A systematic review of human and veterinary applications of noninvasive tissue oxygen monitoring

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Abstract

Objective – To describe the methodology for and utilization of tissue oxygen monitoring by near infrared spectroscopy, and to review the current literature on the use of this monitoring modality in human and veterinary settings.

Data Sources – Scientific reviews and original research found using the PubMed and CAB Abstract search engines with the following keywords: “tissue oxygen monitoring,” “near-infrared tissue spectroscopy,” and “tissue oxygen saturation (StO2).”

Human Data Synthesis – Tissue oxygen monitors have been evaluated in a wide variety of human clinical applications including trauma and triage, surgery, sepsis, and septic shock, and early goal-directed therapy. StO2 more rapidly identifies occult shock in human patients compared to traditional methods, which can lead to earlier intervention in these patients.

Veterinary Data Synthesis – Veterinary studies involving tissue oxygen monitoring are limited, but the technology may have utility for identification of hemorrhagic shock earlier than changes in base excess, blood lactate concentration, or other traditional perfusion parameters.

Conclusion – Tissue oxygen monitoring is most commonly performed utilizing a noninvasive, portable monitor, which provides real-time, continuous, repeatable StO2 measurements. A decline in StO2 is an early indicator of shock in both human and veterinary patients. Low StO2 values in human patients are associated with increased morbidity, mortality, and length of hospitalization, as well as the development of multiple organ system dysfunction and surgical site infections.


Keywords: near-infrared spectroscopy, NIRS, resuscitation, tissue oxygenation, tissue oxygen saturation

Abbreviations

CVP central venous pressure
EGDT early goal-directed therapy
NIRS near infrared spectroscopy
ScvO2 central venous oxygen saturation
SDF side-stream dark field microscopy
SSI surgical site infection
StO2 tissue oxygen saturation
THI total hemoglobin index
VO2 oxygen consumption

VOT vascular occlusion testing

Introduction

Early identification of decreased tissue oxygen delivery in critically ill patients is crucial to ensure appropriate treatment and resuscitation. Traditional methods of detecting altered tissue perfusion (as proposed surrogates for oxygen delivery) include physical examination, body temperature, arterial blood pressure, central venous pressure (CVP), and urine output. All of these have poor correlation to microcirculatory perfusion and cardiac preload, and may fail to indicate early signs of global tissue hypoxia.1–3 Assessment of global oxygenation status includes the measurement of oxygen delivery and consumption (VO2). These values may be obtained using pulmonary arterial or central venous catheterization, both of which are invasive, costly, and time consuming. Alternative parameters of perfusion including base deficit and arterial blood lactate concentrations have
been used in human and veterinary emergency rooms to determine endpoints of resuscitation. The concept of the “golden hours” refers to the time frame during which patients transition from serious illness to critical illness, which is an important period for identification of perfusion abnormalities. Patients with “occult” shock, or subclinical decreases in tissue oxygen delivery, are not detectable using standard perfusion assessments and may receive inadequate resuscitation.

Maintenance of adequate oxygen delivery to tissues is crucial for maintaining organ function. Oxygen delivery is maintained by supporting appropriate intravascular volume, vascular resistance, cardiac output, and systemic blood pressure. Traditional means of assessing the macrocirculation include global perfusion parameters, cardiac output, CVP, base excess, and lactate. Macrocirculatory flow can be normal in states of systemic inflammation, sepsis, and shock, while the flow through microcirculation can be variable. It has been hypothesized that microcirculatory dysfunction may play a key role in the pathophysiology of organ failure, as it plays a fundamental role in gas and nutrient exchange. There are many factors that influence the regulation of the microcirculation; variability can exist in tissue oxygen extraction or delivery, as well as the distribution of blood flow to the capillaries in certain disease states. For this reason the macrocirculatory parameters (eg, heart rate, pulse quality, blood pressure, lactate, mentation, capillary refill time, and mucous membrane color), should always be assessed and normalized first, with evaluation and monitoring of the microcirculation performed in addition to macrocirculatory parameters.

Noninvasive methods, including near infrared spectroscopy (NIRS), dark field videomicroscopy, Doppler flowmetry, gastric tonometry, sublingual capnometry, and transcutaneous carbon dioxide measurement have been evaluated for their ability to detect altered microvascular circulation and occult or compensatory shock in a variety of different settings. NIRS techniques to measure tissue oxygen tension (StO2) have been validated in people and dogs. These measurements have been used to facilitate goal-directed resuscitation and to determine the need for massive transfusions in human trauma patients, and may be associated with prognosis in this population. In addition, StO2 measurements have been used to predict the likelihood of surgical complications and postoperative infections in human patients. This review will focus on the methodology and utilization of near infrared spectroscopy for tissue oxygen monitoring, and will review the current literature pertaining to the application of the tissue oxygen monitor in human and veterinary settings.

**Methodology**

Data sources included scientific reviews, case series, and original research publications identified using the PubMed and CAB Abstract search engines with the following keywords: tissue oxygen monitoring, near infrared tissue spectroscopy, and tissue oxygen saturation (StO2). Inclusion criteria were those studies that evaluated use of near infrared tissue oximetry with vascular occlusion testing (VOT), sepsis, trauma, hemorrhage, shock, surgery, and early goal-directed therapy (EGDT). Studies were also included if they evaluated the methodology of the tissue oxygen monitor (ie, probe size or placement) and the effects on tissue oxygen measurement. Exclusion criteria for this analysis included studies that pertained primarily to cerebral tissue oxygen monitoring, or those that were not related to the above information.

**Tissue spectrometer technology**

Near infrared spectroscopy measures the absorption of infrared light (ie, wavelengths of 700–1000 nm) by tissues to determine the oxygen hemoglobin saturation of blood in vessels less than 1 mm in diameter (ie, microcirculation) within the tissue. Different commercially available machines utilize different wavelengths of light. The transference of light through tissue depends on reflection, absorption, and scattering of the light. Reflection is mainly determined by the angle of the light beam in relation to the tissue surface, and different machines use different trajectories. Infrared light has very low absorption by tissues and therefore passes through skin, bone, and muscle without attenuation. Light absorption by mammalian tissue is altered or attenuated depending on the chromophores that are present within the tissue, specifically cytochrome aa3, myoglobin, and hemoglobin. Melanin also plays a significant role in light absorption, but the absorption of near infrared light by myoglobin is minimal. Each chromophore has a different spectrum of absorption, with specific spectra for oxyhemoglobin and deoxyhemoglobin. Oxyhemoglobin preferentially absorbs higher near-infrared wavelengths (800–1000 nm), whereas deoxyhemoglobin absorbs wavelengths closer to 600–800 nm. Scattering of light is one of the biggest problems encountered when utilizing NIRS technology; 80% of the light emitted is lost through scatter, and therefore the modified Beer Lambert equation is used to estimate the true absorption value, by accounting for the signal loss due to scatter. In addition, probe placement over hematomas, fat, or bone may alter the tissue oxygen reading (excluding cerebral StO2 measurement). Fluctuations in body temperature, as well as excessive movement, can also lead to errors in StO2 measurement.
The InSpectra Tissue Spectrometer, a noninvasive, U.S. Food and Drug Administration (FDA) approved, portable monitor, which provides real-time, continuous, repeatable StO\textsubscript{2} measurements at varying tissue depths by measuring tissue absorbance values between 680 and 800 nm.\textsuperscript{25-27} This spectrometer has been evaluated in people with a wide variety of physiologic conditions.\textsuperscript{25,28} The contact probe sits inside a sensor shield that helps to minimize interference of ambient light. For direct measurement of StO\textsubscript{2}, the sensor, using a variety of probe sizes (15–25 mm) is placed over a muscle bed, allowing for the continuous StO\textsubscript{2} measurement.\textsuperscript{29-31} The muscle belly found to provide the most reliable StO\textsubscript{2} readings in people (despite different body conditions, amount of adipose tissue, and skin pigmentation) is the thenar eminence, the muscle at the base of the thumb. The muscle belly found to produce the most reliable StO\textsubscript{2} values in dogs is the sartorius.\textsuperscript{17}

Total hemoglobin index (THI) is an indicator of signal strength, and is reported as a unitless number between 1 and 99.\textsuperscript{32,33} THI is not a measurement of blood hemoglobin, as it measures the amount of intravascular hemoglobin, intramuscular myoglobin, melanin, and mitochondrial cytochrome c oxidase.\textsuperscript{18,33,34} THI measurements ≤5 indicate a weak hemoglobin signal and may lead to inaccurate StO\textsubscript{2} readings.\textsuperscript{26} The machine’s ease of use and reproducible results make it an attractive tool for evaluating patients with possible microvascular perfusion abnormalities. (Figure 1)

The INVOS Oximeter\textsuperscript{b} is an FDA-approved regional oximeter that enables simultaneous four-channel cerebral and somatic tissue oxygenation monitoring with noninvasive probes available for adults, children, infants, and neonates.\textsuperscript{35} Indications for use include the monitoring of patients following cardiac, vascular, and general surgery, in addition to monitoring patients in the intensive care unit and cardiac catheterization lab, where the brain and body are at risk of reduced-flow or no-flow ischemic states.\textsuperscript{35} Tissue oximetry may also be used to monitor trends in regional hemoglobin oxygen saturation of blood in the brain or other tissues.\textsuperscript{35}

The NIRO-200NX\textsuperscript{c} near infrared tissue oxygen monitor performs continuous noninvasive measurement of StO\textsubscript{2}. It is licensed for investigational use, and has two channels available for simultaneous measurement of cerebral and StO\textsubscript{2}. This machine measures the tissue oxygenation index, the oxygen saturation level, the normalized tissue hemoglobin index, and changes in the concentration of oxygenated, deoxygenated, and total hemoglobin.\textsuperscript{36} Indications for use include the monitoring of human patients during various surgical procedures, on presentation to the emergency room, or during helicopter rescue or transport. This device has also been evaluated for use in people in intensive care units, but is not currently FDA approved.\textsuperscript{36}

The moorVMS-OXY\textsuperscript{d} oximeter noninvasively and continuously measures hemoglobin oxygen saturation in superficial tissues. In addition to StO\textsubscript{2}, this device has probes that measure laser Doppler and skin temperature.\textsuperscript{37} This system can also use needle probes for minimally invasive single or continuous measurement of StO\textsubscript{2} in difficult-to-access tissues such as muscle and brain.\textsuperscript{37} The skin surface probes are generally used with a holder and secured with double-sided adhesive discs, while the needle probes can be used for more invasive measurements such as in bone and visceral tissues.\textsuperscript{37}

**Vascular occlusion testing**

VOT was developed to increase the ability of NIRS to detect abnormalities in tissue oxygen extraction and utilization within vascular beds.\textsuperscript{38-40} VOT determines the baseline StO\textsubscript{2} and then evaluates rates of deoxygenation and reoxygenation following occlusion of regional circulation.\textsuperscript{7} The StO\textsubscript{2} is continuously measured at a distal site (eg, thenar eminence) during occlusion of blood.
flow using a sphygmanometer and pressure cuff (in this example, placed proximal to the elbow). The ischemic challenge lasts for a defined interval of time (3–5 min) or until the StO₂ meets a specific threshold (30%–40% decrease from baseline StO₂). Once the threshold is met, the cuff is deflated rapidly and the StO₂ recovery slope obtained. Due to the lack of standardization in the measurement of StO₂ during the VOT, comparison of results can be difficult between studies; however, VOT may be useful when examining patients with sepsis or septic shock as they often have decreased oxygen extraction (VO₂) from the tissues. Decreased oxygen consumption in patients with septic shock results in a prolonged recovery slope in the VOT. The persistence of a slow VOT recovery in the first 24 hours of sepsis was correlated to a worse outcome. The results of the VOT are highly variable and dependent on the probe size, placement, and ischemic challenge. For this reason, it is currently recommended that a target StO₂ value be used for monitoring instead of the absolute values determined by the VOT. The VOT is a measure of microcirculatory reserve and not a direct representation of microcirculatory perfusion. The application of VOT in healthy or septic veterinary patients has not yet been evaluated. Of the muscle bodies evaluated and recommended for use in dogs, the digital extensors are the muscle belly of choice for VOT in veterinary patients due to the need to apply a sphygmanometer or pressure cuff above the muscle belly where readings are being obtained.

**Human Literature Review**

**Trauma**

Advances in human trauma care in the past 30 years have resulted in increased patient survival following the initial life-threatening insult; however, as much as 50% of these patients develop complications such as multiple organ failure, acute respiratory distress syndrome, and death. Life-saving interventions in the trauma population may be delayed and may lead to organ failure if inadequate tissue oxygenation is not corrected.

Tissue oxygenation determined by NIRS can be used to identify severe tissue hypoperfusion in patients following trauma. Low StO₂ can predict the occurrence of multiple organ dysfunction after sustained traumatic shock, and is more sensitive to predicting multiple organ dysfunction syndrome, the need for massive transfusions, and death in traumatized patients than other diagnostic tools. In a multicenter, prospective, non-randomized study of 383 human patients with shock presenting to the emergency room within 6 hours of trauma, StO₂ measurements were obtained within 30 minutes of arrival and were continuously measured for 24 hours. In this population, an StO₂ <75% measured within the first hour of arrival was predictive of the development of multiple organ dysfunction syndrome, and also of mortality. In addition, patients in this study with StO₂ <75% who required massive transfusions (>10 units of packed red blood cells [pRBCs] within the first 24 hours) experienced increased morbidity and mortality. No adverse events were reported concerning the measurement of StO₂.

The use of tissue oxygen monitoring to identify tissue hypoxia has application on the battlefield, in the emergency room, and in prehospital settings, where it may help to guide intravenous fluid resuscitation and transfusion decisions. An observational study showed that StO₂ reflected resuscitation efforts in patients with battlefield injuries. The StO₂ has also been shown to improve more rapidly than plasma lactate concentration and base deficit after adequate resuscitation, which may lead to lower volumes of intravenous fluids administered to trauma patients. STO₂ has also been shown to be an early and accurate predictor of the need for life-saving interventions compared to plasma lactate concentration and base deficit.

There is a direct relationship between the magnitude of oxygen deficit and the risk of multiorgan failure, which has lead to a treatment rationale that optimizes cardiac output and hematocrit to correct deficits in VO₂ and tissue oxygen delivery. Smith et al showed that StO₂ values predicted the need for early pRBC transfusions in trauma patients. Another study showed that StO₂ values were lower in human patients that had received aged (>21 days) pRBC transfusions, although Creteur et al found no correlation between the age of pRBC and StO₂ following transfusion. It is thought that the decrease in StO₂ associated with aged pRBC was related to the presence of RBC storage lesions.

**Surgery**

Tissue oxygen saturation has been evaluated in human patients in a variety of different surgical and general anesthetic scenarios. In a study of hypovolemic patients undergoing anesthesia for major abdominal surgery, the effects of volume resuscitation on StO₂ were investigated. StO₂ improved with IV fluid administration in 42 fluid challenges, and this occurred prior to normalization of other traditional systemic hemodynamics (eg, arterial blood pressure). In an abstract that described StO₂ measured twice-daily in 502 human patients in a surgical intensive care unit, patients with any StO₂ measurement <70% experienced a significantly increased ICU and hospital length of stay, although there was no significant difference in 28-day mortality.

Tissue oxygen monitoring may be beneficial in the perioperative setting. Some studies have correlated...
lower StO$_2$ values with increased postoperative complications, infection, and graft compromise, although other studies have not found this association with postoperative complications or surgical site infections (SSI).$^{58,60,62,66}$ These differences may be related to the timing of postoperative StO$_2$ measurement. Hopf et al hypothesized that tissue oxygen levels are predictors for SSI because neutrophil oxidative burst is the main defense against SSI.$^{67-70}$ Earlier intervention in states of perioperative pain, hypothermia, hypovolemia, and hypoxemia may lead to improved tissue oxygenation and a lower incidence of SSI.$^{62,68}$ In a study of 59 postoperative patients, those who did not develop an SSI had higher StO$_2$ levels 12 hours after surgery than those who developed an SSI.$^{56}$ The low StO$_2$ values and subsequent SSI in some postoperative patients may also be a result of vasoconstriction and decreased oxygen delivery to the tissues. The effects of decreased tissue oxygen delivery may not be immediately evident; in a prospective, observational study of a cohort of patients that underwent colorectal surgery, 23 developed SSI, and this group had lower StO$_2$ values measured 75 minutes after surgery. These early low StO$_2$ values were predictive of SSI that predominantly occurred more than a week later.$^{62}$ In this study, the correlation between SSI and StO$_2$ measurements taken at the upper arm location was the most significant.$^{62}$

StO$_2$ has also been evaluated in cardiac surgery patients.$^{63}$ Human patients undergoing cardiac procedures had a drop in StO$_2$ of 13 ± 14.8 % with initiation of cardiopulmonary bypass.$^{54}$ Interestingly, this decline was not reflected in the plasma lactate concentration or base deficit for 94 ± 86 minutes. In another study, StO$_2$ and VOT were evaluated in 15 high-risk cardiac surgery patients before and after the induction of general anesthesia.$^{71}$ While there was no statistical difference in StO$_2$ following induction of general anesthesia, there was a significant decrease in the ischemic and reperfusion slope of the VOT, indicating the possibility for decreased reperfusion reserve associated with anesthesia. StO$_2$ may predict postoperative complications in cardiac surgery patients as well. Murkin et al studied 200 patients undergoing cardiac surgery.$^{72}$ The patients received cerebral tissue oximetry monitoring, and the clinicians were either blinded to the results, or allowed to use the StO$_2$ to guide goal-directed therapies to correct cerebral oxygen desaturation during anesthesia. Those that received treatment guided by StO$_2$ had significantly shorter ICU stays, and the control group had a significantly higher incidence of major organ dysfunction, morbidity, and mortality.$^{72}$ Monitoring of StO$_2$ levels during and after anesthetic events may be helpful to prevent postoperative complications such as SSI, duration of ICU hospitalization, and morbidity and mortality.

**Sepsis**

Many different mechanisms contribute to the impaired microvascular function in patients with sepsis. Alterations in vascular reactivity, endothelial barrier dysfunction, functional arteriovenous shunting, formation of microthrombi, vasomotor paralysis, and altered immunologic function can all lead to altered oxygen delivery to the microcirculation.$^{53,75}$ Increased vascular permeability and maldistribution of blood flow can lead to shunting of blood toward the periphery and away from vital organs. Achieving global perfusion end points, such as arterial blood pressure, plasma lactate concentration, and mixed venous oxygen saturation may not be sufficient for resuscitation of the microcirculation in patients with sepsis, and other techniques for monitoring the microcirculation in response to therapy may prove to be beneficial in the treatment of sepsis.$^{73}$

The use of tissue oxygen monitoring in patients with sepsis and septic shock is controversial. Due to the vast alterations in the microcirculation, StO$_2$ can be low, normal, or increased, which makes StO$_2$ monitoring difficult to interpret in the clinical setting. Tissue oxygen monitors also do not distinguish between disturbed mitochondrial oxygen metabolism and decreased tissue oxygen extraction; however, a decreased VO$_2$ could imply an alteration in mitochondrial function.$^{23}$ Some studies have shown that StO$_2$ values are able to distinguish between healthy volunteers and those with sepsis or septic shock,$^{6,29,38,43,46,74}$ while others have shown no difference in StO$_2$ values between the two populations.$^{39,44,45}$ In general, lower StO$_2$ values have been shown to correlate to the severity of disease and to mortality in patients with severe sepsis and septic shock.$^{38,45,75,76}$ In a prospective study by Leone et al, StO$_2$ < 78% correlated with non survival in patients with septic shock.$^{39}$

Textoris et al retrospectively evaluated central venous oxygen saturation (ScvO$_2$) measurements in a large population of patients with septic shock.$^{77}$ They found that nonsurvivors were more likely to have an increased or normal ScvO$_2$ compared to survivors, indicating impaired oxygen utilization in these patients. StO$_2$ values have a weak correlation with global ScvO$_2$ and mixed venous oxygen saturation in patients with severe sepsis and septic shock.$^{5,74,77,78}$

Due to the challenges of monitoring StO$_2$ in the thenar eminence of septic patients, alternate tissue sites have been evaluated. Ait-Oufella evaluated the knee as a potential source of StO$_2$ measurement in patients with septic shock undergoing goal directed therapy.$^{79}$ They concluded that when compared to the thenar eminence, StO$_2$ measured around the knee has a strong predictive value for 14-day mortality in this population of patients.$^{79}$ Patients in this study who died also
had higher blood lactate concentrations, lower urinary output, and lower SvO₂. Another study on patients with severe sepsis evaluated StO₂ at three different muscle bellies (thenar eminence, masseter, and deltoid) during the first 6 hours of resuscitation in ICU. They found some correlation between the thenar eminence measurement and SvO₂; however, the masseter and deltoid StO₂ measurements were more powerful at predicting when the SvO₂ was >70%, and were less likely to be affected by abnormal peripheral perfusion.

The utility of tissue oxygen monitoring in septic patients is controversial and therefore can be used in conjunction with the VOT, which shows an impaired postischemic hyperemic response in patients with sepsis and septic shock. This is thought to be due to impaired mitochondrial function. Septic patients who remain hypotensive following appropriate volume resuscitation often require administration of vasopressors to improve arterial blood pressure. The use of norepinephrine as a constant rate infusion in 28 patients with septic shock led to increases in mean arterial pressure as well as improved StO₂ and VOT recovery slopes. Research suggests that StO₂ is lower in nonsurvivors than in survivors after early goal-directed resuscitation for septic shock.

Early goal-directed therapy

The concept of EGDT was first described by Emanuel Rivers in 2001. This type of therapy is characterized by intensive monitoring for optimization of oxygen delivery in patients with severe sepsis or septic shock. Resuscitation endpoints used in EGDT include targeted values for SvO₂, arterial lactate concentration, pH, base deficit, and hematocrit. Because EGDT is initiated in the emergency room, the resuscitation described in the initial publication took place during the first 6 hours following presentation to the hospital. Rivers provided convincing evidence that EGDT had significant benefits with respect to outcome and significantly reduced mortality rates in patients with sepsis and septic shock. EGDT in sepsis, trauma, and critically ill patients has become standard of care in human medicine. Recently, ProMISe ARISE, and ProCESS trials have cast doubts as to the utility of EGDT in patients with septic shock. The EGDT groups in these studies not only had no difference in 90 day mortality but also were found to have increased costs of treatment.

Although the means of evaluating global oxygenation during EGDT resuscitation are somewhat invasive (e.g., requiring a specific central venous catheter and arterial blood pressure monitoring), the use of less invasive monitors of oxygen delivery such as StO₂ may be useful for guiding resuscitation. Lima et al performed a prospective, observational study on 22 critically ill patients with blood lactate concentrations >3 mmol/L who were admitted to an intensive care unit. Continuous variables including heart rate, mean arterial pressure, CVP, SvO₂, and StO₂ were monitored during an 8-hour resuscitation period. Patients with StO₂ values that remained below 70% after 8 hours of guided resuscitation had a higher incidence of morbidity and multi-organ failure than those in whom StO₂ remained above 70%, or those in whom StO₂ normalized during resuscitation. A prospective study of 221 patients in shock that presented to an emergency department evaluated the effect of clinician access to the patient’s StO₂ during resuscitation. Patients who had resuscitation guided by StO₂ data had a shorter hospital stay. Despite the results of these studies, another prospective, randomized, nonblinded pilot study that used StO₂ in addition to goal-directed therapy and resuscitation in patients with sepsis and septic shock found no difference in day 7 mortality between the patients with unblinded StO₂ monitoring during the first 6 hours of resuscitation.

Veterinary Literature

There are few published studies that evaluate the use of StO₂ in veterinary species. Hall et al established reference intervals for StO₂ in 87 healthy dogs weighing greater than 9 kg, and evaluated different anatomical sites for obtaining consistent and valid StO₂ values. The investigators clipped a 5 × 5 cm section of hair and held the probe over a specific muscle belly for 5–30 seconds until the highest StO₂ reading was obtained. The muscle bodies evaluated included the sartorius, digital extensor, biceps femoris, and epaxial muscles. As in human medicine, a THI < 5 was considered an indicator of poor signal strength. In this population, measurements taken at the sartorius muscle provided the most consistent readings and a StO₂ reference interval of 92 ± 7% was established.

A prospective study by Sullivan et al evaluated StO₂ values in dogs following postoperative ovariohysterectomy. Following surgery, 20 healthy Beagles were randomized to breathe either room air or oxygen administered by nasal insufflation for 2 hours. Tissue oxygen measurements were obtained from positions 2 and 20 mm lateral to the ventral abdominal incision as well as another area in the inguinal region. Measurements were taken at 10, 60, and 120 minutes postoperatively. In this report, oxygen supplementation during recovery increased StO₂ measured at the 20 mm site and inguinal region. Baseline StO₂ values (mean 92.9 ± 7.4%) in this study were lower than reported in Hall et al. They speculated that altitude as well as the use of different anatomical sites of measurement may have influenced the values obtained in this study.
Additionally, the device used to obtain StO2 values was different in both studies. In an unpublished study, StO2 was measured in 38 dogs that presented to an emergency room with hemorrhagic shock. Admission StO2 levels in the dogs with shock were significantly different from StO2 in normal dogs. A more recent study by Pavlisko looked at induced hemorrhagic shock in 14 anesthetized Beagles breathing 100% oxygen. StO2 was measured in dogs in left lateral recumbency, with the probe placed over the sartorius muscle of the dependent limb. Dogs were evaluated during euvoema, hypovolemia, and hypervolemia. Hypervolemia was induced by controlled hemorrhage to a mean arterial pressure of 40 mm Hg, and euvoema was restored by returning the hemorrhaged blood back to the patient. Hypervolemia was induced by IV administration of 20 mL/kg of Hetastarch. Strong correlations were present between mean oxygen delivery index and StO2.

Potential Applications

Definitive indications for the monitoring of StO2 in clinical veterinary patients have not been fully described. Given its demonstrated utility as a tool for triage and evaluation of human patients with trauma, sepsis, and surgical diseases, tissue oxygen monitoring may prove to be of benefit in parallel veterinary applications. As in human medicine, the tissue oxygen monitor may improve veterinary clinicians abilities to detect occult shock.

A retrospective study by Stillion on dogs that had sustained blunt trauma concluded that admission base excess was a positive predictor of mortality and blood transfusion requirement. Conversely, a large-scale retrospective study that evaluated 235 canine patients that had sustained blunt trauma found no correlation between base excess or plasma lactate to predict mortality. Tissue oxygen monitoring may be useful to provide prognostic information and direct resuscitation in veterinary trauma patients as in human trauma patients. In addition, comparison of StO2 and ScvO2 in septic veterinary patients would be useful to determine if StO2 can be used as a noninvasive surrogate in this population. The use of the tissue oxygen monitor in feline patients has yet to be evaluated and reference ranges need to be established in this species.

Conclusions

Tissue oxygen monitoring may be used to detect tissue hypoxia in emergency settings, where monitoring of initial resuscitation may aid in improving outcome. Tissue oxygen monitoring may also be helpful in the clinical setting to identify states of hypoperfusion and may become a part of routine triage assessment of patients. There are significant advantages to tissue oxygen monitoring over other traditional measures of a patient’s hemodynamic status (eg, arterial blood pressure, plasma lactate concentration, base deficit) as it is rapid, continuous, noninvasive, portable, and easy to use. Utilization of the tissue oxygen monitor in combination with conventional methods of evaluating tissue perfusion, may give clinicians the best overall clinical picture of patient status. Although StO2 only has a moderate correlation with ScvO2 in people, tissue oxygen monitoring should be considered in patients who may be at high risk of morbidity and mortality or where more invasive means of measuring ScvO2 or mixed venous oxygen saturation are not feasible. High StO2 levels in patients with sepsis or septic shock may be suggestive of impaired oxygen utilization, and may allow earlier interventions in patients to prevent decompensation.

Limitations to NIRS technology include lack of standardized variables among machines and measurement sites, especially in veterinary patients. StO2 does not measure microcirculatory flow directly and therefore it is difficult to differentiate states of altered tissue oxygen consumption from states of decreased oxygen delivery. Dyshemoglobinemias such as carboxyhemoglobinemia and methemoglobinemia can influence the StO2 level as well. The path length of near infrared light will vary depending on the composition or density of tissue as well as the degree of melanin, and is thus altered in animals with different degrees of pigmentation. Despite these limitations, further investigation of this technology in the context of veterinary medicine is indicated.

Footnotes

a InSpectra Tissue Spectrometer®, Hutchinson Technology, Minneapolis, MN.
b INVOS Oximeter, Somanetics®, Covidien, Boulder, CO.
c NIRO-200NX, Hamamatsu Photonics, Hamamatsu City, Japan.
d MoorVMS-OXY, Moor Instruments Inc, Wilmington, DE.
h Hetastarch, Abbott Laboratories, North Chicago, IL.

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