Difference in leg muscles oxygenation during treadmill exercise by a new near infrared frequency-domain oximeter

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ABSTRACT

Aim of this study was to investigate the oxygenation and the total hemoglobin concentration pattern in vastus lateralis and medial gastrocnemius muscle groups during a standardized treadmill exercise (n=6) by a new near infrared frequency-domain oximeter (ISS Oximeter model 96208). Vastus lateralis saturation and total hemoglobin concentration were 74±3% and 71±15 μM at 0 mph and 72±5% and 79±16 μM at 6 mph, respectively. Gastrocnemius saturation and total hemoglobin concentration were 74±2% and 107±18 μM at 0 mph and 60±6% and 113±23 μM at 6 mph, respectively. The saturation recovered gradually up to the baseline value when the speed was decreased.

Keywords: Near-infrared spectroscopy, oxygenation, skeletal muscle, frequency domain, oximeter

1. INTRODUCTION

Metabolic capacity of different muscle groups has been widely investigated invasively on tissue samples by biopsy[1]. Muscle oxidative metabolism has been also widely investigated non-invasively by continuous wave near infrared (NIR) optical methods[2]. Recently the relationship between muscle oxygenation changes during dynamic exercise and muscle fiber type composition has been investigated[3]. The recent introduction of methods based on pulsed and intensity modulated light sources makes it possible to quantify tissue hemoglobin saturation (Sat, %) and total hemoglobin concentration (Hbtot, μM). The performance of a new frequency-domain tissue oximeter has been recently reported[4].
The aim of this study was to investigate Sat and Hbtot concentration patterns in vastus lateralis and medial gastrocnemius muscle groups during a standardized treadmill exercise by the new NIR frequency-domain oximeter.

2. METHODS

The frequency-domain tissue oximeter (ISS Oximeter model 96208, ISS, Inc. Champaign, IL, USA) has been previously described[4]. Briefly, it uses eight laser diodes, four emitting at 750 and four at 840 nm. This oximeter, which implements the multi-distance measurement protocol, measures separately the absorption (μ_a) and the reduced scattering (μ'_s) coefficients of large muscles. Hence, the absolute values of oxy- and deoxy hemoglobin (HbO_2, Hb), Hbtot (HbO_2+Hb) and Sat (HbO_2/Hbtot) can be derived. The study was performed on 6 healthy and not-athletes males (32±8 years; 79±10 kg b.w.). Fat thickness was measured. The optical probe[4] was firmly positioned on the vastus lateralis. The speed of the treadmill was varied, every 2 minutes, by 1 mph. In the first part of the protocol the subjects were asked to walk at 2 mph, going at a quick pace at 3 mph and running from 4 to 6 mph (maximal speed achieved). In the second part of the protocol, from 6 to 0 mph, the subjects were undergone to an active recovery maintaining the same patterns of movements at the corresponding speed used in the first part. At 0 mph the subjects were in standing position (at rest). The same protocol was repeated, on the same subject, two hours later positioning the optical probe on the medial gastrocnemius.
Data are reported as average (± SD) of the last ten points (about 23 s) of each step.

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3. RESULTS AND DISCUSSION

A typical trace of the oxygenation pattern in the vastus lateralis (a) and in the medial gastrocnemius (b) muscles is shown in Fig. 1. Vastus lateralis Sat sligthly increased in the correspondence of the onset of walking and returned to the pre-exercise level at the end of the 3 mph step. Then Sat progressively decreased since the subject ran (4 mph). The lowest Sat value was achieved at the end of the first part of the protocol (6 mph). Except a transient rise, due to the blood pooling in the standing up position, Hbtot was almost constant up to the end of going at a quick pace (3 mph). Then Hbtot rapidly increased up reaching a plateau at 5-4 mph (second part of the protocol). Then Hbtot slightly and transiently increased at the 4 mph step, and gradually decreased. Since the 3 mph step, Hbtot remained almost constant at a higher level with respect to the baseline value. During the second part of the protocol Sat gradually increased with the decrease of the treadmill speed up to 3 mph, then Sat promptly went up reaching a greater value than baseline, to slowly decrease up to the initial value at the end of the protocol. As it is clearly evident the Sat and the Hbtot patterns are completely different.

Medial gastrocnemius Sat fluctuated around the basal value during walking, started to decrease at 3 mph, and then dropped when the subject ran. The Sat lowest value was almost constant up to end of the first part of the protocol as well as up to the end of the first two steps of the second part of the protocol. Then gradually recovered reaching a value consistently higher than that found before the exercise onset. Hbtot increased since the beginning of the walking. A plateau was reached at the 4 mph step. Only when the speed was decreased at 5 mph (second part of the protocol) Hbtot furtherly increased up to 2 mph. At the end of the protocol Hbtot did not return to the original value.

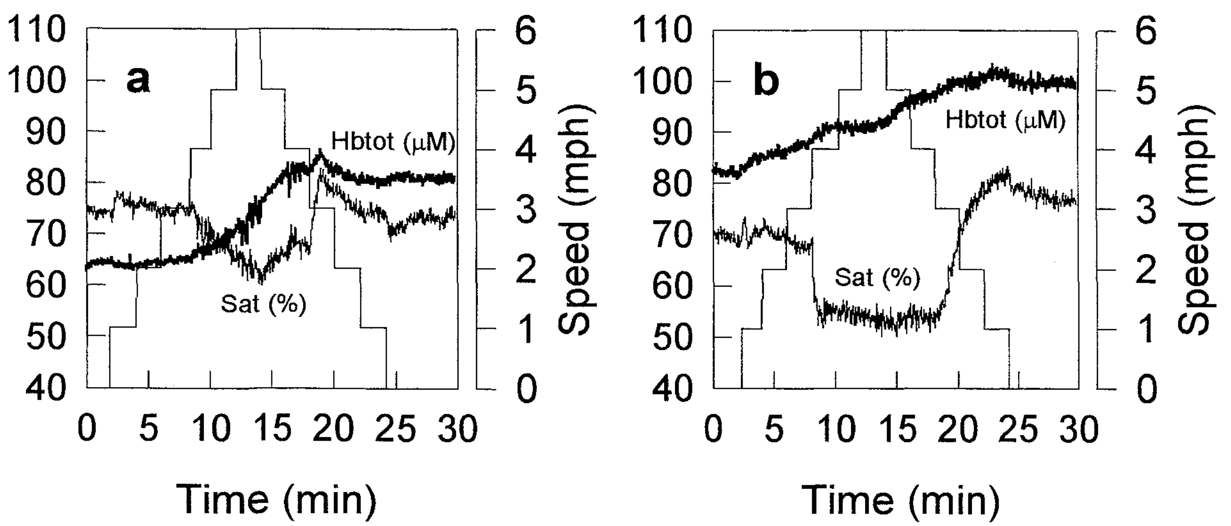

Fig. 1. Typical trace of Sat and Hbtot in vastus lateralis (a) and in medial gastrocnemius (b) muscles during a standardized treadmill exercise. Sampling time 2.24 s. The ramp represents the treadmill speed.

Figures 2 and 3 summarize the results, for each step over the complete protocol, obtained from the vastus lateralis and medial gastrocnemius muscle groups of all subjects. To better evidence the results from both muscle groups in each subject in the first part of the protocol, Sat and Hbtot values at the beginning (0 mph) and at the end (6 mph) are reported in tables 1 and 2, respectively. These results clearly indicate that the two investigated skeletal muscle groups have: a. very similar Sat value at rest; b. different Sat pattern during exercise; c. different Hbtot values at rest; d. Hbtot was not significantly changed over the first part of the protocol.

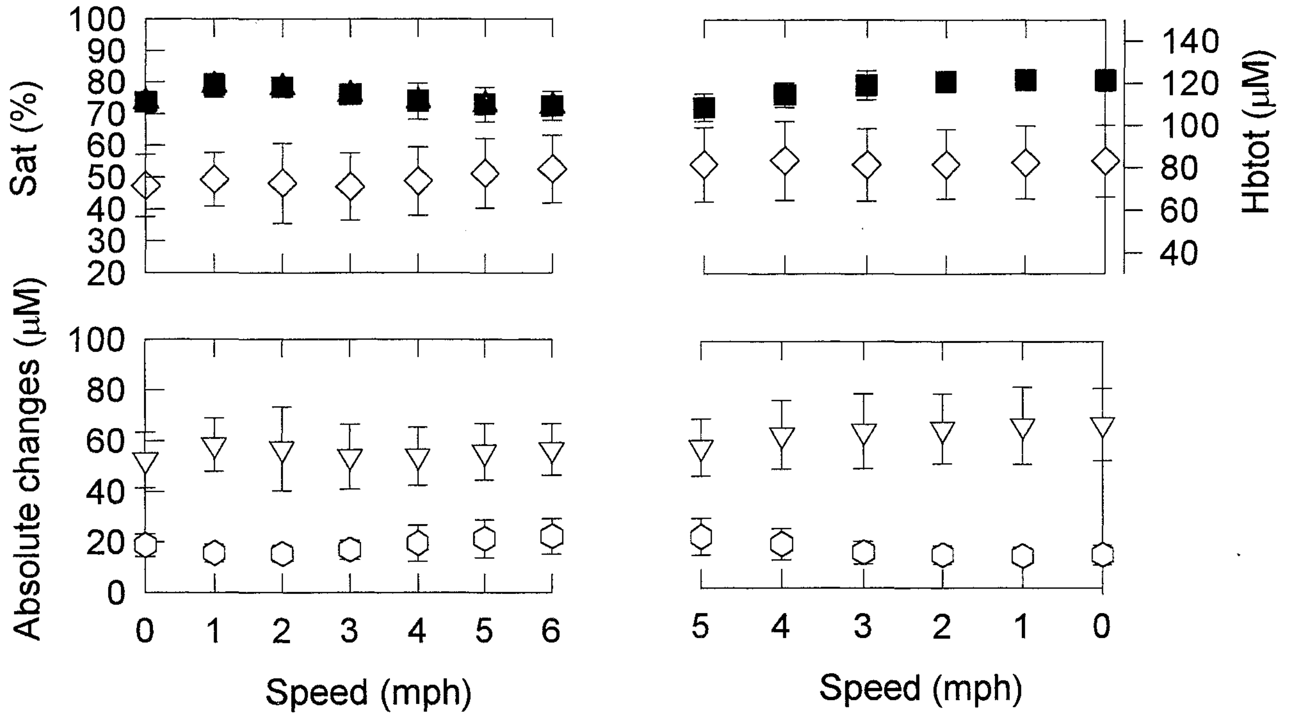

Fig. 2. Saturation and Hbtot (upper panels); oxyhemoglobin and deoxyhemoglobin (lower panels) in the vastus lateralis during a standardized treadmill exercise. Each point represents the average of the last 10 points (22.4 s) for each step. Means ± SD, n=6. Legend: filled square, Sat; rhombus, Hbtot; triangle, HbO_2; diamond, Hb.

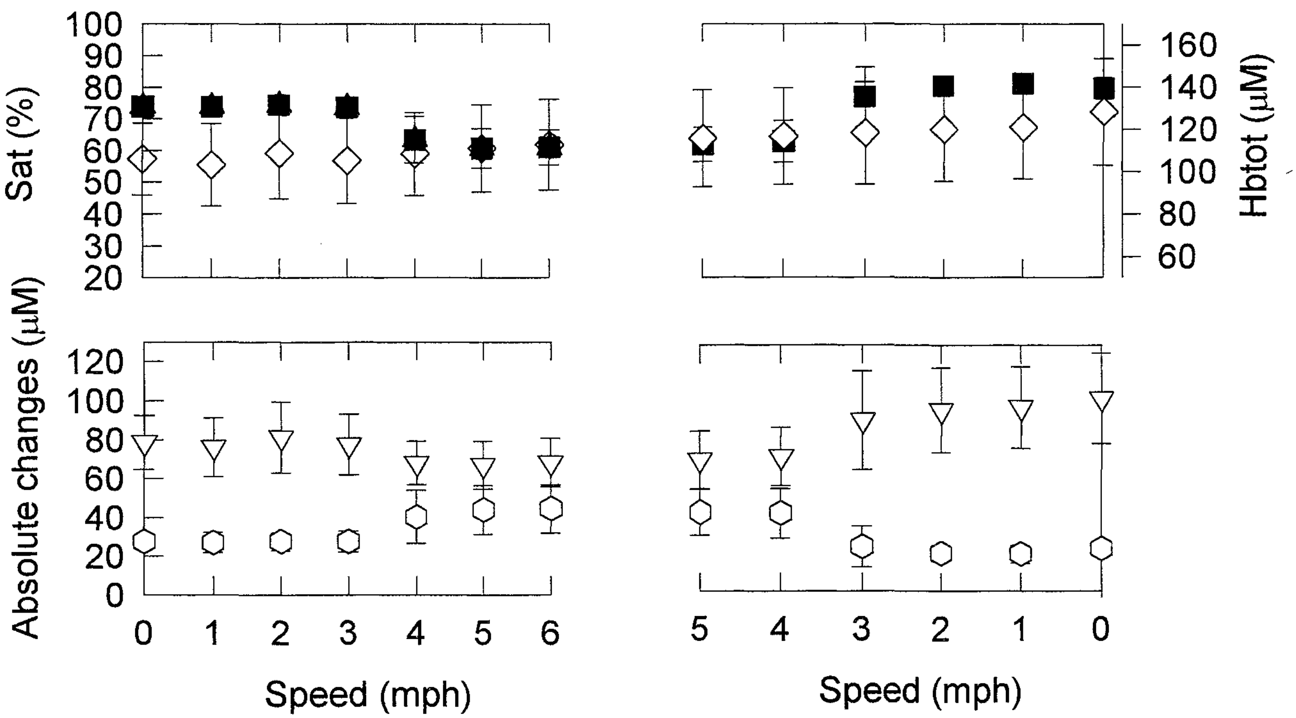

Fig. 3. Saturation and Hbtot (upper panels); oxyhemoglobin and deoxyhemoglobin (lower panels) in the medial gastrocnemius during a standardized treadmill exercise. Each point represents the average of the last 10 points (22.4 s) for each step. Means ± SD, n=6. Legend: filled square, Sat; rhombus, Hbtot; triangle, HbO_2; diamond, Hb.

Table 1. Saturation values (%)

N	Vastus lateralis		Gastrocnemius	
	0 mph	6 mph	0 mph	6 mph
1	72	74	71	54
2	77	65	75	54
3	68	68	71	64
4	77	77	73	70
5	74	75	77	56
6	74	75	74	63
Mean	74	72	74	60
SD	3	5	2	6

Table 2. Hbtot concentration (μM)

N	Vastus lateralis		Gastrocnemius	
	0 mph	6 mph	0 mph	6 mph
1	90	99	114	124
2	90	98	116	109
3	68	76	77	75
4	51	56	108	123
5	58	63	134	149
6	70	82	92	98
Mean	71	79	107	113
SD	15	16	18	23

In particular, medial gastrocnemius Sat dropped at the onset of running and was significantly decreased at the maximal workload (6mph) without a corresponding increase in Hbtot (Fig. 3). This suggests a higher local oxygen metabolic demand. The smallest change in Sat was found in the subject 4 with the highest subcutaneous adipose layer (1 cm). Sat recovered gradually with the decrease of the treadmill speed. Vastus lateralis Sat (Fig. 2) was not significantly decreased at the maximal workload (6 mph), whilst Hbtot increased by 11±3 % with respect to the basal value to compensate the increase of metabolic needs. The different behaviour between the two examined skeletal muscle groups during the same protocol can be attributed to: a. different muscle size; b. diverse metabolic capacities, as a consequence of the different fiber type composition[3]; c. different vascularization; d. different recruitment of the muscle groups; e. differential fatigue patterns for muscle groups. In addition the variability amongst subjects could be attributed to the different subcutaneous adipose layer[5-6] as well as to the different walking/running kinematics (movement pattern) during the protocol.

4. CONCLUSIONS

These results clearly indicate that a good NIRS signal to noise ratio, without any filter procedures, can be obtained even during hard movements (running). The multi-channel approach is relevant for NIRS application in muscle physiology, either to investigate the kinetic of the dynamic recruitment of two or more muscle groups during a given exercise, or to study their oxidative metabolic capacities.

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REFERENCES

1. B. Saltin and P. D. Gollnick, „Skeletal muscle adaptability: significance for metabolism and performance," *In: Handbook of Physiology, Skeletal Muscle, Am. Physiol. Soc., Bethesda MD.* pp. 555-631, 1983.
2. M. Ferrari, T. Binzoni, and V. Quaresima, „Oxidative metabolism in muscle", *Phil. Trans. R. Soc. Lond. B* **352**, pp. 677-683, 1997.
3. T. Hamaoka, M. Mizuno, T. Osada, A. Ratkevicius, A. N. Nielsen, Y. Nakagawa, T. Katsumura, T. Shimomitsu, and B. Quistorff, „Changes in oxygenation and phosphocreatine during exercise and recovery in relation to fiber types and capillary supply in human skeletal muscle", *Proc. SPIE* **3194**, in press.
4. M. A. Franceschini, D. Wallace, B. Barbieri, S. Fantini, W. W. Mantulin, S. Pratesi, G. P. Donzelli, and E. Gratton, „Optical study of the skeletal muscle during exercise with a second generation frequency-domain tissue oximeter", *Proc. SPIE* **2979**, in press.
5. K. Matsushita, E. Okada, and S. Homma, „Influence of adipose tissue on muscle oxygenation measurement with NIRS instrument", *Proc. SPIE* **3194**, in press.
6. K. Yamamoto, M. Niwayama, L. Lin, N. Kudo, M. Takahashi, and T. Shiga, „Accurate NIRS measurement of muscle oxygenation by correcting the influence of a subcutaneous fat layer", *Proc. SPIE* **3194**, in press.