

Original Article

The effect of ambient lighting on Laser Doppler Imaging of a standardized cutaneous injury model

Alan Chuong Q Pham¹, Erik La Hei^{1,2}, John G Harvey^{1,2}, Andrew JA Holland^{1,2,3}

¹The Children's Hospital at Westmead Burns Research Institute, The Burns Unit and The NSW Severe Burns Injury Service, The Children's Hospital at Westmead, The University of Sydney, Westmead, NSW 2145, Australia; ²Department of Paediatric Surgery, The Children's Hospital at Westmead, The University of Sydney, Westmead, NSW 2145, Australia; ³Discipline of Child and Adolescent Health, The Children's Hospital at Westmead Clinical School, The University of Sydney, Westmead, NSW 2145, Australia

Received November 14, 2017; Accepted December 17, 2017; Epub December 20, 2017; Published December 30, 2017

Abstract: Objective: The aim of this study was to investigate the potential confounding effects of four different types of ambient lighting on the results of Laser Doppler Imaging (LDI) of a standardized cutaneous injury model. Methods: After applying a mechanical stimulus to the anterior forearm of a healthy volunteer and inducing a wheal and arteriolar flare (the Triple response), we used a Laser Doppler Line Scanner (LDLS) to image the forearm under four different types of ambient lighting: light-emitting-diode (LED), compact fluorescent lighting (CFL), halogen, daylight, and darkness as a control. A spectrometer was used to measure the intensity of light energy at 785 nm, the wavelength used by the scanner for measurement under each type of ambient lighting. Results: Neither the LED nor CFL bulbs emitted detectable light energy at a wavelength of 785 nm. The color-based representation of arbitrary perfusion unit (APU) values of the Triple response measured by the scanner was similar between darkness, LED, and CFL light. Daylight emitted 2 mW at 785 nm, with a slight variation tending more towards lower APU values compared to darkness. Halogen lighting emitted 6 mW of light energy at 785 nm rendering the color-based representation impossible to interpret. Conclusions: Halogen lighting and daylight have the potential to confound results of LDI of cutaneous injuries whereas LED and CFL lighting did not. Any potential sources of daylight should be reduced and halogen lighting completely covered or turned off prior to wound imaging.

Keywords: Laser Doppler Imaging, ambient lighting, burn assessment

Introduction

Laser Doppler Imaging (LDI) has been used in the diagnosis of burns and prediction of healing potential [1], proving more sensitive and specific in the evaluation of burns compared to clinical evaluation alone. A recent meta-analysis of the diagnostic accuracy of LDI in assessing burn depth concluded that it had a sensitivity and specificity of 89% and 93% respectively [2]. It also has been shown to correlate closely with histological diagnosis of burns depth [3-5]. The ability to define burns according to perfusion has led to improved clinical decision-making ability with regards to prediction of burns that will heal spontaneously vs. those that will require excision and grafting [1, 6-8]. This has resulted in decreased length of stay in hospital,

improved clinical decision capability, and ultimately improved overall burns management [9].

The accuracy of LDI may be influenced by ambient lighting [10]. While no study to date has documented the effect of ambient lighting on LDI, our unit has anecdotally observed instances of arbitrary perfusion unit (APU) value variation under different lighting conditions. While this variation may be due to a combination of factors, it is possible that interference from external sources of electromagnetic radiation may affect the accuracy of detected readings [11]. Sharma *et al.* have suggested the importance of maintaining the same intensity and colour of ambient lighting in addition to covering windows to prevent variability from daylight [12].

The effect of ambient lighting on LDI

Table 1. Spectrometer readings of light intensity at 785 nm under different lighting conditions

Lighting Type	Light Intensity at 785 nm (in milliwatts)
No light (darkness)	0 mW
Halogen	6 mW
Sunlight (overcast day)	2 mW
CFL	0 mW
LED	0 mW

This pilot study aimed to try and identify the potential influence of ambient lighting on the results of LDI scans of a previously validated, standardized cutaneous injury model.

Materials and methods

The standardized cutaneous injury model was previously utilized by Holland *et al.* based on the Triple response with the axon reflex resulting in histamine release in response to a mechanical stimulus [11]. The mechanical stimulus was applied using firm pressure over a period of 10 seconds with the blunt end of a ballpoint pen cap over a distance of 10 cm, without piercing the epidermis. Repeated stimuli were applied until the resulting injury manifested as a wheal due to local oedema as a result of increased capillary and venular permeability in addition to a flare from arteriolar dilatation which normally takes approximately 30-40 minutes to resolve. Another repeat stimulus was applied before each new lighting source was implemented to ensure a consistent response for the duration of the study. Unlike a dermal-thickness burn, this is a dry cutaneous injury with no exudate. No dressing or specialized wound care was necessary after the stimulus was applied. We conducted repeated LDI scans of this injury on the non-dominant anterior forearm of a single healthy volunteer. The volunteer was a previously healthy 33-year-old male, Fitzpatrick skin type IV Southeast Asian ethnicity, with no scars or skin lesions in the scanned region of interest. Approval was obtained from The Children's Hospital at Westmead Ethics Committee.

A Moor Laser Doppler Line Scanner (LDLS-BI) (Moor Instruments Ltd., Axminster, England) was used. It has a Class 3R, 30 mW laser with a wavelength of 785 nm, controlled by an

Advantech touch screen panel PC (Advantech Co. Ltd., Milpitas, USA) using Moor LDLS-BI v1.0 burns imaging software (Moor Instruments Ltd.). The room temperature was stable at 22 to 24°C for the duration of the study. All scans were performed at a distance of 15 cm with a uniform blue cloth background. The scanner head was positioned slightly offset from the perpendicular to avoid the most direct laser reflection as per usage instructions.

A Homemaker brand wooden table lamp (Kmart Australia, Mulgrave, VIC, Australia), E27 large Edison screw bulb globe type, was purchased and used with the shade removed to power three separate light bulbs, thereby providing three different types of ambient lighting for scanning. Only one light bulb was powered to provide a single type of ambient lighting for each scan; no scans were conducted under a combination of light sources. From 2010 minimum efficiency standards were put into effect in Australia that restricted the availability of incandescent (Tungsten) light bulbs [13]. For our study we used an 806-lumen light-emitting-diode (LED) bulb, an 860-lumen compact fluorescent light (CFL) bulb and a 370-lumen halogen bulb. Light bulbs were chosen based on light sources typically available in a hospital or clinic-based setting, and all light bulbs were purchased from the same store off the shelf. Bulbs were positioned 40 cm away from the area of scanning in order to maximise light intensity readings from the spectrometer as well as to minimise the potential confounding effect of the shadow of the scanner head falling onto the area being scanned. Additionally, an angle of incidence was chosen such that no shadows from the machine head fell onto the area being scanned. Scans were also conducted using daylight on an overcast day coming in through a large window in the room as well as in darkness with no significant light sources turned on in the room as a control. We used a Black Comet concave grating spectrometer (StellarNet, Tampa, USA) to measure the intensity of ambient light as a function of wavelength. After the Triple-response stimulus was applied and a wheal and arteriolar flare induced in the anterior forearm of the healthy volunteer, 3 LDI scans were done consecutively under each type of ambient lighting in isolation: darkness, daylight, CFL, LED, and then halogen lighting. Consecutive scans under the

The effect of ambient lighting on LDI

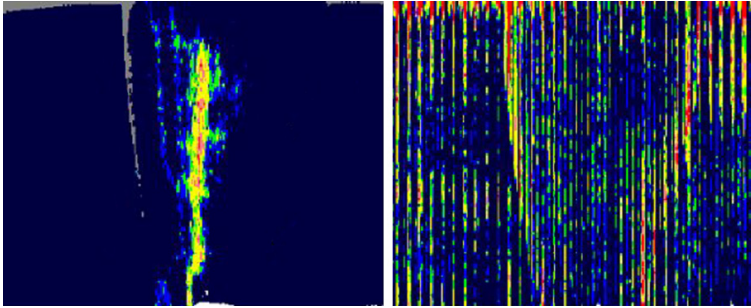


Figure 1. LDI scan images under darkness (left) and under halogen lighting (right). Note that colors depicted in LDI images correspond to arbitrary perfusion unit (APU) values as calculated by the LDI software. The cutaneous injury-induced wheal and flare are located vertically in the midline as seen in the left image. Interference in the right image makes interpretation impossible.

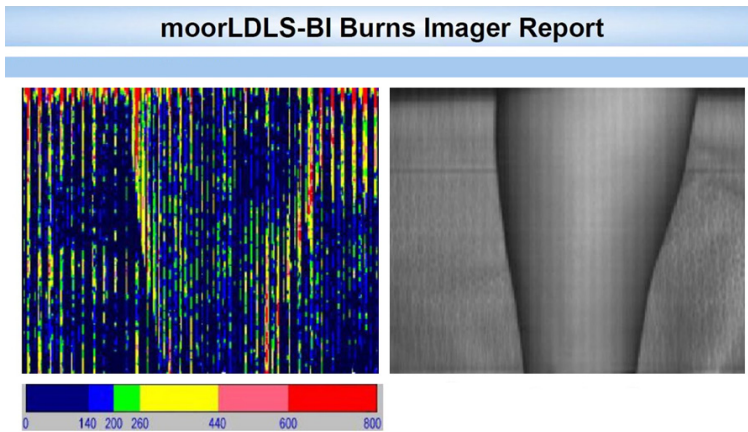


Figure 2. LDI scan image (left) vs. grey-scale reconstructed image (right) scanned under halogen lighting, confirming interference not due to reflectance, as areas of high reflectance would show up as white when depicted in grey-scale. Note that colors depicted in LDI images correspond to arbitrary perfusion unit (APU) values as calculated by the LDI software. The cutaneous injury-induced wheal and flare are located vertically in the midline.

same lighting condition were conducted one after the other. Less than 5 minutes were needed to change ambient lighting conditions between scans under different lighting types. Representative images were then chosen and can be seen in the attached figures. The light bulbs were changed whilst the lamp base itself as well as the scanner head were kept in the same position throughout the duration of the study. The color-based representation of the wheal and flare APU values was compared under each type of ambient lighting.

Results

Table 1 lists readings with the spectrometer showing that no detectable light energy with a

wavelength of 785 nm was emitted by the LED bulb or the CFL bulb. When we opened the curtains on the window and allowed daylight on an overcast day to illuminate the room, we recorded an intensity reading of 2 mW at 785 nm on the spectrometer. The greatest light intensity at 785 nm of 6 mW was found under halogen lighting (**Figure 1**). Based on the reconstructed grey-scale image we were able to confirm that this was not the result of confounding due to reflectance, as areas of high reflectance would show up as white when depicted in grey-scale (**Figure 2**). **Figure 3** shows the readings from the spectrometer depicting the spectral content of halogen (1), daylight (2), CFL (3), and LED lighting (4).

The color-based representation of APU along the length of the cutaneous injury remained fairly consistent between the control, under LED lighting, and under CFL lighting, depicting the injury as mostly yellow (APU = 260-440), pink (APU = 440-600), and red (APU > 600). Under daylight, APU values appeared to be slightly lower, with the central area

depicted as green (APU = 200-260) and a larger percentage of the wound depicted as yellow. **Figure 1** illustrates that by far the greatest interference with LDI scanning was associated with halogen lighting, completely preventing interpretation of the cutaneous injury. **Figure 4** shows the color-based representations of APU values under darkness (1), daylight (2), CFL (3), and LED lighting (4).

Discussion

LDI scanning has been used in burn units world-wide to assist in the evaluation of burns and guide clinical decision-making. It may be operated in a variety of both inpatient and outpatient clinical settings, with the potential for

The effect of ambient lighting on LDI

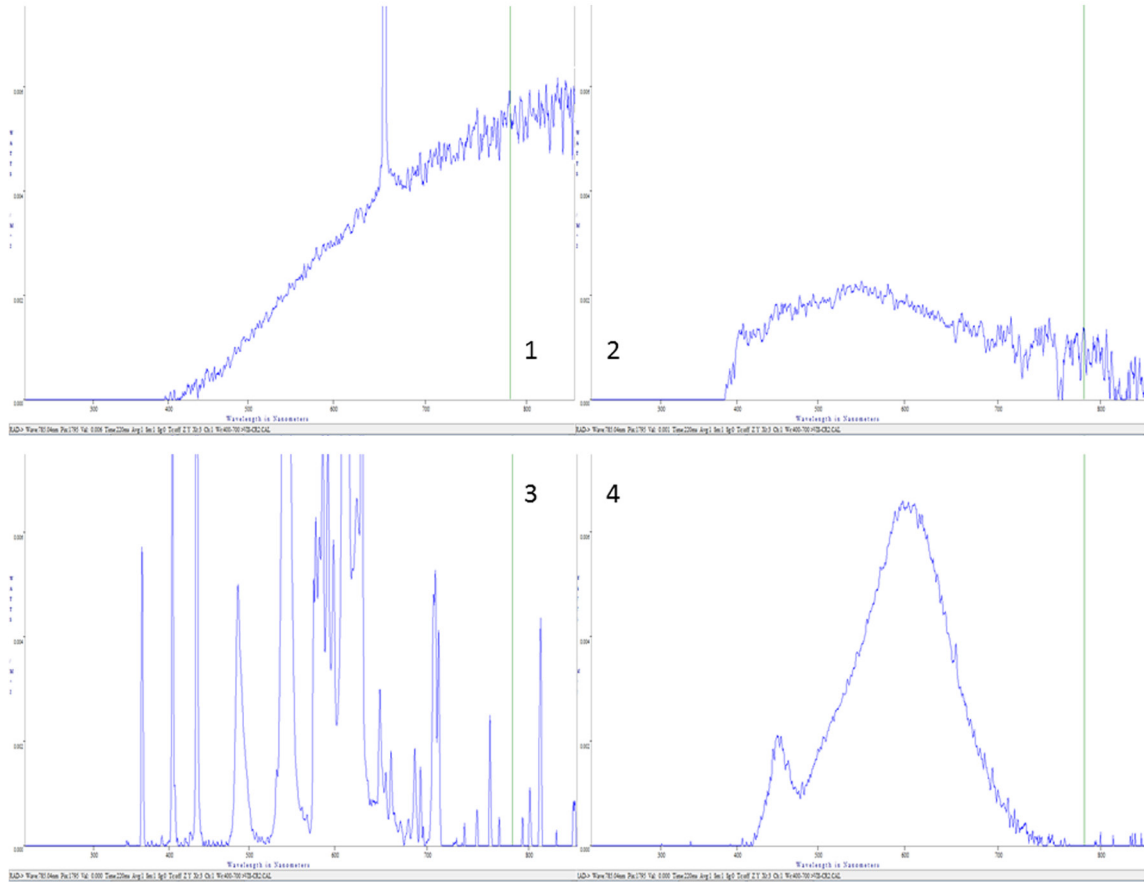


Figure 3. Spectrometer readings showing the spectral content of each separate light source: halogen (upper left), daylight (upper right), CFL lighting (lower left) and LED lighting (lower right). The x-axis denotes wavelength, with the green vertical line marking 785 nm. The y-axis denotes power in watts.

a variety of ambient light sources in the same room as the patient and scanner. Our study shows that LED and CFL light sources do not interfere with the LDI scanner's ability to read and present captured data. We also identified two potential sources of light that interfered with scan results: halogen lighting and, to a lesser degree, daylight. The spectrometer readings of light intensity at 785 nm, the wavelength of interest read by the LDI scanner, consistently match with the amount of variation and interference in color-based representations of APU value in the region of interest under the different lighting sources. In fact, scanning the region of interest under exposure to a halogen light source made it impossible for clinicians to accurately interpret scan results due to interference.

There are some clear limitations to this study that should be acknowledged. As a qualitative pilot study, we are not able to definitively prove the quantum of APU variation between the dif-

ferent lighting sources, and darkness is not a clinically practical control. These scans were all conducted on a Triple response cutaneous stimulus model that, while easily imaged by LDI, is not an exact replication of the cutaneous defect of a burn injury. Furthermore, all images were taken using a single LDI machine from a single manufacturer. The authors believe that, regardless of model or manufacturer, any device that scans using the 785 nm wavelength will have results consistent with what we have shown. Thus, the previous model Moor LDI and LDLS machines, as well as the newer model LDLS2-BI, would all be expected to experience potential confounding results similar to what we have shown. The current Moor LDI-2-BI operates at a wavelength of 633 nm, potentially adding an additional spectrum of confounding ambient light sources which could also be investigated using our model.

At the time of submission, no published studies were identified investigating the potential

The effect of ambient lighting on LDI

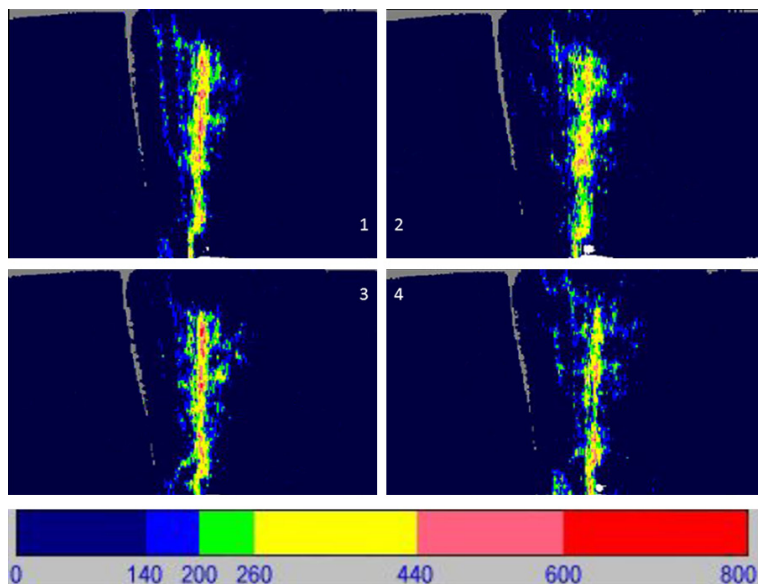


Figure 4. LDI scan images under darkness (upper left), daylight (upper right), CFL lighting (lower left) and LED lighting (lower right). Note that colors depicted in images correspond to arbitrary perfusion unit (APU) values as calculated by the LDI software. The cutaneous injury-induced wheal and flare are located vertically in the midline in each image.

confounding effects of ambient lighting on the results of LDI scanning. Information booklets and online specifications published by Moor, the manufacturer of the LDLS scanner, describe the lighting requirements as “normal, ambient room lighting” [10]. Current New South Wales Health engineering guidelines regarding lighting sources recommend but do not mandate the use of fluorescent and/or LED fittings in public hospital facilities [14]. Similarly, they generally recommend against the use of incandescent or halogen lamps but do not prohibit it [14]. We would clarify this by specifying that scans should always be conducted under either LED or CFL lighting only. To protect the scanner from potential interference, any sources of daylight such as a window or door should be completely covered, and any halogen light sources in the room should be turned off during burn wound scanning. The potential confounding effect of daylight on an LDI scan could result in a perception of poorer blood flow to a region, which in turn may lead to the interpretation of the scan as a deeper burn than it truly is.

Clinical decision-making based on an incorrect perception of burn depth may result in sub-optimal dressing choice and even the poten-

tially erroneous decision to proceed to early skin grafting. Clinicians performing LDI scans with results similar to **Figure 1** should consider the possibility of interference from a nearby light source confounding their scan results. In clinical scenarios where the results of an LDI scan do not correlate with the clinician’s assessment, the manufacturer suggests scanning areas with ambient light sources both on and off to check for any potential interference. The colour video image could also be inspected for well-defined shadows that may indicate that a high-intensity light source was interfering with LDI scanning. Manufacturer representatives during product demonstration and orientation workshops recommend that the operator carefully pat dry burn wounds to prevent reflections from surface moisture interfering with the laser. Particular care should be taken with superficial dermal burn wounds which are often associated with a moist wound bed [15]. Additionally, scans of a normal healthy volunteer’s arm could also be done with normal ambient lighting on and off in any room where patients are anticipated to be seen in order to ensure scans are consistent and not affected by ambient lighting conditions.

Acknowledgements

The authors would like to acknowledge Ms. Madeleine Jacques for her assistance in conducting the LDI scans.

Disclosure of conflict of interest

None.

Address correspondence to: Dr. Alan Pham, M.B.B.S., DCH Burns Registrar Burns Unit, The Children’s Hospital at Westmead, 170 Hawkesbury Road, Westmead, NSW 2145, Australia. Tel: 61-2-9845-0000; Fax: 61-2-9845-0546; E-mail: alan.pham@health.nsw.gov.au

The effect of ambient lighting on LDI

References

- [1] Holland A, Martin H and Cass D. Laser Doppler Imaging prediction of burn wound outcome in children. *Burns* 2002; 28: 11-17.
- [2] Shin JY and Yi HS. Diagnostic accuracy of Laser Doppler Imaging in burn depth assessment: systematic review and meta-analysis. *Burns* 2016; 42: 1369-1376.
- [3] Niazi Z, Essex T, Papini R, Scott D, McLean N and Black M. New laser doppler scanner, a valuable adjunct in burn depth assessment. *Burns* 1993; 19: 485-489.
- [4] Jeng J, Bridgeman A, Shivnan L, Thornton P, Alam H, Clarke T, Jablonski K and Jordan M. Laser Doppler Imaging determines need for excision and grafting in advance of clinical judgment: a prospective blinded trial. *Burns* 2003; 29: 665-670.
- [5] Pape SA, Skouras CA and Byrne PO. An audit of the use of Laser Doppler Imaging (LDI) in the assessment of burns of intermediate depth. *Burns* 2001; 27: 233-239.
- [6] La Hei E, Holland A and Martin H. Laser Doppler Imaging of paediatric burns: burn wound outcome can be predicted independent of clinical examination. *Burns* 2006; 32: 550-553.
- [7] Nguyen K, Ward D, Lam L and Holland AJ. Laser Doppler Imaging prediction of burn wound outcome in children: is it possible before 48 h? *Burns* 2010; 36: 793-798.
- [8] Monstrey S, Hoeksema H, Baker R, Jeng J, Spence R, Wilson D and Pape S. Burn wound healing time assessed by Laser Doppler Imaging. Part 2: validation of a dedicated colour code for image interpretation. *Burns* 2011; 37: 249-256.
- [9] Khatib M, Jabir S, Fitzgerald O'Connor E and Philp B. A systematic review of the evolution of laser doppler techniques in burn depth assessment. *Plast Surg Int* 2014; 2014: 621792.
- [10] Instruments M. *Moor LDLS2 brochure*. [Web Page] 7 October 2016; Available from: <http://us.moor.co.uk>.
- [11] Holland AJ, Ward D and Farrell B. The influence of burn wound dressings on Laser Doppler Imaging assessment of a standardized cutaneous injury model. *J Burn Care Res* 2007; 28: 871-878.
- [12] Sharma VP, O'Boyle CP and Jeffery SL. Man or machine? The clinimetric properties of Laser Doppler Imaging in burn depth assessment. *J Burn Care Res* 2011; 32: 143-149.
- [13] International SA. AS 4934.2-2011: incandescent lamps for general lighting services part 2: minimum energy performance standards requirements.
- [14] Infrastructure H. *Engineering services guideline*. 2016.
- [15] Instruments M. *Laser doppler blood flow assessment training manual*. 2007.