A comparison of lactate concentration in plasma collected from the toe, ear, and fingertip after a simulated rowing exercise

J J Forsyth, M R Farrally

Abstract

***Objective*—To examine the validity of using blood taken from the toe for the assessment of plasma lactate concentration in rowers. To achieve this, values were compared with those taken from the fingertip and earlobe.**

***Methods*—Nine subjects exercised at two separate submaximum workloads on the Concept II rowing ergometer. The loads, each lasting four minutes, elicited mean (SD) heart rate responses of 160.1 (8.5) and 180.1 (5.7) beats/min, which corresponded to 76.4 (6.1)% and 91.9 (4.7)% of the estimated heart rate maximum of the subjects. Blood was simultaneously removed after the cessation of exercise by three experimenters and was analysed for plasma lactate concentration.**

***Results*—At 76.4% of estimated heart rate maximum, the mean (SD) plasma lactate concentrations sampled from the fingertip, toe, and earlobe were 6.36 (1.58), 5.81 (1.11), and 5.29 (1.24) mmol/l respectively. At 91.9% of estimated heart rate maximum, respective values were 8.81 (2.30), 8.53 (1.37), and 8.41 (2.35) mmol/l. No significant differences ($p>0.05$) were found between any of the sites at either work intensity.**

***Conclusions*—The toe may offer a practical alternative for assessing the concentration of lactate during rowing, having the advantage that repeated blood samples can be removed without interruption of the rowing action.**

(*Br J Sports Med* 2000;**34**:35–38)

Keywords: blood sampling; lactate; ergometer; rowing

North East Wales Institute, Wrexham, Wales
J J Forsyth

University of St Andrews, Scotland
M R Farrally

Correspondence to:
J J Forsyth, NEWI, Plas Coch, Mold Road, Wrexham LL11 2AW, North Wales, United Kingdom.

Accepted for publication
18 October 1999

The benefits of measuring blood lactate concentration to assess and improve aerobic capacity have been well documented.[1 2] To advance methods of lactate testing in rowing, it would be beneficial to identify a convenient location for capillary blood sampling, which would neither interfere with the rowing action nor necessitate a discontinuation of incremental and/or steady state type exercise, as interruptions of work may lead to a decrease in the lactate gradient between the blood and muscle, hence distorting the lactate profile.[3–5] To obtain a measurement of capillary blood lactate concentration, the fingertip and earlobe are the conventional sampling locations while subjects are exercising.[6 7] In rowing, the upper body is in constant motion, and hence these two sites are inappropriate unless the exercise is stopped. In a racing shell and on a rowing ergometer, the rower's feet are secured and relatively immobile, making it possible and practical for the experimenter to remove repeated blood samples from the tip of the toe without obstructing performance.

Most studies on lactate testing have focused on differences between arterial and venous blood[8–11] and between plasma, whole, and haemolysed blood,[12] but few have examined whether there are any differences in lactate values when capillary blood is taken from different sampling sites. Dassonville *et al*[3] found fingertip capillary blood lactate levels to be higher than earlobe capillary levels for both leg cycle ergometry and treadmill exercise. It was suggested that the gripping of the handlebars during the cycle ergometry resulted in local lactate release, increasing lactate concentrations in this area. However, Heller *et al*[13] also found that capillary blood lactate levels sampled from the fingertip were significantly higher than those sampled from the earlobe, especially after five minutes of recovery from both treadmill and cycle ergometry exercise. Smith *et al*[14] found that lactate concentration in blood sampled from the toe was significantly lower than that taken from the earlobe after arm only exercise, and concluded that the lack of involvement of the lower body resulted in less lactate being produced in this region. As rowing is a whole body action, this finding may have limited application. Differences in sampling site may affect the delineation of lactate variables, especially as far as training and performance prediction are concerned.[13 15] For instance, differences have been shown to influence exercise intensity corresponding to a fixed lactate concentration of 4 mmol/l,[10–12 16] and to an intensity corresponding to the lactate threshold.[9 17]

The purpose of this study was to compare lactate concentration in plasma taken from the toe with that from the earlobe and fingertip after steady state rowing exercise equivalent to 75% and 90% of the subject's estimated heart rate maximum. These two percentages were chosen as they represented the range of values that rowers are able to sustain for prolonged periods without excessive amounts of lactate accumulating in the blood.[18 19] It was hypothesised that concentrations of lactate would not differ significantly between sampling sites.

Methods

Nine subjects (four men and five women), who gave their informed consent, volunteered to

Table 1 Summary of performance data at the two estimated work intensities

	Women (n=5)	*Men (n=4)*
Work intensity 1		
500 m split time (minutes:seconds)	2:48 (0:10)	2:08 (0:05)
Heart rate (beats/min)	164.6 (8.7)	154.4 (3.6)
Percentage of estimated heart rate maximum	79.7 (6.3)	72.3 (2.6)
Work intensity 2		
500 m split time (minutes:seconds)	2:26 (0:14)	1:48 (0:05)
Heart rate (beats/min)	178.7 (3.3)	181.5 (8.1)
Percentage of estimated heart rate maximum	90.8 (3.0)	93.2 (6.5)

Values are mean (SD).

participate in the study. Four of the subjects were members of a university rowing club, and the remaining five were endurance athletes, who regularly used a rowing ergometer as a training mode. Means (SD) of age, height, and weight for the male subjects were 23.3 (3.8) years, 1.83 (0.05) m, and 81.9 (6.5) kg respectively. For the women, the corresponding values were 28.0 (9.2) years, 1.64 (0.05) m, and 69.4 (10.6) kg.

Exercise was performed on the Concept II rowing ergometer (model B; Concept, Morrisville, Vermont, USA), set with the vanes fully closed and on the larger of the two drive cogs. The electronic performance monitor was used to obtain information about the stroke rate (strokes/min), exercise intensity, expressed as the time taken to cover 500 m (minutes:seconds), and elapsed time (minutes, seconds). The 500 m split time was used as a guideline to elicit a certain heart rate response. A relative percentage of maximum heart rate was used rather than a percentage of maximal oxygen consumption ($\dot{V}O_2MAX$), as a linear relation has been found to exist between oxygen consumption and heart rate up to intensities equivalent to 90% $\dot{V}O_2MAX$.[20] All subjects were familiar with the Concept II having used this type of simulator extensively in training. Heart rate was measured by short range telemetry (PE3000 Sport Tester, Polar Electro OY, Kempele, Finland).

A test developed by Lakomy and Lakomy[21] was used to establish exercise intensities for each subject. The test required subjects to row on the ergometer for four minutes at a speed that they felt was comfortable and were able to maintain. The stroke rate was confined to within 24 and 28 strokes/min, a comfortable training range for most rowers.[22] The speed (500 m split time) and heart rate were recorded during the final minute of exercise. After a short break, subjects completed two separate four minute workloads, one at 75% of their estimated heart rate maximum, and the other at 90%, the order being randomly assigned. These percentage values were calculated from exercise intensity prediction tables produced by Lakomy and Lakomy.[21] Adequate rest (denoted by heart rate recovery to within 10% of that before the exercise) was given between work bouts. During this rest interval, subjects remained seated on the rowing ergometer. During the final minute of exercise, heart rate and 500 m split time were recorded.

Table 2 Lactate levels in plasma sampled from capillary blood at the three different sites

Work intensity (% HR max)	*Site of sample*	*Lactate (mmol/l)*
76.4	Finger	6.36 (1.58)
	Toe	5.81 (1.11)
	Ear	5.29 (1.24)
91.9	Finger	8.81 (2.30)
	Toe	8.53 (1.37)
	Ear	8.41 (2.35)

Values are mean (SD). HR max, maximum heart rate.

Immediately after the cessation of each workload, 50 µl capillary blood was taken simultaneously from each site by three experimenters. The area of sampling was prepared using non-alcoholic mediwipes. Blood was collected using a heparinised capillary tube marked at 50 µl, and immediately placed into a standardised 4 µl preservative (fluoride/EDTA reagent) to prevent coagulation. The samples were centrifuged for five minutes, and 20 µl supernatant plasma was frozen for subsequent analysis, using the enzymatic method described by Noll.[23]

A three way analysis of variance was used to determine differences and to look at interaction effects between sampling sites, subjects, and workloads. The level of significance was set at $p<0.05$. A Pearson product-moment correlation coefficient *(r)* was used to look at the relation between lactate values at different sites, and a normal scores plot was used to check the distribution of values.

Results

Tables 1 and 2 give respectively performance data and plasma lactate values found at the three sites. The lactate response data for all subjects were pooled (table 2), as no significant differences occurred when the lactate data were analysed separately for each sex.

No significant differences ($p = 0.085$) were found in the amount of lactate at the three different sampling sites at either work intensity. Interaction analysis suggested that any small variations in lactate that were found at the different sites could be accounted for by differences between subjects rather than between sites.

The normal scores plot disclosed a correlation of 0.98, greater than 0.96 for normality. At the first workload, the Pearson product-moment coefficient showed significant correlations of lactate values between the toe and the earlobe ($r = 0.74$), between the toe and the fingertip ($r = 0.79$), but not between fingertip and earlobe ($r = 0.64$). At the second load, correlation coefficients were significant between the toe and earlobe ($r = 0.79$), between the fingertip and earlobe ($r = 0.67$), but not between the toe and fingertip ($r = 0.46$). When the values achieved at the same site but at different work intensities were compared, all relations were significantly different, and correlations were low.

Discussion

At both work intensities, the mean concentrations of plasma lactate found at the toe, fingertip, and earlobe were not significantly different ($p = 0.085$). Although only nine subjects were involved in the study, a normal scores plot indicated an even distribution of lactate

response, suggesting that the findings would be the same if larger numbers were tested. These results contradict the results of Smith *et al*,[14] who found that lactate concentration in blood sampled from the toe was significantly lower than that in blood taken from the earlobe after arm only exercise. In the study of Dassonville *et al*,[3] differences in lactate levels in blood taken from the fingertip and earlobe after arm only exercise were not significant until the last stages of incremental exercise, when the levels in the blood from the earlobe were lower than those in the blood from the fingertip. After leg exercise (cycle and treadmill), Dassonville *et al*[3] found earlobe values to be lower at all exercise intensities than the fingertip values. In the present study, although differences were not significant, mean earlobe values were also lower than fingertip values at both the lower and higher workloads (table 2). Pearson product-moment coefficient showed low correlations between the earlobe and fingertip values at the first workload ($r = 0.64$). A greater appreciation of lactate kinetics may be needed to explain some of the discrepancies in these findings. Smith *et al*[14] proposed that less lactate was produced and more metabolised within the inactive legs, resulting in lower net amounts of blood lactate at the toe. Similar conclusions about lactate uptake by non-exercising muscle have been reached by other researchers.[24–27] In studies in which blood was removed from inactive muscle, such as from the arm during leg exercise, lactate levels were found to be lower in venous blood than in arterial blood, suggesting that lactate is metabolised within the inactive muscle.[11] In studies in which blood was removed from active muscle, lactate concentrations were found to be higher in venous blood than in arterial blood,[3 27] suggesting higher lactate production than removal in active muscle. Factors that influence net concentration of lactate at the peripheral sampling site may include changes in local blood flow as the result of vasoconstriction and dilatation, and changes in local lactate production and elimination.[28] In rowing, the muscles of the legs, back, and arms are highly active,[29] suggesting a more even distribution, from both production and utilisation, of lactate in the blood. This may explain why no significant differences were found in lactate concentration in blood sampled from the fingertip, earlobe, and toe in this study. The mean earlobe values were, however, lower than mean fingertip values at both work intensities (table 2). It has been suggested[3] that the earlobe may be less affected by lactate release in the arms and legs. Although it is difficult to give definite reasons for the differences in lactate levels in the earlobe, fingertip, and toe in this study, they may reflect the type of exercise undertaken.

It should be pointed out that the study was not intended to assess training status or physiological response to exercise. The aim was simply to compare lactate concentrations in plasma from the three different sampling sites at two different work intensities. The data therefore suggest that the toe may be a valid site for assessing plasma lactate concentration at these intensities and duration. It should be possible to use a continuous protocol for assessment of lactate during steady state exercise or incremental load protocols without interference with the rowing action. However, further research needs to be carried out to compare the different sampling sites during different test protocols. In addition, further research may be required to determine whether local pressure in the toe affects measurements in samples taken during continuous rowing. In conclusion, the use of the toe as a sampling site may offer a practical alternative for assessing plasma lactate concentration during rowing, as removing blood from this area does not require the rower to stop exercising.

1 Davis JA. Anaerobic threshold: review of the concept and directions for the future. *Med Sci Sports Exerc* 1985;**17**:6–18.
2 Farrell PA, Wilmore J, Coyle E, *et al*. Plasma lactate accumulation and distance running performance. *Med Sci Sports* 1979;**11**:338–44.
3 Dassonville J, Beillot, J, Lessard Y, *et al*. Blood lactate concentrations during exercise: effect of sampling site and exercise mode. *J Sports Med Phys Fitness* 1998;**38**:39–46.
4 Heck J, Mader A, Hess G, *et al*. Justification of the 4-mmol/l lactate threshold. *Int J Sports Med* 1985;**6**:117–30.
5 Stegmann H, Kindermann W. Comparison of prolonged exercise tests at the individual anaerobic threshold and the fixed anaerobic threshold of 4 mMol.l^{-1} lactate. *Int J Sports Med* 1982; **3**:105.
6 Langill RH, Rhodes EC. Comparison of the lactate and ventilatory responses during a progressive intensity test. *Aust J Sci Med Sport* 1992;**24**:100–2.
7 Urhausen A, Coen B, Weiler B, *et al*. Individual anaerobic threshold and maximum lactate steady state. *Int J Sports Med* 1993;**14**:134–9.
8 Knowlton RG, Brown DD, Hetzler RK, *et al*. Venous and fingertip blood to calculate plasma volume shift following exercise. *Med Sci Sports* 1990;**22**:854–7.
9 Robergs RA, Chwalbinska-Moneta J, Mitchell JB, *et al*. Blood lactate threshold differences between arterialized and venous blood. *Int J Sports Med* 1990;**11**:446–51.
10 Williams JR, Armstrong N, Kirby BJ. The influence of the site of sampling and assay medium upon the measurement and interpretation of blood lactate responses to exercise. *J Sports Sci* 1992;**10**:95–107.
11 Yoshida T, Takeuchi N, Suda Y. Arterial versus venous blood lactate increase in the forearm during incremental bicycle exercise. *Eur J Appl Physiol* 1982;**50**:87–93.
12 Foxdal P, Sjödin A, Östman B, *et al*. The effect of different blood sampling sites and analyses on the relationship between exercise intensity and 4.0 mmol.l^{-1} blood lactate concentration. *Eur J Appl Physiol* 1991;**63**:52–4.
13 Heller J, Bunc V, Novotny J. Effect of site of capillary blood sampling on lactate concentrations during exercise and recovery. *Acta Universitatis Carolinae Gymnica* 1991;**27**:29–38.
14 Smith M, Hale T, Harley R, *et al*. Blood lactates sampled from different sites [conference communications]. *J Sports Sci* 1991;**9**:431.
15 El-Sayed MS, George KP, Wilkinson D, *et al*. Fingertip and venous blood lactate concentration in response to graded treadmill exercise. *J Sports Sci* 1993;**11**:139–43.
16 Bishop PA, May M, Smith JF, *et al*. Influence of blood handling techniques on lactic acid concentrations. *Int J Sports Med* 1992;**13**:56–9.
17 Yoshida T. Effect of exercise duration during incremental exercise on the determination of anaerobic threshold and the onset of blood lactate accumulation. *Eur J Appl Physiol* 1984:**53**;196–9.
18 Koutedakis Y, Sharp NCC. Lactic acid removal and heart rate frequencies during recovery after strenuous rowing exercise. *Br J Sports Med* 1985;**19**:199–202.
19 Zhou D. A study of the dynamic heart rate anaerobic threshold of Chinese elite oarswomen. *Sports Sci* 1990;**10**: 56–8.
20 Lakomy HKA, Lakomy J. Estimation of maximum oxygen uptake from submaximal exercise on a Concept II rowing ergometer. *J Sports Sci* 1993:**11**:227–32.
21 Lakomy HKA, Lakomy J. *Endurance fitness and the Concept II rowing ergometer.* [Manual] Morrisville, VT: Concept II.
22 Steinacker JM. Physiological aspects of training in rowing. *Int J Sports Med* 1993;**14**(suppl 1):S3–10.
23 Noll F. L-(+)-Lactate. Determination with LDH, GPT and NAD. In: Bergmeyer HU, ed. *Methods of enzymatic analysis*. 2nd ed (translated from 3rd German ed). New York and London: Verlag Chemie Weinheim and Academic Press, 1974:1475–8.
24 Bassett DR, Smith PA, Getchel LH. Energy cost of simulated rowing using a wind-resistance device. *Physician and Sports medicine* 1984;**12**:113–18.
25 Karlsson J, Jacobs I. Onset of blood lactate accumulation during muscular exercise as a threshold concept. Theoretical considerations. *Int J Sports Med* 1982;**3**:190–201.

26 Secher NH, Clausen JP, Klausen K, *et al.* Central and regional circulatory effects of adding arm exercise to leg exercise. *Acta Physiol Scand* 1977;**100**:288–97.
27 Ahlborg GL, Hagenfeldt L, Wahren J. Substrate utilization by the inactive leg during one-leg or arm exercise. *J Appl Physiol* 1975;**39**:718–23.
28 Gullstrand L, Sjödin B, Svedenhag J. Blood sampling during continuous running and 30-second intervals on a treadmill. *Scandinavian Journal of Medical Science in Sports* 1994: **4**;239–42.
29 Mazzone T. Kinesiology of the rowing stroke. *National Strength and Conditioning Association Journal* 1988;**10**:4–11.

Take home message
For activities in which the upper body is in constant motion, particularly rowing, use of the toe as a sampling site for assessing plasma lactate concentration is viable.