TITLE PAGE

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Non-invasive monitoring of canine tissue hemodynamics undergoing a hyperbaric chamber treatment (HBO_2) by time domain near infrared spectroscopy

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ABSTRACT

A novel technique to treat different diseases from inflammation to poisonous bites from snakes on small animals is the hyperbaric chamber treatment [1]. Non-invasive and real-time hemodynamic monitoring of patient's tissue could be useful to quantify the effect of oxygen therapy on the patient. In this pilot study, we explored the possibility of noninvasively detecting canine tissues optical properties by Time Domain Near-Infrared Spectroscopy (TD-NIRS) and then retrieving hemodynamic parameters (deoxygenated and oxygenated hemoglobin molar concentration and tissue oxygen saturation) on different tissues (Triceps Brachii, Biceps Femoralis and Head) of dogs. Four dogs with different hair length and color undergoing to hyperbaric chamber treatment were measured before and after the treatment, on each of the three sites and on both sides of the animal. In *Triceps Brachii* and *Biceps Femoralis* we found an increase in the absorption coefficient for both wavelengths after the treatment, meaning that the total concentration of blood has increased. Different results were obtained in the head, where the total hemoglobin concentration is decreased. The use of TD-NIRS oximetry technology seems a clinically feasible means to assess tissue oxygenation in most of dogs, thanks to a sufficiently high signal-to-noise ratio that allows to evaluate the optical parameters and consequently the physiological parameters of the area under investigation. Moreover, the presence of hair and dark skin did not prevent the possibility of obtaining robust readings.

Keywords: Time Domain Near Infrared Spectroscopy, diffuse optics, hyperbaric chamber, non-invasive monitoring, oxygen therapy, oximetry

INTRODUCTION

Time Domain Near Infrared Spectroscopy (TD-NIRS) is a technique that uses laser pulses to monitor tissue hemodynamics [2] which, being non-invasive and in real time, improves patient comfort and applicability. This is made possible by the fact that the photons in the near infrared region experience very little absorption, penetrating for few centimeters into the tissue. By exploiting the time distribution of diffusing photons, it is possible to retrieve the absolute values of the optical proprieties of the tissue such as absorption coefficient and reduce scattering coefficient. Knowing the absorption coefficient at two different wavelengths it is possible to retrieve the molar concentration of oxygenated and deoxygenated hemoglobin in the tissue and hence derive tissue oxygen saturation. In recent years, especially in the veterinary field, the use of total body oxygen therapy is growing. The oxygen therapy is based on placing the patient inside a pressurized chamber and increasing the concentration of oxygen in the air up to values of about 100%. In this way the organism is overstimulated, and a maximum care reaction arises from the organism itself to consume the excess oxygen.

In this preliminary study we evaluated whether it was possible to monitor the tissue hemodynamics of patients undergoing oxygen therapy and if we were able to quantify the amount of oxygen absorbed by the tissue. As a future prospect we had set ourselves the goal of being able to quantify which were the optimal periods of time that patient must spend in the hyperbaric chamber to obtain the best reaction from the organism.

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MATERIALS AND METHODS

Device

The time domain oximeter that has been used was the NIRSBOX device (PIONIRS s.r.l., Milan, Italy) (fig.1a) [3] that is a single channel TD-NIRS device. It is characterized by its limited weight, portability, and compactness. It has two pulsed laser diodes at 685 nm and 830 nm, and a time-to-digital-converter with a temporal resolution of 10 ps for recording of the photon distribution of time of flight. The Full Width at Half Maximum (FWHM) is below 200 ps when measuring the Instrument Response Function (IRF). Laser light is injected and collected placing optical fibers directly in contact with the tissue with a source-detector distance of 2.5 cm. The ergonomic optical probe (PIONIRS s.r.l.) was tailored to the purpose of this study, characterized by two smoothed spring tips (end of the optical fibers) (fig.1a) which allowed the light to penetrate inside the hair of the subjects. The probe is linked to the device by a 1.5 m long fiber bundle composed of two optical fibers (100 μm core, multimode graded index, silica) on the injection side and a 1.5 m long collection fiber (1 mm core, multimode, graded index, POF).

Protocol

Four dogs with different hair length and color undergoing to hyperbaric chamber treatment were recruited. Dogs were not sedated nor shaved, emphasizing the fact that procedure was completely non-invasive. The animals were measured on three sites and on both sides before and after treatment. The three positions chosen were: *Triceps Brachii*, *Biceps Femoralis* and Head (fig.1b). For each site, the measurement was acquired three times (replacing the probe on the tissue every time) to certify the repeatability of the measurement. Each measurement consisted of 10 repetitions and each repetition was acquired with an integration time of 500 ms. The period that the dog spends in the hyperbaric chamber could vary from 40 minutes to 1 hour depending on the disease.

a)

b)

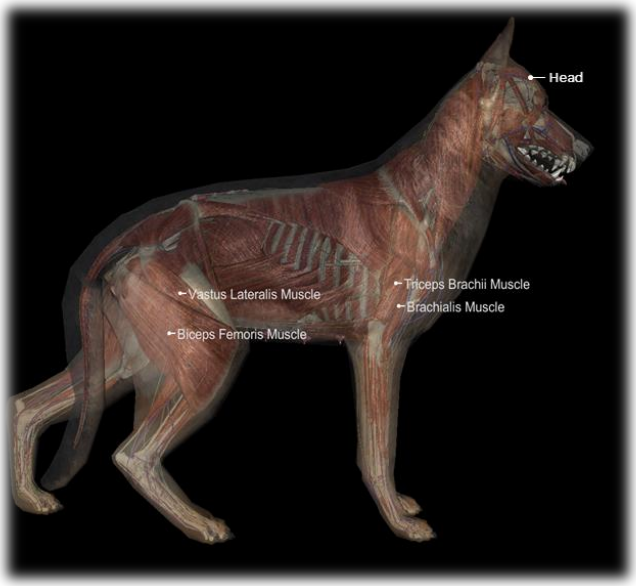

Figure 1. (a) Picture of device and probe; (b) Dog anatomical diagram in which the three sites are represented [5]

Data Analysis

To derive the optical properties, i.e., the absorption coefficient μ_a and the reduced scattering coefficient μ_s', we have used a home-made optimization software, based on Levenberg-Marquardt nonlinear least-squares algorithm, that interpolates the experimental TD NIRS data (photon distribution of time of flight) with a model of photon diffusion in a semi-infinite homogeneous turbid medium [4] taking also in account convolution with the IRF. Knowing the absorption coefficient at two different wavelengths and the molar extinction of the two chromophores it is then possible to evaluate the absolute value of the molar concentration of hemodynamics parameters (oxygenated hemoglobin O_2Hb, and deoxygenated hemoglobin, HHb) and to derive tissue oxygen saturation $S_tO_2 = O_2Hb/(O_2Hb+HHb)$.

RESULTS

Table 1 shows the optical properties obtain from one of the dogs, as an example. The values of the absorption and reduced scattering coefficients are averaged over the three measurements carried out one after the other and on both sides. For both muscles (*Triceps Brachii* and *Biceps Femoralis*) we have an increase in the absorption coefficient for both wavelengths after the therapy. This means that in the area measured, before and after the hyperbaric chamber, the total concentration of blood has increased, since both the deoxygenated and oxygenated hemoglobin have increased as shown in Table 2. Different results were obtained in the head, where the total hemoglobin concentration is decreased.

Table 1. Absorption coefficient and scattering coefficient at 685 nm and 830nm in the three positions before and after the therapy

Site	*Condition*	$\mu_a(\sigma)_{685nm}$ [cm^{-1}]	$\mu_a(\sigma)_{830nm}$ [cm^{-1}]	$\mu_s'(\sigma)_{685nm}$ [cm^{-1}]	$\mu_s'(\sigma)_{830nm}$ [cm^{-1}]
Triceps Brachii	*Before Treatment*	0.173 (0.034)	0.161 (0.0275)	10.41 (0.55)	6.965 (0.29)
	After Treatment	0.338 (0.0945)	0.302 (0.0615)	11.37 (2.23)	6.44 (0.9)
Biceps Femoralis	*Before Treatment*	0.182 (0.041)	0.165 (0.033)	11.33 (0.73)	7.52 (0.38)
	After Treatment	0.385 (0.232)	0.333 (0.1805)	15.23 (3.11)	8.94 (0.53)
Head	*Before Treatment*	0.405 (0.1075)	0.324 (0.0965)	13.85 (1.03)	6.465 (0.65)
	After Treatment	0.287 (0.0115)	0.225 (0.015)	14.425 (1.135)	7.28 (0.77)

Table 2. Hemodynamic parameters in the three positions before and after the therapy

Site	*Condition*	O_2Hb (σ) [μM]	HHb (σ) [μM]	tHb (σ) [μM]	S_tO_2 (σ) [%]
Triceps Brachii	*Before Treatment*	29.1 (5.9)	37.2 (7.0)	66.3 (9.17)	56.2 (0.6)
	After Treatment	57.3 (17.1)	74.8 (13.4)	132 (21.71)	57.2 (3.5)
Biceps Femoralis	*Before Treatment*	30.6 (7.1)	38.6 (8.7)	69.3 (11.21)	55.6 (1.1)
	After Treatment	65.8 (40.4)	81.6 (45.5)	147.3 (60.82)	56.6 (2.8)
Head	*Before Treatment*	70.4 (18.1)	74.8 (26.5)	145.2 (32.12)	50.7 (3.1)
	After Treatment	50.3 (1.8)	48.6 (4.9)	99 (5.18)	48.8 (1.7)

CONCLUSIONS

The use of TD-NIRS muscle oximetry technology seems a clinically feasible means to assess non-invasively tissue oxygenation in dogs, thanks to a sufficiently high signal-to-noise ratio that allows to evaluate the optical parameters and consequently the physiological parameters of the area under investigation. Moreover, the presence of hair and dark skin did not prevent the possibility of obtaining robust readings.

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