Can Peripheral Venous Lactate Levels Substitute for Arterial Lactate Levels in The Emergency Department? An Observational Study

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Abstract

Background: Arterial lactate (AL) level is an important parameter used to predict patients' prognosis. AL and peripheral venous lactate (PVL) in blood gas analysis have a low concordance rate, and PVL cannot be used as a substitute for AL. However, if the AL range can be predicted from PVL, PVL may be an alternative method of predicting patient prognosis, and the risk of arterial puncture complications with AL may be reduced. This could become a safe and rapid test method.

Methods: This was a retrospective observational study of 143 cases in which blood gas analysis was performed on both arterial blood and venous blood in an emergency department. Spearman's rank correlation coefficient (r) and Bland−Altman analysis were performed. Sensitivity, specificity, and the area under the curve (AUC) were calculated for PVL to predict AL < 2 mmol/L or < 4 mmol/L.

Results: The median [interquartile range] AL and PVL were 1.82 [1.25−2.58] vs 2.09 [1.57−3.29], respectively, r was 0.799 (*p*<0.0001), and a strong correlation was observed; however, Bland−Altman analysis showed disagreement. When AL < 2 mmol/L was used as the outcome, AUC was 0.974, the PVL cutoff value was 2.55 mmol/L, sensitivity was 87.9%, and specificity was 94.1%. If PVL < 2 mmol/L was the outcome, the sensitivity for AL < 2 mmol/L was 100%, and for PVL levels ≥ 3 mmol/L, the specificity was 100%. When AL < 4 mmol/L was used as the outcome, AUC was 0.970, the PVL cutoff value was 3.4 mmol/L, sensitivity was 100%, and specificity was 84.5%. When PVL < 3.5 mmol/L was the outcome, the sensitivity for AL < 4 mmol/L was 100%, and for PVL levels ≥ 4 mmol/L, the specificity was 93.8%.

Conclusions: This study revealed that PVL and AL levels in the same critically ill patients do not perfectly agree with each other but are strongly correlated. Furthermore, the high accuracy for predicting AL ranges from PVL levels explains why PVL levels could be used as a substitute for AL level ranges.

Background

In early emergency care, it is important to promptly determine the severity of a patient's condition because severity affects prognosis. Shock, heart failure, severe trauma, and sepsis are the most common pathological conditions causing lactic acidosis [1]. In patients with these conditions, elevated lactate levels may be associated with morbidity and mortality [2−4]. In patients with shock that could not be differentiated regarding cause, the prognosis was poor when lactate levels were higher than 4 mmol/L [5]. In those who survived, lactate levels had decreased by 10% within 1 hour following treatment initiation [6]. According to these findings, blood lactate levels are useful for evaluating the severity of shock and determining the effects of treatment [7, 8]. Thus, blood gas analyses are performed repeatedly to measure arterial lactate (AL) levels in patients with severe conditions. However, this testing requires arterial puncture and catheterization (arterial line placement) for blood collection, which is invasive and involves a risk of complications [9].

In the emergency department (ED), venous blood gas analysis is usually performed as an alternative to arterial blood gas analysis to reduce the risk of complications due to arterial puncture when determining

the effects of treatment. However, because of disagreement between venous and arterial blood gas analyses, it is necessary to determine to what extent values agree between the analyses and whether venous blood gas analysis can substitute for arterial blood gas analysis. Previous studies have reported that parameters in venous blood gas analysis that can substitute for those of arterial blood gas analysis are the hydrogen-ion (pH) and bicarbonate ion (HCO3) concentrations. Carbon dioxide partial pressure (pCO2), oxygen partial pressure (pO2), and lactate levels could not be used as substitutes [10, 11]. Although pCO2 and lactate levels did not match when using as substitutes, parameters in the reference values for venous blood gas analysis provide useful clues for predicting a similar trend to corresponding values for arterial blood gas analysis [10, 11].

AL is an important parameter used to predict patients' prognosis. In sepsis, septic shock with sepsis-3 is defined as a lactate level ≥ 2 mmol/L with the need for vasopressors to maintain mean blood pressure at 65 mmHg [12]. Mortality due to septic shock can be estimated by a lactate level ≥ 2 mmol/L instead of lactate clearance [13]. In addition, previous studies have shown that the cutoff lactate level for a poor prognosis is ≥ 3 mmol/L [14, 15] or 4 mmol/L [3, 5, 16, 17]. Thus, despite disagreement between AL and venous lactate (VL) concentrations, VL can be used to predict prognosis in critically ill patients if the AL cutoff can be predicted from VL. According to previous reports evaluating the relationship between AL and VL levels, when VL levels are within the reference values (< 2 mmol/L), AL levels are also within the reference values (< 2 mmol/L) [18]. Furthermore, when VL levels are ≥ 4.5 mmol/L, AL levels are predicted to be ≥ 4.0 mmol/L [19].

To the best of our knowledge, no studies have confirmed whether VL levels can substitute for ranges of AL levels in critically ill patients. Thus, this study aimed to investigate the relationship between VL and AL levels in the same critically ill patients and to determine whether VL levels can substitute for ranges of AL levels. If VL levels can be used as a substitute for AL levels, venous blood gas analysis (which reduces the risk of complications associated with arterial puncture required for AL measurement) may be a safer and faster test for critically ill patients.

Methods
Study Design

This was a retrospective, single center, observational study performed at Yokohama Municipal Citizen's Hospital (Yokohama, Japan). Yokohama Municipal Citizen's Hospital's catchment area is the central area of Yokohama City, which had an estimated population of 3.7 million in 2020.

Design

The current study was a secondary analysis of data from a retrospective observational study that was performed to examine the relationship between quantitative capillary refill time (Q-CRT) and lactate in patients in the ED [20, 21]. In the current study, we examined patients who had undergone arterial and

venous blood gas analyses at the time of initial examination. This study was approved by the institutional review board of Yokohama Municipal Citizen's Hospital (approval number: 17-07-01). All patients or their families provided informed consent to participate in this study.

Patients

Of 174 patients participating in the Q-CRT trial in our hospital's ED from August 2017 to February 2020, we included only patients with a measured arterial and venous blood gas in the ED, in the current study. When patients were brought to the ED by ambulance, an intravenous line was first established. Then, we collected blood samples and measured venous blood gas. We performed arterial blood gas measurement only for particular pathological conditions. In this study, all VL levels were peripheral venous lactate (PVL) levels.

Blood Gas Analyzer

Our hospital used the SIEMENS RAPID Point 500 gas analyzer (Siemens Healthcare Diagnostics, Inc., Tarrytown, NY) to measure blood lactate. The measurable value ranges from 0.18 nmol/L to 30 mmol/L with this analyzer.

Data Analysis And Statistical Methods

Stata (R) 13.1 (StataCorp, College Station, TX, USA) was used for the statistical analyses. Data were presented as median with interquartile range (IQR) for continuous variables and as number and percentage for categorical variables. Student's t test, the Mann–Whitney U test, Spearman's correlation, Bland–Altman analysis, and the χ^2 test were used for the univariate analysis. Sensitivity, specificity, and the area under the curve (AUC) were calculated for PVL to predict AL. A p value of < 0.05 was considered statistically significant.

Results

In the Yokohama Municipal Citizen's Hospital, we measured Q-CRT in 174 patients from August 2017 to February 2020, and 143 underwent both arterial gas analysis and venous gas analysis. Patients' baseline characteristics are shown in Table 1. Regarding the baseline characteristics, the most common pathological conditions in the ED were respiratory disorders (74 cases, 51.7%), followed by digestive disorders in 23 cases (16%) and genitourinary disorders in 20 cases (13.9%). The mean age was 81 years (72–86 years). Men constituted 62.2% of all patients, and most patients in this study had infections. Mean body temperature was 38.4 °C (37.5–39.1 °C), and the mean peripheral oxygen saturation (SpO2) was 96% (94–98). The median AL was 1.82 mmol/L (1.25–2.58), and PVL was 2.09 mmol/L (1.57–3.29) (all data are median (IQR)).

Pearson's correlation coefficient between AL and PVL was 0.900 (γ2 = 0.799) (Fig. 1a). As shown in the Bland−Altman plot (Fig. 1b), the mean difference between AL and PVL was 0.47 ± 0.83 mmol/L. The limits of agreement were between − 2.1 mmol/L and 1.16 mmol/L.

For predicting AL levels < 2 mmol/L from the PVL levels, the best cutoff value for PVL was 2.55 mmol/L, with a sensitivity and specificity of 87.9 and 94.1, respectively. The area under the receiver operating characteristic (ROC) curve was 0.974, as shown in Fig. 2a. Figure 3 shows the sensitivity and specificity of all PVL levels from which AL levels were predicted to be < 2 mmol/L. When PVL levels were < 2 mmol/L, the sensitivity was 100%. In contrast, when PVL levels were ≥ 3 mmol/L, the specificity was 100%.

For predicting AL levels < 4 mmol/L from the PVL levels, the best cutoff value for PVL was 3.4 mmol/L, with a sensitivity and specificity of 100 and 84.5, respectively. The area under the ROC curve was 0.970, as shown in Fig. 2b. Figure 4 shows the sensitivity and specificity of all PVL levels from which AL levels were predicted to be < 4 mmol/L. When PVL levels were < 3.5 mmol/L, the sensitivity was 100%. In comparison, to achieve a specificity of 100%, PVL levels needed to be ≥ 7.0 mmol/L. When PVL levels were ≥ 4.0 mmol/L, as with AL levels, the specificity was 93.8%.

Figure 5 shows the sensitivity and specificity of PVL levels from which AL levels were predicted to be less than or equal to PVL levels. When PVL levels were < 3.5 mmol/L, AL levels were predicted to be < 3.5 mmol/L with a high sensitivity.

Discussion

In this study, we investigated the relationship between PVL and AL levels in the same critically ill patients and determined whether PVL levels could substitute for ranges of AL levels. Our results showed that PVL and AL levels did not perfectly agree with each other but were strongly correlated. Thus, the high accuracy of predicting ranges of AL levels from PVL levels prompts us to consider PVL levels as a potential substitute for AL levels. In addition, using PVL levels may reduce the risk of complications associated with arterial puncture in critically ill patients.

A previous study showed that VL levels are slightly higher than AL levels, but that VL correlates strongly with AL levels [22]. This finding is similar to the results in patients with PVL < 3.5 mmol/L, in the current study. However, when PVL levels were ≥ 3.5 mmol/L, AL levels were higher than PVL levels in 8 of 33 patients. Another study showed that PVL levels do not agree with AL levels and cannot be substituted for AL levels [23]. We also demonstrated that PVL levels were not a direct substitute for AL levels.

Lactic acidosis is a biomarker of tissue hypoxia caused by insufficient oxygen supply and indicates a poor prognosis [24]. In sepsis, lactate levels are reported to be more strongly associated with mortality than other parameters [25]. Adverse events occur in septic patients with a lactate level of 2−4 mmol/L [26, 27]. In sepsis-3, septic shock is defined as a lactate level ≥ 2 mmol/L and requiring vasopressors to

maintain a mean blood pressure of 65 mmHg [12]. These findings suggest that lactate ≥ 2 mmol/L is associated with prognosis.

In another study, the rates of serious complications and mortality increased in patients with lactate ≥ 3 mmol/L at the end of hepatectomy [14]. In patients with shock that could not be differentiated, the prognosis was poor when lactate was ≥ 4 mmol/L [5]. When patients with infection were analyzed in three groups (lactate 0–2.5 mmol/L, lactate 2.5–4 mmol/L, and lactate ≥ 4 mmol/L), mortality was 28.4% higher in patients with lactate ≥ 4 mmol/L [3]. Thus, the prognosis of sepsis is poor in patients with lactate ≥ 4 mmol/L [16]. Lactate ≥ 4 mmol/L is an indicator of tissue hypoperfusion [17]; thus, this lactate level is considered to be an important cutoff value.

Based on these findings, we conclude that it may be possible to better predict arterial lactate levels from venous lactate levels by considering a range of arterial lactate levels, rather than a specific value. We examined our results to determine whether AL ranges could be predicted from PVL levels. First, AL levels were always < 2 mmol/L when PVL levels were < 2 mmol/L, and AL levels were always ≥ 2 mmol/L when PVL levels were ≥ 3 mmol/L, as shown in Fig. 3. Additionally, we examined patients with AL < 4 mmol/L. Figure 4 shows that AL levels were always < 4 mmol/L when PVL levels were ≤ 3.5 mmol/L. Meanwhile, AL levels were always ≥ 4 mmol/L only when PVL levels were ≥ 7 mmol/L; unlike in the 2 mmol/L group, the difference between AL and PVL levels increased. When PVL levels were ≥ 4 mmol/L, AL levels were ≥ 4 mmol/L in 93.8% of our patients. Figure 5 shows the sensitivity and specificity of PVL levels to predict AL levels that were lower than or equal to the same PVL levels. Specifically, when PVL levels were ≤ 3.5 mmol/L, AL levels were predicted to be < 3.5 mmol/L with high sensitivity.

Taken together, our findings revealed that patients with PVL < 2 mmol/L have an AL level < 2 mmol/L, and re-examining arterial blood gas is unnecessary. When PVL levels are 2–3 mmol/L, AL levels are < 4 mmol/L; re-examination is unnecessary to determine whether AL levels are < 4 mmol/L in patients with these PVL levels. Re-examination is only necessary to determine whether AL levels are ≥ 2 mmol/L. When PVL levels are 3 – 3.5 mmol/L, AL levels are 2–4 mmol/L. Re-examination is unnecessary unless a detailed trend in lactate numerical values needs to be examined. When PVL levels are > 3.5 mmol/L, AL levels are ≥ 2 mmol/L. Re-examination is necessary to determine whether AL levels are ≥ 4 mmol/L and to obtain accurate AL levels for calculating lactate clearance.

Thus, PVL levels are a good marker to predict ranges of AL levels. In the ED, venous blood gas analysis appears to be useful for understanding a patient's condition, thus reducing the risk of complications related to arterial puncture.

Limitations

This study has several limitations. First, this was a retrospective, single-center, observational study. Thus, patient selection bias is possible, and our findings lack external validation. Second, variability in technical skill during blood sample collection was not considered, which limits the internal validity of the findings. Third, we did not measure the duration of tourniquet application during venous blood collection, nor did

we specify the collection site. Although both venous and arterial blood samples were collected during the initial examination, samples were not collected at the same time, which might have introduced information bias. In this study, all venous blood samples were collected from peripheral veins while most arterial blood samples were collected from the femoral artery. Further prospective multi-center studies are required to validate our findings.

Conclusions

This study revealed that PVL and AL levels in the same critically ill patient do not perfectly agree with each other but are strongly correlated. Furthermore, the high accuracy of predicting ranges of AL levels from PVL levels explains why PVL levels could be used as a substitute for ranges of AL levels. A prospective multi-center study must be performed to validate our findings.

Abbreviations

AL, arterial lactate; ED, emergency department; PVL, peripheral venous lactate; Q-CRT, quantitative capillary refill time; AUC, area under the curve; ROC, receiver operating characteristic curve; pH, hydrogen ion concentration; HCO_3, bicarbonate; pCO_2, carbon dioxide partial pressure; pO_2, oxygen partial pressure; IQR, interquartile range

Declarations

Declarations

Ethics approval and consent to participate

The study was approved by our hospital's institutional review board. All patients provided informed consent to participate.

Consent for publication

Not applicable.

Availability of data and materials

The dataset supporting the conclusions of this article is included within the article (and its supplementary information files).

Competing interests

All of the authors declare that they have no competing interests.

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Tables

Table 1 Baseline Characteristics of the study population (n = 143)

Variables	Median/Frequency	IQR/%
Sex Men*	89	(62.2)
Age (years)	81	(72–86)
Systolic blood pressure (mmHg)	135	(116–153)
Heart rate (beats/min)	102	(88–117)
Respiratory rate (breaths/min)	24	(19–28)
Body temperature (degrees Celsius)	38.4	(37.5–39.1)
SpO2 (%)	96	(94–98)
Peripheral venous lactate (mmol/L)	2.09	(1.57–3.29)
Arterial lactate (mmol/L)	1.82	(1.25–2.58)
Disease type based on ICD-10*		
Certain infectious and parasitic diseases	5	3.4%
Neoplasms	3	2%
Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism	0	0%
Endocrine, nutritional and metabolic diseases	0	0%
Mental and behavioral disorders	0	0%
Diseases of the nervous system	1	0.6%
Diseases of the eye and adnexa	0	0%
Diseases of the ear and mastoid process	0	0%
Diseases of the circulatory system	5	3.4%
Diseases of the respiratory system	74	51.7%
Diseases of the digestive system	23	16%

IQR interquartile range, SpO2 peripheral oxygen saturation, ICD International Classification of Diseases

| Table 1 Baseline Characteristics of the study population (n = 143)		
Diseases of the skin and subcutaneous tissue	6	4.1%
Diseases of the musculoskeletal system and connective tissue	1	0.6%
Diseases of the genitourinary system	20	13.9%
Pregnancy, childbirth and the puerperium	0	0%
Certain conditions originating in the perinatal period	0	0%
Congenital malformations, deformations and chromosomal abnormalities	0	0%
Symptoms, signs, and abnormal clinical and laboratory findings not classified elsewhere	0	0%
Injury, poisoning, and certain other consequences of external causes	5	3.4%
* frequency (%); other values: median (IQR)		
IQR interquartile range, SpO2 peripheral oxygen saturation, ICD International Classification of Diseases		

Figures
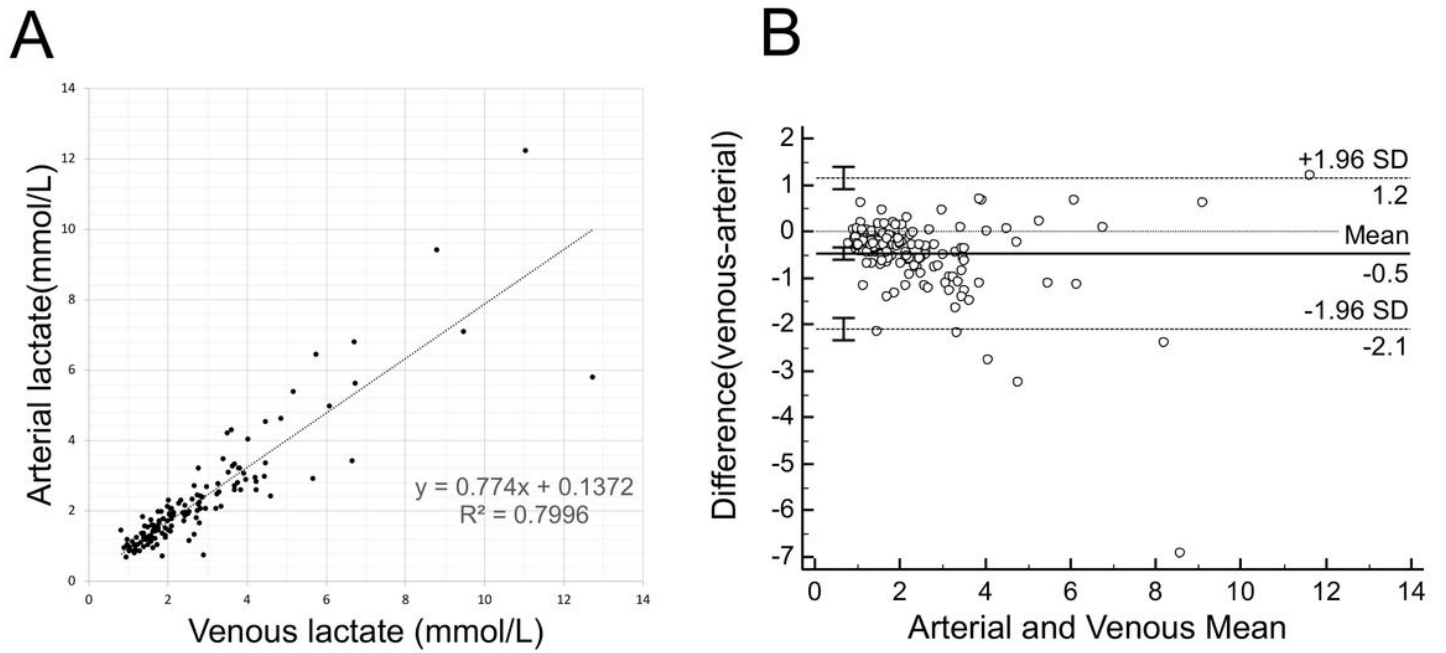
Fig. 1.

Figure 1

Paired arterial and peripheral venous lactate analysis. a. Correlation between arterial and peripheral venous lactate levels in individual patients. b. Bland–Altman bias plot for paired venous and arterial lactate measurements within the same ER. SD standard deviation
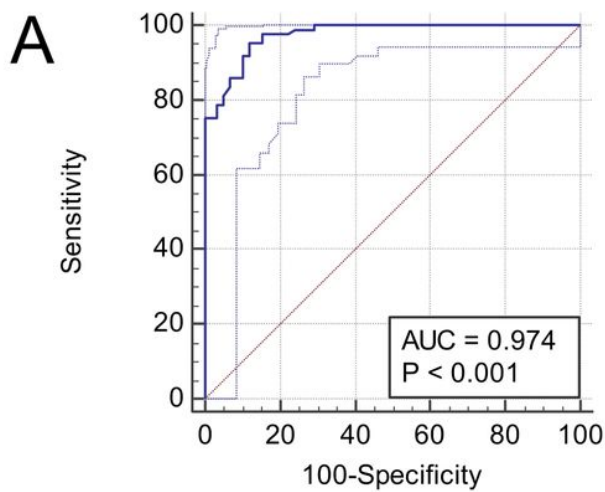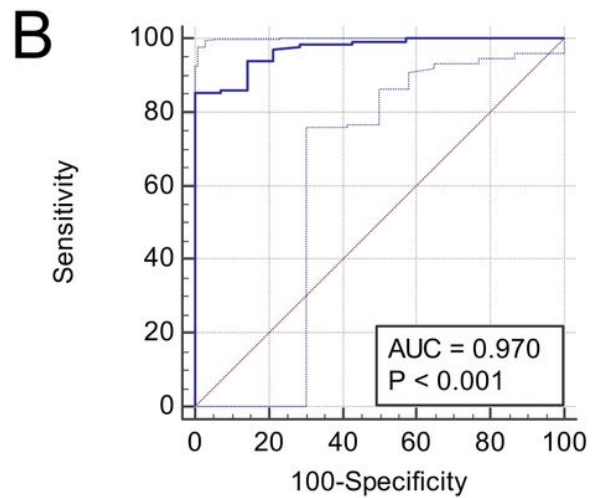
AL (mmol/L)	AUC	95%CI	p value	Cutoff	Sensitivity	Specificity
Arterial lactate < 2	0.974	0.954 – 0.993	<0.001	2.55	87.93	94.1
Arterial lactate < 4	0.969	0.939 – 1.000	<0.001	3.4	100	84.5

Fig. 2.

Figure 2

Performance of peripheral venous lactate for predicting arterial lactate levels. a. Arterial lactate < 2 mmol/L b. Arterial lactate < 4 mmol/L. AL arterial lactate, AUC area under the curve, CI confidence interval
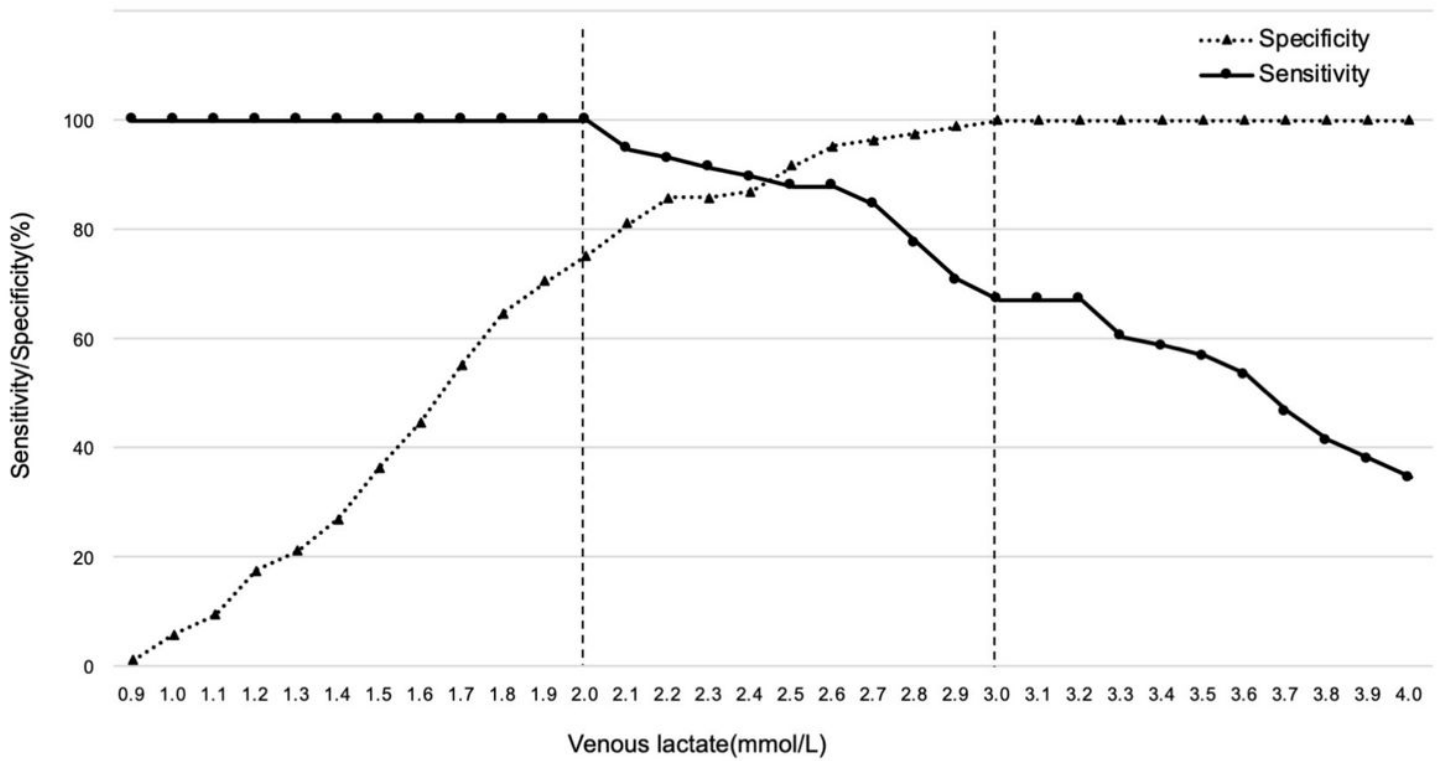
Fig. 3.

Figure 3

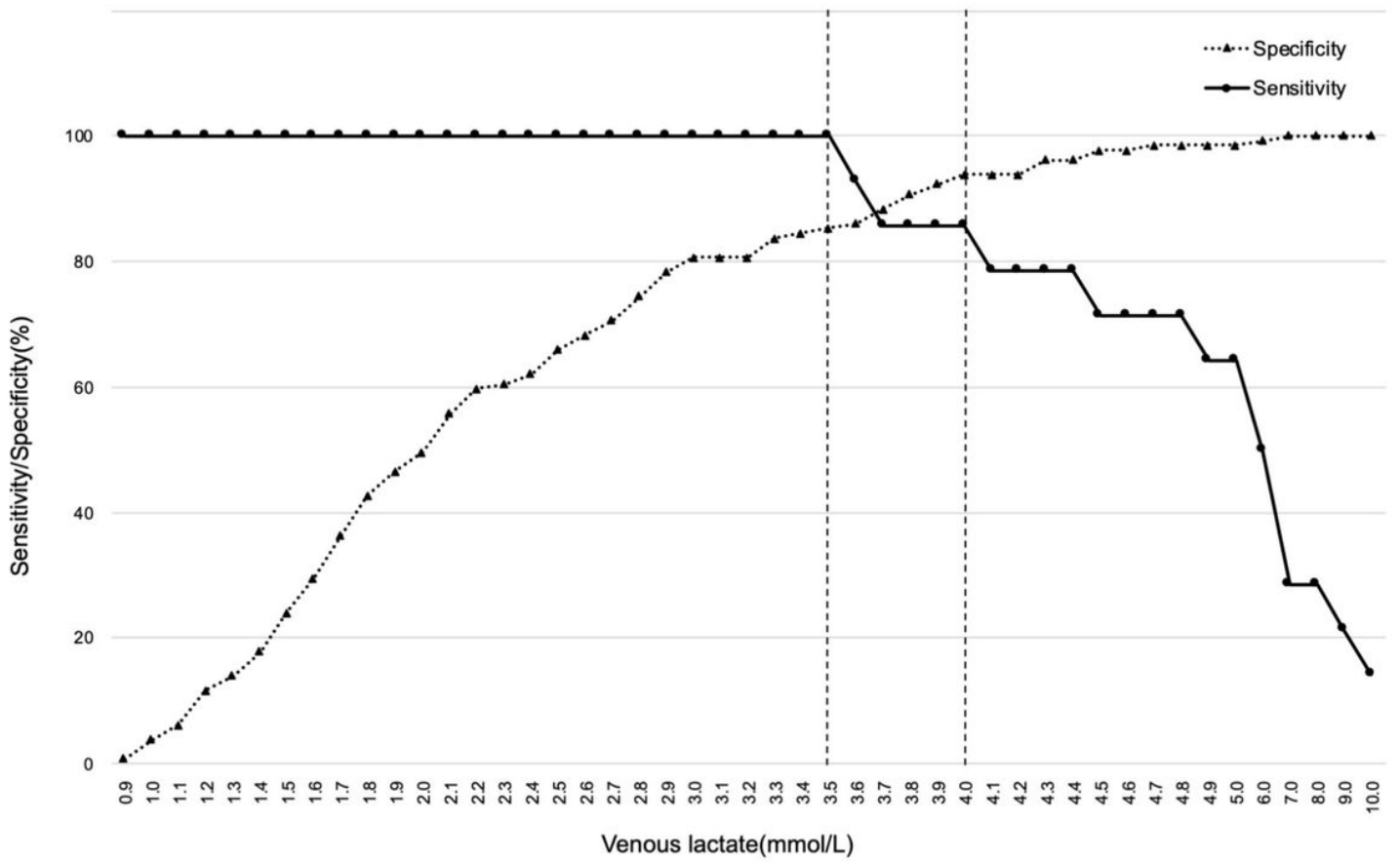Predicting venous lactate lower than arterial lactate < 2 mmol/L.

Fig. 4.

Figure 4

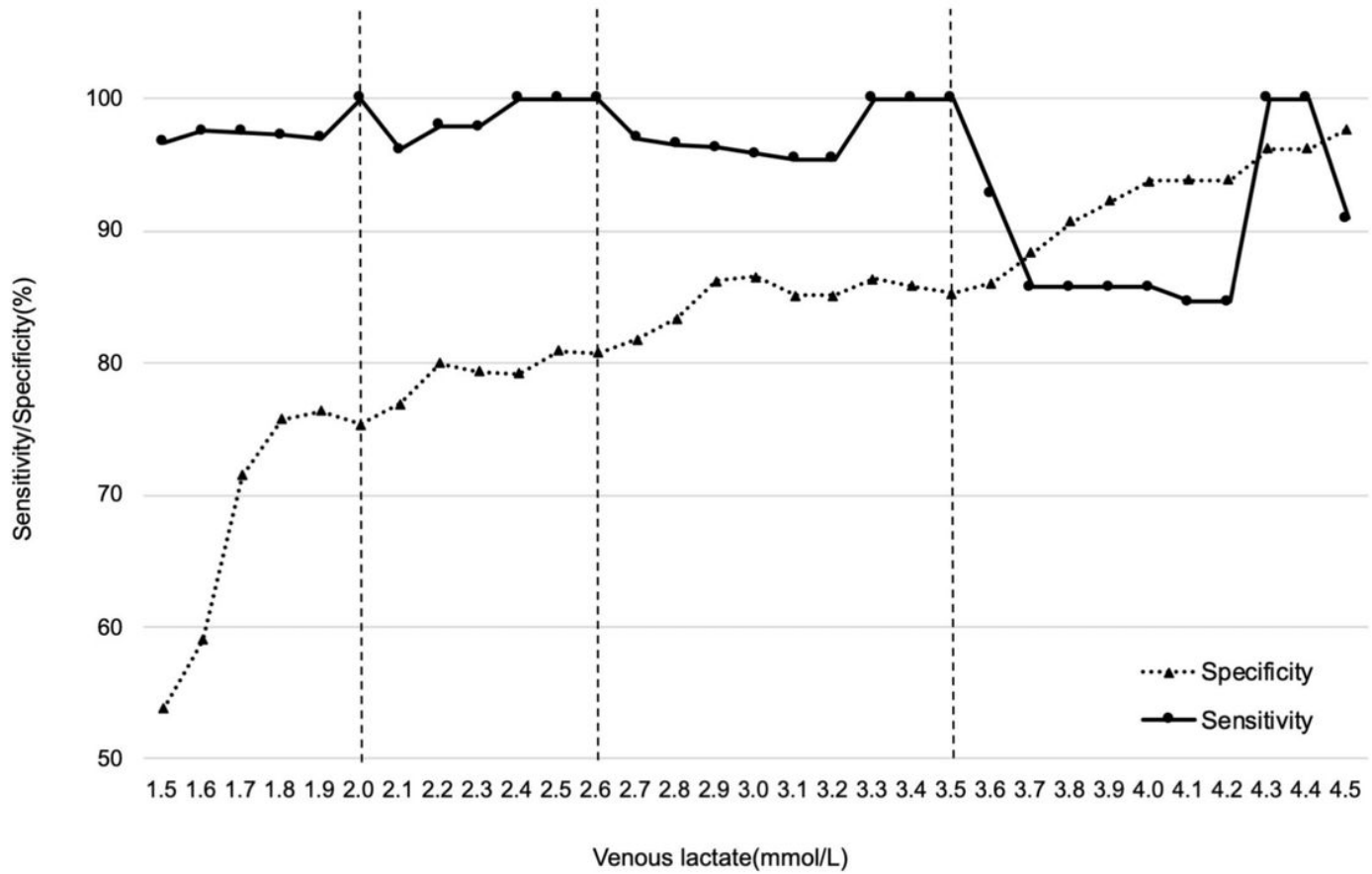Predicting venous lactate lower than arterial lactate < 4 mmol/L.

Fig. 5.

Figure 5

Predicting venous lactate level below the same arterial lactate level.

Supplementary Files

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- SupplementaryMaterialxlsx.xlsx