT as a healing adjunct extensively in partial-thickness burns

Clinicians have used ICG-VA and LDI in burn wound depth assessment for over a decade. No report has more objectively and visually documented the effect of HBOT on compromised tissue as recorded by LDI and ICG-VA. In the following case, we used LDI and ICG-VA to characterize a burn wound before and after HBOT prior to surgical management.

Case Report

A 43-year-old female diabetic sustained a burn limited to the plantar surface of her right foot after sleeping in close proximity to a space heater. The ICG-VA used in this case was the SPY Elite system (Lifecell Corp, Branchburg, NJ); the LDI system used in this

case was the PeriScan PIM 3 (Perimed AB, Järfälla-Stockholm, Sweden). Five mg of ICG powder was reconstituted with sterile water and injected intravenously rapidly with flush to facilitate ICG-VA. We used both LDI and ICG-VA to characterize her wound at 24 hours post burn (**Figure 1**). These images reveal particularly poor perfusion to the lateral side of the great toe and the plantar surfaces of the other toes. We started HBOT on this patient, due to her significantly impaired microcirculation secondary to diabetes. The first HBOT treatment was 24 hours after her burn. After two HBOT dives for 90 minutes at 2.0 atmospheres and 100% oxygen, we re-imaged the patient with the LDI and ICG-VA using the same parameters. We performed this imaging approximately 20 hours after her second HBOT dive. There was a definite improvement in clinical appearance and ICG-VA and LDI after two HBOT dives, especially on the medial plantar surface of the great toe, second toe, and inferior portion of the plantar foot burn (**Figure 2**).

We discharged the patient from inpatient care and she subsequently completed three additional dives. No grafting was performed initially on the full thickness toe burns, even though the LDI and ICG-VA predicted no blood flow and no healing. At

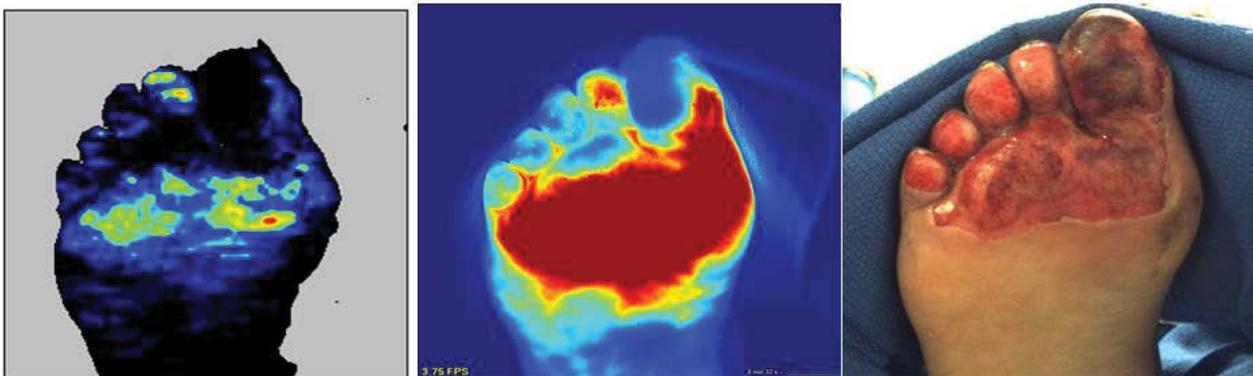


Figure 1 Imaging at 24 hours post-burn. Left to right: laser Doppler image of the plantar surface of the right foot, colorized ICG VA image, and corresponding clinical photograph. Note the multiple areas of full-thickness burns on the plantar surface of the toes and foot.

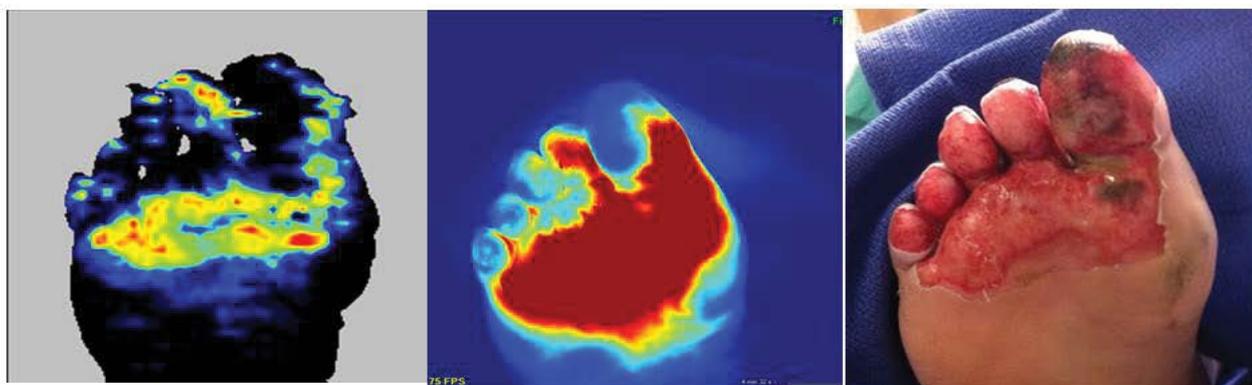


Figure 2 Imaging approximately 20 hours after two HBOT 90 minute dives. Left to right: laser Doppler image of the plantar surface of the right foot, colorized ICG VA image, and corresponding clinical photograph. After two dives, the medial side of the great toe and second toe and the inferior portion of the burned plantar foot appear to have improved perfusion on the LDI and ICG VA images. The clinical picture also appears improved.

her two-week follow-up appointment, the plantar surfaces of the toes failed to show any meaningful clinical evidence of healing (**Figure 3**). We did note improvement in apparent perfusion possibly due to HBOT of several areas—most notably the medial great and second toe and the inferior portion of the plantar foot burn which did not need excision and grafting. At three weeks after her burn, we performed excision and split-thickness skin grafting of the plantar surfaces of her right five toes (**Figure 4**). Her postoperative course was unremarkable and at subsequent follow-ups we noted successful graft incorporation.

Discussion

HBOT appears to have a beneficial effect in the healing of burn wounds. While a sizable body of literature supports the use of HBOT in burns, a 2004 Cochrane review failed to establish clear guidelines for the use of HBOT in burn therapy [15]. A 1974 randomized, controlled study demonstrated accelerated healing and lower mortality in acute burn patients who received HBOT [16]. HBOT's mechanism of providing benefit is controversial, especially at the cellular level. HBOT produces a hyperoxemia which extends to tissue perfusion. The oxygen gradient increases between well-perfused and poorly-perfused tissues, and macrophages respond to these increased oxygen gradients and release angiogenic factors, which have been shown to induce neovascularization in poorly vascularized tissues [17]. Most HBOT protocols involve treatments with 100% oxygen interrupted by brief sessions of room air oxygen to allow physiologic antioxidant mechanisms to prevent overaccumulation of reactive oxygen species (ROS) [16]. The ability for leukocytes to generate ROS in wounds during HBOT is beneficial regarding antimicrobial effects and contributes to prevention of infections [17]. HBOT has few contraindications which include restrictive lung disease and pneumothorax. Complications are extremely rare and include



Figure 4 Clinical photograph three weeks after burn. This is an immediate post-operative photograph of split-thickness skin grafting to the lateral and plantar surfaces of the toes and the superior portion of the plantar foot burn.

barotrauma and seizures [18].

LDI is already a useful tool in the burn surgeon's armamentarium. Most studies have evaluated wounds 24-72 hours post burn with LDI [3,8,19] and noted it to be an accurate assessment of depth [8]. LDI is relatively easy to perform, generally takes under 5 minutes per scan, and is completely noninvasive. These advantages have obvious benefit in the management of burn patients, and, as recent research suggests, can significantly decrease cost of treatment and length of stay of burn patients [20]. Even though LDI has no contraindications, the major disadvantages of the LDI systems are their cost and inability to be absolutely calibrated. Furthermore, reliability of LDI is decreased in several situations, including: patient movement, ambient light changes, inability to position the sensor perpendicular to the imaged surface in all situations (i.e. curved surfaces), and application of topical antimicrobials [3].

ICG-VA has some distinct advantages over previously used fluorescent modalities. Fluorescein leaks out of the capillaries into the interstitial tissues where it can remain for up to 12 hours. ICG instead is bound to plasma albumin; it is not nephrotoxic, is rapidly cleared by the liver (plasma half-life of 3-5 minutes), and does not accumulate in the extravascular space and thus can be used multiple times during the same procedure [9,21]. The dose of ICG in ICG-VA manufacturers' recommendation is a range from 2.5-10 mg, given rapidly intravenously and VA recording begins immediately. Anecdotally, we have our best imaging in burn depth determination after administration of 5 mg of ICG. ICG has a very low side effect profile. The total adverse effect rate of ICG has been reported as 1:42,000; anaphylactic and anaphylactoid reactions, while reported, are extremely rare [9,22]. Because ICG is an iodide, patients with allergies to iodine should not be administered ICG.9 Imaging with ICG-VA is typically recorded in real-time in grayscale, but recently software began to feature the ability to colorize images and place contour lines to more easily



Figure 3 Clinical photograph 16 days after burn. The patient received two HBOT dives while inpatient and three outpatient HBOT dives. The last dive was 10 days before this photograph, which shows worsening clinical appearance, especially of the plantar and lateral surfaces of the five toes.

delineate between perfused and non-perfused tissue.

In direct comparison, each system has advantages. The ICG-VA, which has real time imaging, is much less sensitive to minor patient movement than LDI, which requires from 1-5 minutes of patient stillness. Both systems enable the user to analyze images after capture. LDI software allows the user to determine the perfusion units in regions of interest. The ICG-VA allows for application of color and contour lines to the original image to more easily delineate perfused and non-perfused areas. Both systems are static snapshots and are limited by the dynamic physiologic parameters which influence tissue perfusion. External factors influencing perfusion are caffeine, alcohol, smoking, bathing, and temporal proximity to the patient's most recent meal [21]. Moreover, dressings and ointments heavily hamper LDI and ICG-VA ability to evaluate tissue perfusion [21]. Finally, LDI is influenced by hypovolemic shock, which is a considerable factor in acutely injured burn patients [23].

In this case report, we find that LDI and ICG-VA are acceptable methods to objectively document improvement in partial thickness burn wounds after HBOT. Additionally, we suggest

that improvement in tissue perfusion with HBOT is likely noted with LDI and ICG-VA more quickly than with clinical observation alone. Of particular note, the LDI and ICG-VA are not very useful in determining tissue perfusion deep to a skin graft immediately after the graft; the clinician must rely exclusively on exam after grafting. Objective measurement of improved perfusion in burn wounds after HBOT is possible with LDI and ICG-VA; both warrant prospective investigation.

Acknowledgment

This research was supported in part by appointment of one of the authors (LCC) to the Knowledge Preservation Program at the U.S. Army Institute of Surgical Research, administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and the U.S. Army Medical Research and Materiel Command.

The opinions or assertions contained herein are the private views of the authors are not to be construed as official or as reflecting the views of the Department of the Army, Department of the Air Force, or the Department of Defense.

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