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Ear Oximetry during Progressive Hypoxia

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ABSTRACT

The BIOX III Pulse oximeter for measuring arterial oxygen saturation (SaO_2) was compared during rest and under progressively hypoxic conditions, with SaO_2 values based on arterial blood samples. The measurements were performed in 16 subjects undergoing tests of ventilatory response to hypoxia, by a rebreathing method. For each individual subject, there was a linear response relationship (r=0.99), while for all 126 comparative values the regression equation was: y= 0.83 X + 14.7 (r=0.98). The observed ventilatory response was lower when the calculations were based on oximeter readings. We conclude that the oximeter has acceptable correlation between the BIOX III and SaO_2 measurements for clinical use, especially when SaO_2 is above 70%.

INTRODUCTION

A method for continuous non-invasive monitoring of arterial oxygen saturation (SaO_2) by oximetry was described more than 50 years ago, but was not generally accepted in clinical practice until recently, because of doubts about the accuracy of the method (1, 8, 9). With the marked improvement in instrumentation, this technique, which is based on transmission of light through the vascular bed of the ear lobe (5), is now gaining increasing attention, both for research and clinical purposes (2, 3, 4).

Comparative studies between oximetry and measurements based on

arterial samples have been limited. On the other hand, there is increasing interest in continuous monitoring of blood gas changes, especially during investigations of sleep-related breathing disturbances. The aim of this prospective study was therefore to estimate the accuracy and reliability of a two-wavelength oximeter for determining SaO_2 as compared with arterial blood samples, taken at rest and during progressive hypoxia.

MATERIAL and METHODS

Patients: The study comprised 16 consecutive patients, who had been referred to the Department of Lung Medicine of the University Hospital, Uppsala, Sweden for investigation of sleep related breathing disturbances. Their mean age was 51 years (range 38-63) (Table 1). All were habitual snorers, and some also complained of daytime sleepiness and were thus suspected of suffering from the sleep apnoea syndrome (6). They all had normal serum bilirubin values and none had skin pigmentation. Eleven of the patients were obese, with a body mass index (weight/(height)^2) $\geq$ 28.0 kg/m^2 (7), four had an airway obstruction and three showed an increase in residual volume by more than 20% (Table 1). The hypoxic ventilatory response test was a part of their investigation programme, which had previously been accepted by the Ethics Committee of the Medical Faculty of Uppsala University.

Ear oximetry: Oxygen saturation was measured by a BIOX III Pulse oximeter (Ohmeda, Colorado, USA) calibrated according to the manufacturer's instructions, and its normal response mode was used (2). The ear probe of the oximeter was fitted to the ear lobe of the subject after production of vasodilation by rubbing with alcohol.

Blood SaO_2: Arterial blood samples (6-8 ml) were drawn into heparinised glass syringes (10ml) through an indwelling cannula in the radial artery and placed in ice-water until analysed. The analyses were performed within 30 minutes. The sampling procedure lasted 5-10 seconds. Oxygen saturation was measured photometrically with an OSM 2 oxygen saturation meter (Radiometer, Copenhagen, Denmark).

Table 1. Characteristics of the patients and results of tests.

Case No.	Age years	BMI kg/m^2	VC %pred.	RV %pred.	FEV1.0 %pred.	$\Delta V/\Delta SaO_2$ (l/min/%SaO_2) based on oximetry	$\Delta V/\Delta SaO_2$ (l/min/%SaO_2) based on arterial SaO_2
1	39	36.0	89	86	91	0.39	0.41
2	48	22.8	84	122	82	0.43	0.62
3	38	31.0	108	57	114	0.12	0.12
4	54	27.1	106	93	117	0.23	0.24
5	57	32.6	101	89	109	0.37	0.46
6	41	26.9	112	65	119	0.74	0.90
7	52	24.5	90	83	95	0.64	0.63
8	61	31.4	57	92	53	0.73	0.89
9	63	29.0	80	100	80	3.78	4.40
10	49	27.8	103	119	113	1.15	1.20
11	38	39.1	90	127	103	0.55	0.65
12	39	28.4	102	71	106	0.85	1.00
13	60	29.0	124	111	134	1.59	1.63
14	58	30.4	93	103	96	0.70	0.85
15	43	39.8	65	213	69	0.53	0.57
16	59	30.5	83	91	80	0.45	0.48
Mean	50	30.4	93	101	98	0.83	0.94
SD	9	4.7	17	36	21	0.86	0.99

Abbreviations: BMI: Body mass index; VC: vital capacity; RV: residual volume; FEV1.0: Forced expiratory volume in one second.

Hypoxic ventilatory test: The subjects sat comfortably and breathed room air for approximately 10 minutes until a steady state value of SaO2 was attained. The hypoxic test was performed by a method similar to that described by Rebuck and Campbell (8). Briefly, the patients rebreathed 8 litres of room air from a Bernstein spirometer. During the rebreathing procedure the concentration of the inspired oxygen fell as a consequence of oxygen consumption. The ventilatory response was registered as the increase in ventilation (ΔV) calculated for each 1% recorded decrease in SaO_2 (ΔSaO_2).

The pairs of SaO_2 values were divided into groups (90-99%, 80-89% and so on) and their differences were further analysed. The results are presented in Table 2. The values displayed by the oximeter were found to be significantly lower than the arterial values when above 90%, but higher when below 80% (Table 2).

Table 2. Differences between oximeter readings and arterial SaO_2 in different ranges. n: number of simultaneous measurements, d: mean of the differences. SEEd: standard error of the estimate.

		SaO_2 (%)		
Range	**n**	**d**	**SEE_d**	**p**
90-99%	70	-1.39	1.17	<0.001
80-89%	22	0.41	2.28	N.S.
70-79%	21	2.48	2.34	<0.001
60-69%	11	2.82	2.68	<0.01

The ventilatory response to hypoxia ($\Delta V/\Delta SaO_2$) was 0.83 l/min/1% SaO_2 (± 0.86) when based on oximeter readings, and 0.94 l/min/1% SaO_2 (±0.99) when based on arterial values (Table 1). The ventilatory responses based on arterial and oximetric values were highly correlated to each other ($r=0.995$); but as a consequence of the relationships presented in Table 2 the ventilatory response was significantly higher ($p<0.05$) when the calculations were based on arterial measurements (paired t test). The differences between arterial and oximetric values were not correlated to age, to degree of overweight, or to the results of the pulmonary tests (Table 1). There was no electrode drift, the ear probe was well tolerated and no technical difficulties arose during oximetry.

DISCUSSION

In this study we chose to evaluate the oximeter readings during progr-essive hypoxia in order to determine the validity of oximetry

An arterial blood sample was taken at rest just before the hypoxic test began, and a sample was then taken every minute during and one 2.5 and 5 minutes after the test. When approximately 50% of the arterial sample had been drawn into the syringe, the SaO_2 reading as displayed by the oximeter was recorded. All arterial sampling and recordings were done by the same person.

Statistical analyses: Values are presented as mean (±SD). The strength of the correlation between arterial SaO_2 and oximeter readings was evaluated by least-square linear correlation. Statistical probability was assessed by Student's paired t test

RESULTS

A total of 126 pairs of simultaneous SaO_2 readings were obtained, 16 during steady state, 78 during hypoxia and 32 one and three minutes after the test (Fig. 1). The range of arterial SaO_2 values was 55-99%. There was no overall bias, as the mean SaO_2 value was the same (88.7%) when measured with the oximeter as when based on the arterial samples. For each subject the oximeter readings were a linear function of the arterial SaO_2, with a mean correlation coefficent r of 0.993 (±0.01) (range 0.983-0.999), where as for all values the regression equation was y= 0.83 x +14.7 (r=0.976) (Fig. 1).

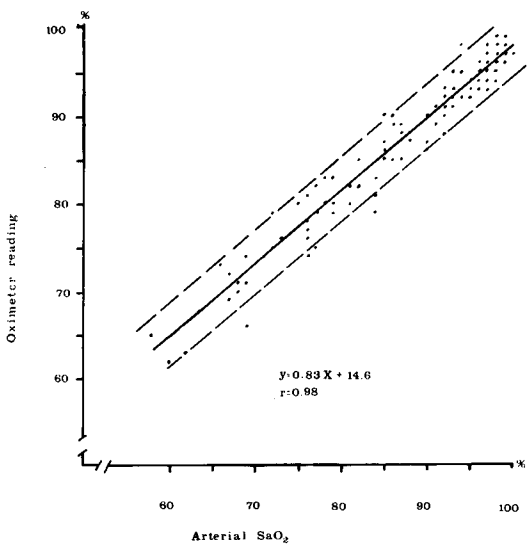

Fig. 1.Relation between 126 SaO_2 values obtained simultaneously by oximetry and from arterial blood samples. The linear regression equation (solid line) and the 95% confidence limits (broken lines) are shown.

during rapid changes of SaO_2 (similar to those observed during sleep apnoea) and also to check the reliability of this method during the hypoxic ventilatory test, which is used to estimate the sensitivity of peripheral chemoreceptors (8).

The high correlation between arterial and oximetric readings for each individual subject (r=0.993) suggests that the ear oximeter is very accurate in indicating changes in SaO_2. The total correlation between arterial and oximeter readings is also fully acceptable for clinical purposes and even better than has been found by other authors (3). However, one must be aware of the increasing differences at low SaO_2 levels (2), which may imply that oximetry may lead to an overestimation of SaO_2 in monitoring of critically ill patients and to a situation in which patients with sleep-related breathing disturbances may have more severe oxygen desaturation than is detected. The commonly found cardiac arrythmias in the sleep apnoea syndrome might also have a disturbing effect on the oximeter reading, a factor which needs to be further investigated. On the basis of calculations from the hypoxic ventilatory response tests, we agree with Chapman et al (2) that SaO_2 values below 70% should be omitted.

In summary, the Biox III Pulse oximeter has been found to correlate acceptabley with SaO_2, is easy to apply and is well tolerated by patients. Obviously the non-invasive approach in continuous monitoring of blood gases is a rapidly expanding field which must be followed up by comparative studies to clarify the characteristics of these techniques.

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