

## Blood gas measurement during exercise: a comparative study between arterialized earlobe sampling and direct arterial puncture in adults

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**ABSTRACT:** Sampling arterialized earlobe blood is thought to be easier and less painful than direct arterial puncture, and to allow measurement of blood gas values during exercise without the need to insert an arterial cannula. However, arterialized earlobe oxygen tension ( $PO_2$ ) often underestimates arterial  $PO_2$  at rest, and is not fully validated during exercise. We have therefore conducted a prospective study to compare values of  $PO_2$  and carbon dioxide tension ( $PCO_2$ ) and the discomfort experienced by adult subjects undergoing the two methods of blood sampling during exercise.

Seventy consecutive adult patients were studied. Blood samples were drawn simultaneously from the radial artery and arterialized earlobe of each patient during the last minute of an 8 min exercise. Values of  $PO_2$  and  $PCO_2$  were measured by means of blood gas electrodes.

The correlation coefficients between the two samples were 0.92 for  $PO_2$  and 0.91 for  $PCO_2$ . However, the bias and the limits of agreement between the two methods were wide for  $PO_2$  (mean $\pm$ 2SD of the differences between the two methods:  $0.63\pm 1.50$  kPa ( $4.7\pm 11.2$  mmHg)). The bias and the limits of agreement were smaller for  $PCO_2$ . Patients felt that the earlobe method was not associated with less discomfort than radial artery puncture.

We conclude that arterialized earlobe blood oxygen tension is not a good substitute for arterial oxygen tension during exercise, and should not be used to assess arterial oxygen tension in adults during exercise.

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Measurement of arterial blood gas tensions is routinely used to assess gas exchange in patients with acute and chronic respiratory disorders. The accepted technique established in clinical practice is blood sampling by direct arterial puncture. In the 1960s, it was proposed that blood gas values could be measured using arterialized earlobe blood samples [1]. This method is thought to be easier and less painful than direct arterial puncture [2]. It is based on the assumption that, provided sufficient vasodilatation can be achieved locally by means of topical application of a vasoactive cream on the earlobe, arterial and venous oxygen tension ( $PO_2$ ) in the earlobe tend to converge, and the arterialized earlobe  $PO_2$  resembles the arterial  $PO_2$ .

Initial [1, 3–7] or more recent [8] studies have concluded that the earlobe method might be accurate enough to replace arterial blood samples for clinical purposes. This contention is based mainly on positive and strong correlations that have been found between the two methods. However, most investigators have sought correlation using simple regression analysis instead of the method of BLAND and ALTMAN [9]. This approach has probably rendered the conclusion of most studies flawed by statistical bias. In fact, two recent studies using BLAND and ALTMAN [9] analysis have stated that arterialized earlobe  $PO_2$  at rest often

underestimates arterial  $PO_2$ , therefore making this method unsuitable for clinical assessment [10, 11].

One factor considered to be an advantage of arterialized earlobe sampling is that it allows measurement of blood gas tensions during exercise without the need to insert an arterial cannula. However, few studies [5, 7, 12, 13], and no recent study, have compared the two methods during exercise. Moreover, insertion of an arterial cannula during exercise is probably unnecessary in most cases with use of the new commercially available kits for arterial punctures. Furthermore, the common belief that greater discomfort is associated with direct arterial puncture as compared with the earlobe hyperaemia and incision requires re-evaluation.

Therefore, the aim of the present study was to compare arterial and arterialized earlobe blood samples both at rest and during exercise in adult patients in terms of  $PO_2$  and carbon dioxide tension ( $PCO_2$ ), and to compare the discomfort associated with each method of sampling.

### Materials and methods

The study group included 70 consecutive adult patients (39 males and 31 females; mean age $\pm$ SD  $39\pm 17$  yrs) investigated in our pulmonary function laboratory for various

conditions. They all attended the laboratory  $\approx$ 1 h postprandially, and none was in cardiovascular shock.

Blood samples were simultaneously drawn from a radial artery and arterialized earlobe of each patient at two time points: baseline (after a 10 min rest in a sitting position); and during an 8 min exercise testing (during the last minute at the peak of exercise workload). The first 35 patients undertook an incremental exercise on a cycle ergometer (Meditronic 40-3; Hellige, Germany), and the subsequent 35 patients on a treadmill (Gymrol control 1500; MSR, Antony, France). The initial workload ranged 10–25 W, and was increased by 10–25 W every 1 or 2 min. After the exercise, patients answered the question: "was the arterial puncture less, as, or more painful than the earlobe procedure?"

A commercial capillary system with a 25-gauge needle (AVL Microsampler; Schaffhausen, Switzerland) was used to collect arterial samples. The earlobe capillary blood was arterialized by the application of an irritant cream (Fin-algon®, Boehringer-Ingelheim, Reims, France) for 5–10 min. A qualified technician then incised the earlobe with a blood lancet (Becton Dickinson, Mountain View, CA, USA). Earlobe samples were collected in heparinized glass capillaries (Corning Medical and Scientific, Halstead, UK). Arterial and arterialized earlobe blood samples were immediately introduced into a blood gas analyser (ABL330; Radiometer, Copenhagen, Denmark). The quality control of pH, blood gas tensions, electrolytes and blood oximetry for the blood gas analyser was checked every day (Quali-check 2, Radiometer, Copenhagen, Denmark).

As there was no difference for  $PO_2$  and  $PCO_2$  during exercise on the cycle ergometer or treadmill, results were plotted and expressed as mean $\pm$ SD. Statistical analysis for assessing agreement between arterial and arterialized earlobe blood gas tensions at rest and on exercise was performed according to BLAND and ALTMAN [9].

## Results

The total workload for the group as a whole was 139 $\pm$ 41 W. It was greater on the cycle ergometer (155 $\pm$ 32 W) as compared to the treadmill (123 $\pm$ 43 W;  $p < 0.001$ ). For the group as a whole, the duration of the exercise was 8 $\pm$ 1 min, and the percentage of predicted maximum cardiac frequency was 74 $\pm$ 11%. There was no difference in either parameters between the cycle ergometer and the treadmill.

During the course of the study, three patients could not be included because of unsuccessful radial artery blood drawing at the end of the exercise. These unsuccessful blood drawings were observed during the first weeks of the study and were clearly related to the training of the technician.

No complication in the drawing of blood samples was observed with either method. Twenty five patients found the drawing of arterial blood sample more painful than the drawing of arterialized earlobe blood sample, while 29 patients found it less painful, and 16 found no difference in terms of pain between the two methods.

The range of arterial  $PO_2$  on exercise was 6.3–14.4 kPa (47–108 mmHg), median 11.1 kPa (83 mmHg). The range of arterialized earlobe  $PO_2$  on exercise was 6.1–13.5 kPa

(46–101 mmHg), median 10.5 kPa (79 mmHg). Arterial and arterialized earlobe  $PO_2$  were highly correlated both at rest ( $r=0.84$ ;  $p < 0.0001$ ) (data not shown) and on exercise ( $r=0.92$ ;  $p < 0.0001$ ) (fig. 1a). The means (bias) $\pm$ SD and the ranges of the differences, as well as the 95% confidence intervals for the lower and upper limits of agreement are reported in table 1. Arterialized earlobe  $PO_2$  on exercise

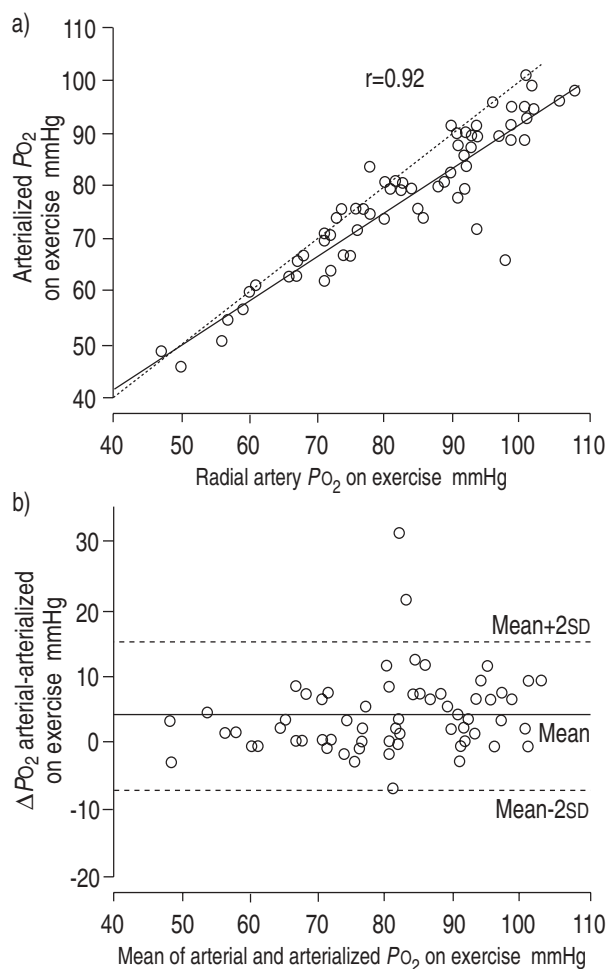


Fig. 1. – a) Correlation between radial arterial blood oxygen tension ( $PO_2$ ) values and arterialized earlobe blood  $PO_2$  values on exercise. b) Differences in arterial-arterialized  $PO_2$  values ( $\Delta PO_2$ ) on exercise plotted against mean of arterial and arterialized  $PO_2$  values on exercise (1 mmHg=0.133 kPa). ..... : line of identity.

Table 1. – Limits of agreement of the differences in oxygen tension ( $PO_2$ ) values at rest and on exercise between arterial and arterialized earlobe blood samples

	$\Delta PO_2$ at rest		$\Delta PO_2$ on exercise	
	kPa	mmHg	kPa	mmHg
	0.90 $\pm$ 0.79	6.7 $\pm$ 5.9	0.63 $\pm$ 0.75	4.7 $\pm$ 5.6
	(-0.54–2.81)	(-4–21)	(-0.80–4.29)	(-6–32)
95% CI of mean-2SD	-1.00 to -0.36	-7.5 to -2.7	-1.17 to -0.56	-8.7 to -4.2
95% CI of mean+2SD	2.16 to 2.80	16.1 to 20.9	1.82 to 2.43	13.6 to 18.1

Data are presented as mean $\pm$ SD, and range in parenthesis.  $\Delta PO_2$ : difference in oxygen tension (arterial-arterialized); 95% CI: 95% confidence interval.

were lower than arterial  $PO_2$  values in most cases, and the differences increased as arterial  $PO_2$  increased (fig. 1b). The limits of agreement for  $PO_2$  on exercise were: mean  $-2SD$  of the differences  $-0.87$  kPa ( $-6.5$  mmHg) and mean  $\pm 2SD$  of the differences  $2.12$  kPa ( $15.9$  mmHg). Thus, the arterialized earlobe  $PO_2$  could be  $0.87$  kPa ( $6.5$  mmHg) above or  $2.12$  kPa ( $15.9$  mmHg) below the arterial  $PO_2$ . These results show that the limits of agreement for  $PO_2$  on exercise were wide, disclosing a lack of agreement between the two methods.

The range of arterial  $PCO_2$  on exercise was  $4.1$ – $6.7$  kPa ( $31$ – $50$  mmHg), median  $5.2$  kPa ( $39$  mmHg). The range of arterialized earlobe  $PCO_2$  on exercise was  $4.3$ – $6.3$  kPa ( $32$ – $47$  mmHg), median  $5.1$  kPa ( $38$  mmHg). Arterial and arterialized earlobe  $PCO_2$  were highly correlated, both at rest ( $r=0.89$ ;  $p<0.0001$ ) (data not shown) and on exercise ( $r=0.91$ ;  $p<0.0001$ ) (fig. 2a). The means (bias) $\pm 2SD$  and the ranges of the differences, as well as the 95% CIs for the lower and upper limits of agreement are reported in table 2. For  $PCO_2$ , the mean differences between the two methods on exercise were close to zero, and the limits of agreement were narrow (fig. 2b).

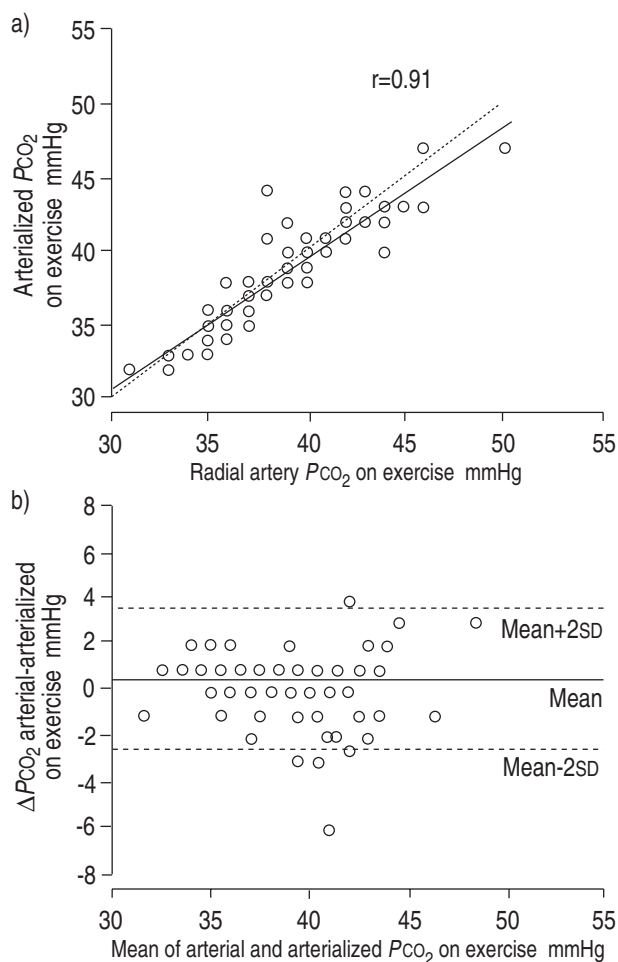


Fig. 2. – a) Correlation between radial arterial blood carbon dioxide tension ( $PCO_2$ ) values and arterialized earlobe blood  $PCO_2$  values on exercise. b) Differences in arterial-arterialized  $PCO_2$  values ( $\Delta PCO_2$ ) on exercise plotted against mean of arterial and arterialized  $PCO_2$  values on exercise ( $1$  mmHg= $0.133$  kPa). ..... : line of identity.

Table 2. – Limits of agreement of the differences in carbon dioxide tension ( $P_aCO_2$ ) values at rest and on exercise between arterial and arterialized earlobe blood samples

	$\Delta PCO_2$ at rest		$\Delta PCO_2$ on exercise	
	kPa	mmHg	kPa	mmHg
	$0.03 \pm 0.2$	$0.2 \pm 1.5$	$0.05 \pm 0.20$	$0.4 \pm 1.5$
	$(-0.54-0.54)$	$(-4-4)$	$(-0.80-0.54)$	$(-6-4)$
95% CI of mean-2SD	-0.44 to -0.28	-3.3 to -2.1	-0.43 to -0.27	-3.2 to -2.0
95% CI of mean+2SD	0.35 to 0.51	2.6 to 3.8	0.39 to 0.55	2.9 to 4.1

Data are presented as mean $\pm 2SD$ , and range in parenthesis.  $\Delta PCO_2$ : difference in carbon dioxide tension (arterial-arterialized); 95% CI: 95% confidence interval.

## Discussion

We have shown: 1) that arterial and arterialized earlobe  $PO_2$  are not interchangeable in adult patients, either at rest or during exercise; 2) that  $PCO_2$  is correctly determined by arterialized earlobe blood samples both at rest and on exercise; and 3) that arterial puncture is not more painful than the earlobe procedure.

Numerous studies published many years ago concluded that the method using arterialized earlobe blood for  $PO_2$  and  $PCO_2$  analysis at rest was accurate enough to replace arterial blood samples for clinical purposes [1, 3–7]. However, the validity of this method has been discussed in two recent studies [10, 11] showing with the analysis of BLAND and ALTMAN [9] that  $PO_2$  was usually lower in earlobe than in arterial blood, and that the limits of agreement were wide between the two methods. In the present study, we have confirmed the study by SAUTY *et al.* [10] and our previous results [11] on different subjects at rest.

Few studies have attempted to compare the two methods during exercise [5, 7, 12, 13]. These studies were usually based on a limited number of patients and used questionable statistical methods, such as simple regression analysis or simple comparisons. KOCH [12], GODFREY *et al.* [5] and SPIRO and DOWDESWELL [7] have thus shown a lack of significant difference between arterialized earlobe and arterial blood  $PO_2$  and  $PCO_2$ . By contrast, FORSTER *et al.* [13] have shown a significant difference between arterialized earlobe and arterial blood  $PO_2$ . Our study of a larger group of patients has shown that, during exercise, the regression line between arterial  $PO_2$  and arterialized earlobe  $PO_2$  is closer to the line of identity than at rest. However, using the method of BLAND and ALTMAN [9], we have shown that the limits of agreement were quite as wide on exercise as at rest. Moreover, the differences in  $PO_2$  measured with both methods on exercise are wider than the error of 2–4% allowable by the current recommendations [14]. Therefore, arterialized earlobe  $PO_2$  appears to be an unacceptable substitute for arterial blood  $PO_2$  both at rest and on exercise.

Insufficient arterialization of blood due to venous admixture is the main cause of underestimation of arterial  $PO_2$  in earlobe samples. The venous admixture in earlobe blood depends on the arterio-venous  $PO_2$  difference. As the arterio-venous  $PO_2$  difference for normal subjects is slightly higher on exercise ( $10$  kPa ( $75$  mmHg)) than at rest ( $8$  kPa ( $60$  mmHg)), one could have expected a worse arterialization of blood and a worse agreement during exercise than at rest. However, the application of the vasoactive cream

to the earlobe is likely to overcome the decrease of cutaneous capillary blood flow usually observed on exercise.

The advantages of the earlobe method that are advocated are that: it can be performed by nonmedical staff; it is safe; it is associated with less discomfort than radial artery puncture [2]; and it allows measurement of  $PO_2$  on exercise without the need to insert an arterial cannula [15]. However, as the collection of an earlobe blood sample must be fully anaerobic [3], the method requires trained personnel. Although complications of arterial punctures have been described [16], complications of radial arterial punctures are extremely low, in our experience, and none were observed in the present experiment. Unlike the results reported by DAR *et al.* [2], in the present study radial puncture was not systematically more painful than earlobe hyperaemia and incision. This might be explained by the thinner needle we have used for arterial puncture. Moreover, the use of a capillary kit with a very thin needle allowed us an easy radial artery puncture even on exercise. It is of interest to note that the low rate of unsuccessful arterial blood drawings on exercise was reduced with the training of the technician. The radial artery puncture prevented us from having to insert an arterial cannula, which is a source both of discomfort and complications. However, an arterial line might be needed when multiple samples are required during an exercise.

In conclusion, we have confirmed that at rest arterialized earlobe blood oxygen tension is not an acceptable substitute for arterial blood oxygen tension in adults, and have shown that the same is true on exercise. The usual low discomfort associated with the earlobe method as compared to the arterial puncture was not reproduced in our study, and should not be advocated as a reason to prefer arterialized earlobe blood sampling to arterial puncture, the latter giving far more accurate values of oxygen tension than the former.

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