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Effect of Ambient Light on Near Infrared Spectroscopy

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Abstract

Background: Concerns have been raised about the ability of Near Infrared Spectroscopy (NIRS) to monitor skeletal tissue regional oxygen saturation (rSO_2) in excessive light conditions, as are found under the overhead lights of the operating room. This study seeks to determine whether varying intensities of ambient light exert an influence on NIRS measurements of skeletal tissue rSO_2.

Methods: Thirty people were recruited from the staff of a local surgical center to participate in the study. Three separate NIRS devices (Covidien INVOS Cerebral Oximeter 510°C, Nonin EQUANOX Model 7600, and a CASMED MC-2030C Cerebral Oximeter) were used to obtain readings from the anterior compartment of the leg. Illuminance was recorded simultaneously with oximetry data in an operating room with (1) no lights on, (2) room lights, and (3) surgical lamps set to maximal intensity.

Results: No differences were seen in rSO_2 values under the different lighting conditions while using the Nonin device. There was a statistically significant difference between rSO_2 for lights off versus room lights (-0.933, p=0.0045) as well as for lights off versus operating room (OR) lamps (level 5) (-0.50, p=0.0035) for the INVOS device, although the INVOS device was not always able to produce a reading in the presence of high-intensity OR light. While there was no difference found between lights off and room lights when using the CASMED device, it was unable to display a value in the presence of high-intensity OR lamp light.

Conclusions: The results indicate that the presence of light has an effect on oximetry readings; however, the presence of such an effect is dependent upon the device being used. While other applications of the device, such as cerebral oximetry, may allow for drapes to cover the areas being monitored, monitoring for compartment syndrome of the leg would not be as forgiving. This application would be best served by a device capable of monitoring at all light levels.

Keywords: Near infrared spectroscopy; Skeletal tissue regional oxygen saturation; Skeletal tissue

Background

Near-infrared spectroscopy (NIRS) is a powerful analytical technique that allows for noninvasive assessment of percentage of oxygenated hemoglobin [1] as well as local assessment of blood flow and oxygen consumption [2,3]. NIRS devices consist of a light source, an optode(s) to detect the unabsorbed light, and a computer to calculate meaningful data related to the absorptivity; these calculations are derived from the Beer-Lambert law, which correlates absorbance to the extinction coefficient, path length, and concentration of light-absorbers in the sample. NIRS sensors used for oximetry monitoring contain both the light source as well as the light sensor on the same pad, which is coated with an adhesive and attached superficially to the skin. The depth of near-infrared light penetration is equal to roughly half the distance between the light source and sensor. Most devices emit multiple wavelengths of light and have two or more sensors on them. The first sensor detects light with shallow penetration to correct for any potential interference by superficial skin and adipose; the presence of adipose may confound measurements from muscle tissue, and melanin has been shown to attenuate reported rSO_2 values [3-5]. The second sensor is designed to detect light that has penetrated more deeply into the underlying muscle.

When sampling human tissue, measurements reflect oxygenation at the level of the microcirculation, which consists of arterioles, capillaries, and venules. As the majority of blood rests within the venous system, readings are more heavily weighed towards blood that has already passed by the end target and released its oxygen. Larger vessels contain such high concentrations of red blood cells that near-infrared light is completely absorbed before reaching the optode. A number of NIRS devices are currently FDA approved for monitoring cerebral perfusion and or somatic perfusion; such machines have proprietary algorithms for deriving oxygen saturation. NIRS monitoring has found utility in a number of clinical settings, such as monitoring patients at risk for decompensating into shock, undergoing cardiac surgery, suffering from epilepsy, or those who are at risk of developing compartment syndrome [6-9]. As such, NIRS is a technology with multiple applications that may provide critical information for patients in an intensive care unit (ICU).

Studies by Shuler et al. have demonstrated the potential of NIRS in monitoring patients with limb trauma and compartment syndrome [10]. Research has shown differences in both injured and noninjured limbs, and emphasizes the utility of using a contralateral uninjured limb, if possible, as a control for monitoring trauma patients [5]. Injured tissue typically exhibits higher tissue oxygenation values due to a hyperemic response to trauma. Additionally, the use of NIRS as

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a potential indicator of adequate pressure release with a fasciotomy performed inside the operating room suite requires that the technology be accurate and effective in different lighting situations. This study seeks to determine whether varying intensities of ambient light exert an influence on NIRS measurements of skeletal tissue rSO_2. NIRS may be a valuable postoperative tool for trauma patients who are at risk of developing compartment syndrome. With proper sensor placement, this technology may provide the caregiver with accurate information regarding local oxygenation in multiple compartments, and spares the use of invasive measurements. Close postoperative monitoring in the trauma patient may lead to earlier intervention as well as reduction in the number of unnecessary fasciotomies. The hypothesis was different levels of ambient light would not affect NIRS readings between all manufacturers.

Subjects and Methods

After approval by the University of Georgia Institutional Review Board, thirty patients were enrolled from the staff at Athens Orthopedic Clinic between January 1, 2014 and February 1, 2014. Individual consent from the study participants was obtained. Exclusion criteria included ages under 18 and over 65, as well as the possibility of pregnancy.

NIRS measurements were obtained using an INVOS Cerebral Oximeter 5100C (Somanetics; Troy, Michigan), an EQUANOX Model 7600 Oximeter (Nonin; Plymouth, Minnesota), and a CASMED MC-2030C Cerebral Oximeter (CAS Medical Systems; Branford, Connecticut). Measurements were obtained in one of three operating rooms at a local surgical center based upon room availability. The various light settings used for the measurements included: dark (no light), room (room lights), and operating (surgical lamps plus room lights). The operating rooms used Amsco SQ240 Surgical Lights, which were controlled by an Amsco Quantum Intensity Control (Steris; Montgomery, Alabama). The surgical lamp controls could be set to increasing intensities from one to five. By default, all measurements with the surgical lamps were set to the highest intensity, five as this setting is the standard setting for surgical procedures. At the start of the study, measurements were only taken using the highest intensity and measurements that failed to register due to excessive ambient light were recorded as 'N.A.'. Halfway through the study it was decided that if the highest intensity failed to register a measurement on the oximeter, then lower light settings (three and one) would be used as well on the Amsco Quantum Intensity Control. Quantitation of room light was performed via a Dr. Meter LX1330B Digital Light Meter (Hisgadget; Union City, California). Skin color measurements were obtained using a Cortex Instruments DSM II Colorimeter (Cortex Technology ApS; Denmark).

Patients were seated on an operating table with their left leg resting on the table and scrub pants rolled up to the knee. Care was taken to insure no compression due to the scrubs was present. An alcohol pad was used to cleanse the area to be tested. NIRS sensors were placed over the anterior compartment approximately 3 cm inferior and 2 cm lateral to the tibial tuberosity (Figure 1). Two surgical lamps were set up in each operating room. For the OR lamp readings, one light was aimed directly over the NIRS sensor while the other was aimed directly at the digital light meter, both of which were approximately equidistant from their respective light sources. Oximetry measurements were then taken (INVOS followed by EQUANOX and finally CASMED) at increasing light settings while the illuminance was simultaneously measured. Oximetry data were recorded after 4 cycles of a stable value. The INVOS 5100C cycled every 6 seconds, whereas the CASMED MC-2030C device is cycled every 3 seconds and EQUANOX Model 7600 every 1.4 seconds. Most values were obtained within 60 seconds.

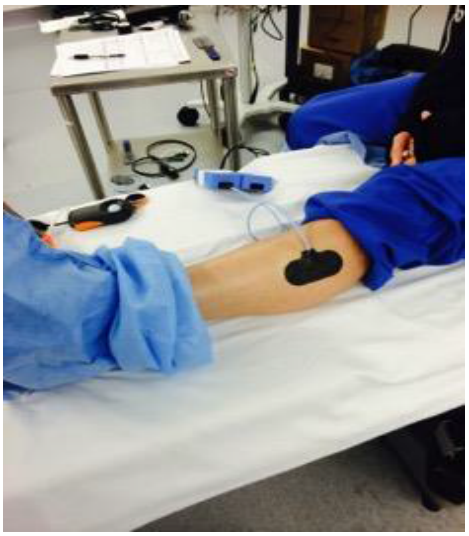

Figure 1: Sensor placement over anterior compartment of leg.

Data analysis

Lux values for each light setting were compared between devices to look for significant differences between measurements. Real differences in rSO_2 values were compared between each device to itself at the various light levels. As there were significant differences between lux values on INVOS and CASMED readings, the devices could not be compared against one another. A paired t-test was performed to compare readings at lights off versus room light, as well as lights off versus OR lights *(level 5)*.

Results

A total of twenty-six females and four males were enrolled in the study, with a mean age of 36.3 (range 19-60). Mean BMI was 25.6 (range 17.6-41.2). Of the thirty subjects, twenty-nine were Caucasian, one was African-American, and one of the Caucasian subjects was part Hispanic (Table 1).

Mean lux values for the various light settings were as follows; off - 0.174 lux (range 0.1-0.4, standard deviation 0.0923); room - 904 lux (range 642-1347, standard deviation 195); OR lamp *(level 1)* - 19800 lux (range 12500-32500, standard deviation 5520); OR lamp *(level 3)* – 25200 lux (range 20400-37800, standard deviation 8380); OR lamp *(level 5)* - 51500 lux (range 32100-91000, standard deviation 14600).

Real differences between oximetry readings, reported as ΔrSO_2, are compared between different light settings in Tables 2a-2f. The CASMED MC-2030C failed to display oximetry values on each attempt with the surgical lamp; the displayed error is shown in Figure 2a. This explains why no table was generated for the CASMED readings comparing lights off to surgical lamps. Similarly, the INVOS 5100C was unable to report oximetry data in 21 out of 30 readings done under surgical lamps set to the highest intensity; the device reported the error as shown in Figure 2b. As such, the data in Table 2b reflects only 9 measurements, rather than 30. For the INVOS measurements that failed to report rSO_2 due to excessive light (OR lights level 5), the OR light intensity was decreased to level 1. The real differences between lights off and OR lights (level 1)

Characteristic	Mean (SD)	Range
Age	36.33 (10.72)	19, 60
BMI	25.57 (5.87)	17.6, 41.15
Gender (# Female/N)	26/30	
Race	Count	
White (Hispanic)	29 (1)	
Black	1	

Table 1: Subject demographics.

ΔrSO_2	Frequency (n)	% of Readings
-7	1	3.33
-3	3	10
-2	4	13.33
-1	9	30
0	8	26.67
1	5	16.67

ΔrSO_2	Frequency (n)	% of Readings
-14	1	11.11
-5	4	44.44
-4	2	22.22
-2	1	11.11
-1	1	11.11

ΔrSO_2	Frequency (n)	% of Readings
-3	2	6.67
-2	2	6.67
-1	4	13.33
0	15	50
1	4	13.33
2	3	10

ΔrSO_2	Frequency (n)	% of Readings
-4	1	3.33
-3	1	3.33
-2	3	10
-1	2	6.67
0	15	50
1	6	20
2	2	6.67

ΔrSO_2	Frequency (n)	% of Readings
-6	1	3.33
-3	1	3.33
-1	5	16.67
0	8	26.67
1	11	36.67
2	2	6.67
3	2	6.67

ΔrSO_2	Frequency (n)	% of Readings
-6	1	14.29
-4	1	14.29
-3	1	14.29
-2	2	28.57
-1	2	28.57

a: INVOS: Off - Room
b: INVOS: *Off – OR lights (level 5)*
c: EQUANOX: *Off – Room*
d: EQUANOX: *Off – OR lights (level 5)*
e: CASMED: *Off – Room*
f: INVOS: *Off – OR lights (level 1)*

Table 2: Oxygen saturation changes.

are reported in Table 2f. Out of 12 measurements taken at this setting, 6 failed to record due to excessive light. Of the 6 that did register, 5 failed to register when the OR lights were increased to level 3. These data were excluded from statistical analyses because of the limited size, and as such should be considered anecdotal.

A paired t-test was performed to compare readings with lights off versus room lights, as well as lights off versus OR lights (level 5). Regarding the INVOS device, there was a significant difference in rSO_2 when lights were off versus room lights (difference of -0.933; p=0.0045) as well as when lights were off versus OR lights set to level 5 (difference of -5.0; p=0.0035). No significant differences were found in the data obtained from the EQUANOX device. For the CASMED device, no significant differences were found between lights off versus room lights; due to the absence of readings with the OR lamp on, lights off versus OR lamp could not be calculated.

Discussion

NIRS is capable of providing clinicians with data regarding tissue perfusion and oxygenation in a noninvasive manner. As previously mentioned, continued recordings of oximetry values may be of utility in tracking patients who may be progressing into shock, developing

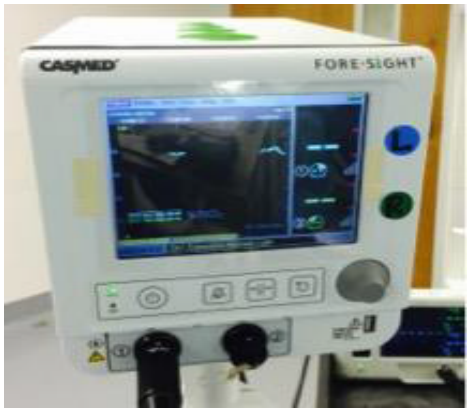

Figure 2a: CASMED device unable to obtain reading due to 'Excessive Ambient Light'. Note error reading at bottom of screen.

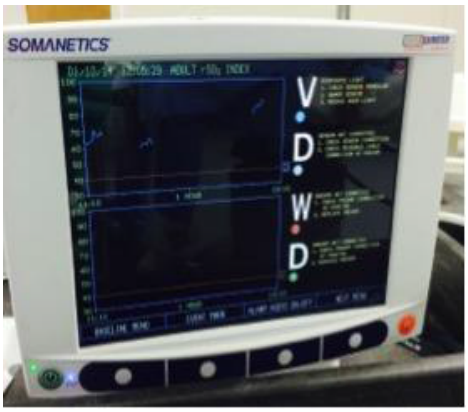

Figure 2b: INVOS device reading error demonstrated to the right of row marked by 'V'.

compartment syndrome, or have neurological issues such as in patient transport to trauma centers by emergency medical services (EMS) or even evacuation of wounded warriors; broadly speaking, NIRS has utility in monitoring patients in critical states.

A number of variables have been shown to be involved in accurate interpretation of reported oximetry values obtained by NIRS. Such variables include the presence of trauma, adipose, and skin pigmentation [3,5]. These are factors that vary from patient to patient as well as between different device manufacturers; hence, understanding their bearing on NIRS readings is crucial to accurate interpretation of oximetry readings. In this study all patient variables were maintained constant by using the subject as an internal control and only comparing values within the same subject and not across subjects. Therefore, differences were isolated to inter-device variability in this study.

The three varying levels of illuminance used for each measurement were 'Off', 'Room', and 'OR lamp – *(level 5)*; these corresponded to mean lux values of 0.174, 904, and 51500, respectively. As such, oximetry changes in response to illuminance variance could be assessed on multiple orders of magnitude. ' For reference, the 'Recommended Illumination' found in the user manual for the luxmeter suggested 30-75 lux for a darkroom; 75-150 lux for an x-ray room or stairway; 150-300 lux for a surgical post-op room; 300-750 lux for an office, nurse room, first-aid room, or dispensary; 750-1500 lux for an operating room; and 300-10000 lux for ophthalmological purposes.

The results from the experiments revealed that the devices had varying responses to increasing degrees of illuminance. The INVOS 5100C was found to have a statistically significant difference between lights off and room lights (-0.933, p=0.0045) as well as for lights off versus OR lamps (level 5) (-0.50, p=0.0035). As these changes were calculated as the difference of rSO_2 light source from rSO_2 no light, a negative value implies that rSO_2 increased with illuminance. Only 9 of 30 readings under the OR lamp were able to be obtained. However, each of these readings was found to be increased relative to the reading obtained in the absence of light. As previously mentioned, this was found to be statistically significant. Therefore, the INVOS device demonstrated a proportional relationship of measured rSO_2 to light. Data obtained from the EQUANOX Model 7600 demonstrated that 50% of the obtained rSO_2 values remained unchanged when a light source was added. Furthermore, ~25% of the values changed within ±1 of the rSO_2 reading obtained in darkness. Therefore, ~75% of all the measurements obtained on the EQUANOX device had an absolute change ≤1 in the presence of light. The EQUANOX device was the only one that was able to obtain readings at all light settings, 100% of the time. The CASMED MC-2030C yielded similar results to the EQUANOX device, with the majority (~80%) of readings at room light falling within ±1 of the rSO_2 reading obtained in darkness. However, the device failed to register a single reading in the presence of surgical lamps, even at the lowest intensity (level 1). No statistically significant changes were found between measurements in the presence and absence of light.

Since NIRS is often used in the operating room to monitor brain perfusion during cardiac surgery as well it has been postulated that NIRS may be a beneficial tool in insuring adequate decompression of compartments with restoration of flow during surgery, this demonstrates that the EQUANOX device does work reliably under light intensities up to ~50000 lux.

It is noteworthy to mention that although the INVOS and CASMED devices occasionally failed to report rSO_2 in the presence of ambient light, there was no cutoff value identified where the devices consistently stopped generating data. With the INVOS device we found that we were able to obtain rSO_2 values with lux as high as 82900, whereas on other occasions readings failed to register with lux as low as 33100. When readings were not reported we ensured proper sensor placement, complete adhesion to skin, and that there were no faulty connections. We were unable to identify any errors that could have explained why some measurements did not register.

These findings help us gain a more complete understanding of the variables that may affect NIRS readings. As previously mentioned, traumatized tissue exhibits a hyperemic response that leads to a predictable increase in measured rSO_2. Skin pigmentation has been shown to influence NIRS readings due to the absorption of a portion of the near-infrared spectra by melanin [5,11]. Temperature has also been shown to affect the near-infrared spectra of blood [12-14]. This data suggests that light may have an effect on NIRS measurements, although this appears to depend on the device being used. Given that there are a number of variables which may affect NIRS readings, continued monitoring may be more advantageous that single measurements in following patients in need of critical care.

There are a number of limitations to the study. Firstly, a rather small sample size (n=30), and the demographic characteristics were not broad (mainly young Causasian females). Skin pigment, subcutaneous fat as well as other potential confounders between individuals were not evaluated in this study. Those factors were outside the scope of the study and are only applicable when evaluating absolute values across individuals. By using changes in the same individual for comparison, all of these factors are constant and therefore controlled. Due to statistically significant variances in light between the several operating rooms used for this study, devices could not be compared to one another, rather each device was compared to itself at various light settings.

Future studies may seek to characterize NIRS oximeters further and determine whether a response to light is a common finding. Also, work may be done to determine what other factors may cause a device to generate an excessive light warning, as there was no way to identify why some measurements were obtained at lux values much higher than other failed readings.

Conclusions

This study demonstrates several factors associated with obtaining NIRS values. First, ambient light can affect NIRS readings depending on the design and construction of the NIRS sensor. In one device, increases in ambient light increased the NIRS value. While in the setting of OR lights, two manufacturers had significant difficulties providing a reading at all. The EQUANOX (Nonin) showed the best capacity to maintain constant readings in all light settings as well as providing an actual reading in all light setting. This factor needs to be considered when using NIRS either in the operating room or in other setting such as patient transportation or wounded warrior evacuation.

Conflict of Interest Statement

Funding for this research was provided through a grant by the Department of Defense. MSS has a license for patent with Nonin Medical Inc. for the use of NIRS for acute compartment syndrome.

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