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Computed exercise plasma lactate concentrations: A conversion formula

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ABSTRACT

Objectives: Blood lactate measurements are common as a marker of skeletal muscle metabolism in sport medicine. Due to the close equilibrium between the extracellular and intramyocellular space, plasma lactate is a more accurate estimate of muscle lactate. However, whole blood-based lactate measurements are more convenient in field use. The purpose of this investigation was therefore (1) to establish a plasma-converting lactate formula for field use, and (2) to validate the computed plasma lactate levels by comparison to a laboratory standard method.
Design and methods: A total of 91 venous samples were taken from 6 individuals with type 1 diabetes during resting and exercise conditions and assessed for whole blood and plasma lactate using the YSI 2300 analyzer. A linear model was applied to establish a formula for converting whole blood lactate to plasma lactate. The validity of computed plasma lactate values was assessed by comparison to a laboratory standard method.
Results: Whole blood YSI lactate could be converted to plasma YSI values (slope 1.66, intercept 0.12) for samples with normal hematocrit. Computed plasma levels compared to values determined by the laboratory standard method using Passing-Bablok regression yielded a slope of 1.03 (95%CI:0.99:1.08) with an intercept of -0.11 (95%CI:-0.18:-0.06).
Conclusions: Whole blood YSI lactate values can be reliably converted into plasma values which are in line with laboratory determined plasma measurements.

1. Introduction

Blood lactate is an important parameter in sports physiology experiments, many of which take place in the field. Due to the lack of laboratory facilities for sample preparation in field settings, assessment of blood lactate concentrations is mostly based on whole blood measurements. However, plasma concentrations are considered to be a better estimate of muscle lactate due to the close equilibrium between the intramyocellular and extracellular compartment [1]. The YSI 2300 analyzer is considered to be a rapid, accurate and reliable measurement device and is therefore commonly used for field testing of lactate in non-hemolyzed whole-blood specimens. The instrument determines extracellular fluid lactate as intracellular lactate is not accessible to the measurement electrode [1–3]. It is well known that the extracellular fluid concentration displayed on the instrument does not represent the plasma lactate concentration. This discrepancy results from the fact that the YSI 2300 analyzer employs a volume-dependent measurement method, and the erythrocytes exert a diluting effect [4].

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As a consequence, the assessed extracellular lactate concentration is always lower than the measured value derived from centrifuged plasma. Computing plasma lactate values by means of a whole blood-based formula would be advantageous in a field study setting often lacking laboratory facilities. However, the manufacturer's literature states there is no reliable way to convert whole blood to plasma lactate values [3].

The purpose of this investigation was therefore to compare whole blood and plasma lactate values obtained with the YSI 2300 analyzer and to establish a conversion formula within a clinically relevant range of lactate concentrations. We also aimed to validate the conversion formula by comparing the computed plasma values with actual plasma measurements using a standard laboratory method.

2. Methods

2.1. Study procedures

This work was part of a study assessing exercise-related fuel metabolism in individuals with type 1 diabetes, approved by the local ethics committee and registered on www.trialregister.nl (NTR02068638). Blood samples were taken from 6 young male adults with well controlled (mean haemoglobin A1c [$\pm$ SD] 7.0 $\pm$ 0.6%) and complication-free type 1 diabetes both at rest and during exercise conditions designed to elicit lactate concentrations that could be classified as low (0.5–4 mM), moderate (4-8 mM) and high ($>$ 8 mM). Exercise modality was 90 min of intermittent intensity cycling (baseline intensity at 50% VO_2max with interspersed all out 10 s sprints every 10 min). Lithium heparinised blood specimens were collected from an indwelling catheter in the antecubital vein before, during, and after the sprints. Whole blood samples were immediately measured using the YSI 2300 analyzer and then centrifuged. The plasma obtained was kept on ice and analyzed by the YSI 2300 and laboratory reference method within the next 30 minutes.

3. Instruments

Whole-blood and plasma lactate was measured using the YSI 2300 glucose and lactate analyzer from Yellow Springs Instruments (Yellow Springs, OH, USA), which utilizes membrane-bound enzyme electrochemical technology. Validation of computed plasma values based on YSI 2300 whole-blood measurements was performed by comparison with the standard laboratory method for plasma lactate on the Roche MODULAR analyzer (Roche Diagnostics AG, Rotkreuz, Switzerland). Both instruments utilize the L-lactate oxidase reaction, which catalyzes the conversion of L-lactate into pyruvate and hydrogen peroxide. Whereas the lactate concentration in the YSI 2300 analyzer is detected by measuring an electric current, the MODULAR instrument detects the resulting color reaction. Both analyzers were calibrated routinely according to the manufacturer's recommendations, and met all quality assurance performance standards during the study period. The MODULAR method was standardized against primary reference material.

4. Data analysis

The *conversion* formula for whole blood lactate to plasma lactate was computed by fitting a linear model using a Graphics Processing Unit (GPU) enabled QR decomposition [5] from the YSI whole blood and plasma lactate measurements, followed by the computation of bias-corrected and accelerated (BCa) bootstrap confidence intervals (R = 1000). This approach was applied since QR decomposition (decomposition of the data matrix in an orthogonal matrix Q and an upper triangular matrix R) offers in comparison with e.g. Singular Value Decomposition (SVD) or Cholesky decomposition the best balance between efficiency and precision [6,7]. In addition, inverting an upper triangular matrix is easier and less prone to error than is inverting a sum of squares matrix [7]. *Comparison* between the different methods of lactate determination were performed using Passing-Bablok linear regression [8,9]. Kendall's rank correlation coefficient was used to determine the degree of association between lactate concentrations derived from the different assessment methods. The level of agreement was assessed using the methods described by Bland and Altman [10]. All statistical analysis were performed using the gputools and Rcmdr (with plugin KMggplot2) packages of the statistical software R 3.1.2 (R Foundation for Statistical Computing, Vienna, Austria).

5. Results

A total of 91 samples were included in the analysis. Hematocrit was within the reference range (0.40–0.50 for men) for all except 1 participant who had a hematocrit of 0.55 (hematocrit range = 0.42–0.55; median = 0.46). Comparison between whole blood and plasma lactate values obtained by the YSI 2300 analyzer showed good correlation (Kendall's tau = 0.96) and yielded the following QR decomposition-based conversion equation: