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RESEARCH ARTICLE

Double Product and Shock Index: Can These Macrocirculatory Parameters Provide Sufficient Information About Microcirculation?

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ABSTRACT

Objectives: This study aims to examine the relationship between microcirculation and macrocirculation in the early period after extracorporeal circulation (ECC). Specifically, it investigates whether macrocirculation parameters such as Double Product (DP) and Shock Index (SI) can predict microcirculation by studying their correlation with lactate levels, a marker of microcirculation, in the early post-ECC period.

Methods: The study analyzed the demographic, hemodynamic, and laboratory data of 2039 patients who underwent isolated coronary bypass surgery with ECC at Acıbadem Kadıköy and Acıbadem Altunizade Hospitals between 1999 and 2023. The data included serum lactate levels, DP, and SI measurements taken before induction and after ECC for all patients, as well as for the subgroup with DP values above 12,000.

Results: The analysis did not find any correlation between plasma lactate levels and DP and SI during the post-ECC period; p=0.11, r=0.04 (-0.01; 0.08) and p<0.001, r=0.11 (0.06; 0.15), respectively. Similarly, no correlation was found between plasma lactate values and DP in patients with DP values >12,000 (n=284) (p=0.643, r=0.03 (-0.09; 0.14)).

Conclusion: Vital parameters do not fully capture circulatory disorders. It would be more appropriate for critically ill patients to assess microcirculation using parameters such as lactate directly. Therefore, further studies are necessary to evaluate microcirculation and develop independent parameters.

Keywords: Double product, extracorporeal circulation, macrocirculation, microcirculation, open heart surgery, shock index

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Introduction

Monitoring vital parameters is an integral part of anesthesia practice. Vital parameters like heart rate and systolic arterial pressure help assess the patients' clinical condition, stabilize hemodynamics, and indirectly evaluate the adequacy of oxygen delivery to tissues.

It is recognized that assessing hemodynamic parameters alone may not be sufficient.[1,2] Formulations incorporating different parameters have been developed to address these limitations. One such parameter is the Double Product (DP), calculated by multiplying heart rate and systolic arterial pressure. This parameter indirectly reflects myocardial oxygen consumption and cardiac workload.[3–5] Another parameter used in hemodynamic assessment is the Shock Index (SI), which represents the ratio of heart rate to systolic arterial pressure.[6]

While multiple vital parameters are assessed simultaneously, their predictions regarding microcirculation are limited. The current approach prioritizes monitoring tissue perfusion adequacy at the microcirculation level. Plasma lactate level is one of the most easily accessible and frequently used markers in clinical practice for evaluating microcirculation.[7,8]

When physiological conditions are maintained, macro- and microcirculation are correlated. However, this correlation may be disrupted due to various reasons related to the patient or the surgery. Extracorporeal circulation (ECC) disrupts this relationship in patients who are undergoing open-heart surgery.[9]

In this study, we examined whether there was a correlation between lactate and DP and between lactate and SI in the early post-ECC period. For this purpose, we analyzed the data of 2039 patients who had undergone open-heart surgery under ECC from 1999 to 2023.

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Methods

The study included patients who underwent isolated coronary bypass surgery and received ECC at Acıbadem Kadıköy and Acıbadem Altunizade Hospitals between 1999 and 2023. The ethics committee of Acıbadem Mehmet Ali Aydınlar University has approved the analysis (ATADEK 2024-10/431). The study was designed following all principles of the Helsinki Declaration.

Patients under 18 years of age or who underwent perioperative resuscitation, total circulatory arrest, or deep hypothermia, and patients with preoperative high lactate or moderate-severe liver failure were excluded from the analysis.

Our clinic follows a specific anesthesia protocol for patients who undergo open-heart surgery. Below is a detailed mention of the procedure.

Before surgery, the patient is given Alprazolam (0.5 mg PO) as a premedication. Midazolam (125 µg/kg IM) is administered thirty minutes before the surgery. A 16 G intravenous cannula establishes vascular access, and physiological saline infusion is initiated at 100 ml/hour. For anesthesia induction, we use Midazolam (50 µg/kg iv), Propofol (1–2 mg/kg iv), and Fentanyl (25–35 µg/kg iv). After intubation, muscle relaxation is initiated with a Vecuronium bolus (0.15 mg/kg iv) and an infusion (80 µg/kg/hour iv). For anesthesia maintenance, either Desflurane or Sevoflurane inhalation is used with a target MAC value of 0.9–1. Hemodynamic monitoring is provided through electrocardiogram (DII, V5), pulse oximetry (SpO_2), and invasive arterial pressure monitoring with right radial artery catheterization. Right internal jugular vein catheterization also monitors central venous pressure and oxygen saturation.

The hematocrit (Hct) level was maintained during the ECC between 25–30%. The mean arterial pressure (MAP) was regulated at 50–80 mmHg, and the pump flow rate (CO) was set at 2–2.5 L/m^2/minute. All patients were kept under moderate hypothermia (32°C). The adequacy of tissue perfusion during ECC was determined by closely monitoring several parameters, such as venoarterial partial carbon dioxide difference (Pv-aCO_2), lactate level, arterial and venous blood gas analyses, urine output, and hemodynamic parameters.

Upon admission to the intensive care unit, patients were warmed until their rectal body temperature reached 37°C. Sedative and muscle relaxant infusions were stopped, and patients were extubated as soon as they met the extubation criteria. Morphine (0.1 mg/kg) met their analgesic needs. Routine monitoring of hemodynamics, blood gases, biochemistry, electrolytes, and body temperature was carried out regularly and as required.

Serum lactate, DP, and SI levels of the patients included in the study were measured at two time points as baseline values before induction and after ECC. The correlation between them was examined. Then, patients with DP values above the upper limit of normal at rest (>12000) were selected, and the correlation between DP and lactate was examined again in the high DP subgroup.

Patient characteristics were presented as mean (standard deviation), median (quartiles), and percentage. Correlations were analyzed using Pearson and Spearman tests. Statistical significance was set at $p<0.05$. The analysis was performed using SPSS version 29.

Results

Table 1 presents demographic data for the 2039 patients in the study. The average age of the patients was 66 (range 60–75), the mean body mass index (BMI) was 26.7 (range 24.6–29.9), and 73.9% of the patients (n=1506) were male.

Table 2 presents the patients' vital signs and blood gas analyses at two time points: baseline and post-ECC.

The correlation between plasma lactate levels and Double Product (DP) and Shock Index (SI) in the post-ECC period is depicted in Figure 1 (p=0.11, r=0.04 (-0.01;0.08), p<0.001, r=0.11 (0.06;0.15), respectively).

Figure 2 shows the correlation between plasma lactate values and DP in patients with DP values >12000 (n=284) in the post-ECC period (p=0.643, r=0.03 (-0.09;0.14)).

Discussion

In anesthesia practice, particularly with high-risk patients, monitoring vital signs is crucial for assessing the adequacy of oxygen delivery at the cellular level. However, there are various limitations to monitoring parameters. Firstly, more than individual parameters alone are required, and it is better to evaluate multiple vital signs together.[1,2] Secondly, in patient groups with disrupted macro and microcirculation relationships, basic monitoring parameters may not indicate tissue-level hypoperfusion, necessitating advanced monitoring.[9]

The Double Product (DP) assesses two vital parameters simultaneously and was developed to overcome the limitations mentioned above.[3–5] DP is calculated as 'DP=Heart Rate×Systolic Arterial Pressure' and provides information about myocardial oxygen consumption and cardiac workload.[1–3] The normal range of DP varies at rest and during exercise. It is expected to be between 6000–12000 at rest and can go up to 40000 with exercise.[10]

Table 1. Patients' characteristics

Patients, (n)	2039
Age, (years)	66 (60–75)
BMI (kg/m^2)	26.7 (24.6–29.9)
Male, n (%)	1506 (73.9)

BMI: Body mass index.

Table 2. Comparison between parameters of two times

	Baseline	Post-ECC	p
HR/min	79 (70–89)	90 (81–100)	**<0.001**
SAP, mmHg	143 (130–161)	107 (97–118)	**<0.001**
DAP, mmHg	79 (71–88)	67 (60–74)	**<0.001**
MAP, mmHg	102 (92–113)	81 (74–90)	**<0.001**
HR x SAP	11319 (9577–13376)	9600 (8282–11067)	**<0.001**
HR:SAP ratio	0.46 (0.39–0.54)	0.85 (0.72–0.98)	**<0.001**
pH	7.42 (7.41–7.44)	7.39 (7.36–7.42)	**<0.001**
$PaCO_2$, mmHg	38 (35–40)	36 (33–39)	**<0.001**
PaO_2, mmHg	76 (68–85)	202 (138–271)	**<0.001**
HCO_3, mmol/L	25.0 (24.0–26.0)	23.0 (21.0–24.0)	**<0.001**
SBE, mmol/L	1.0 (-0.3 ; 2.0)	-2.0 (-3.0 ; –1.0)	**<0.001**
Hct, %	41.0 (38.0–45.0)	32.1 (29.0–36.0)	**<0.001**
Hb, g/dL	13.0 (12.0–14.1)	10.3 (9.1–12.0)	**<0.001**
Lactate, mmol/L	0.9 (0.7–1.0)	1.6 (1.3–2.0)	**<0.001**
Na, mmol/L	137 (135–139)	136 (134–137)	**<0.001**
Cl, mmol/L	107 (105–110)	111 (108–113)	**<0.001**
K, mmol/L	3.9 (3.7–4.1)	3.9 (3.6–4.1)	0.233
Ca, mmol/L	1.10 (1.10–1.19)	1.20 (1.10–1.30)	**<0.001**
Glucose, g/dL	105 (96–125)	144 (125–176)	**<0.001**
AG, mmol/L	5 (2–8)	3 (0–6)	**<0.001**
Osmolality, mOsm	280 (277–284)	280 (276–283)	0.188

ECC: Extracorporeal circulation; HR: Hearth rate; SAP: Systolic arterial pressure; DAP: Diastolic arterial pressure; MAP: Mean arterial pressure; $PaCO_2$: Arterial partial pressure of carbon dioxide; PaO_2: Arterial partial pressure of oxygen; HCO_3: Bicarbonate; SBE: Standard base-excess; Hct: Hematocrit; Hb: Hemoglobin; Na: Sodium; Cl: Confidence interval; K: Potassium; Ca: Calcium; AG: Anion gap.

High DP during exercise or in cardiac stress tests indicates that the heart is working harder, leading to higher oxygen consumption. In cardiac patients, high DP values are associated with a poor prognosis due to increased heart oxygen consumption and cardiac workload, which can lead to myocardial ischemia.[11] DP is effective in predicting the risk of cardiovascular disease and mortality in healthy populations.[12–14] In patients with acute coronary syndrome, high DP levels have been linked to increased morbidity.[15]

The Shock Index (SI) is also a parameter that combines more than one vital sign. It is formulated as 'SI=Heart Rate/Systolic Arterial Pressure.' Under normal conditions, this ratio should be less than 0.7.[16,17] As the ratio approaches 1, it indicates the presence of shock.[6] Higher SI ratios can help predict various health issues, particularly mortality in emergency room triage,[18] trauma patients,[19,20] and sepsis.[21]

Despite the clinical benefits of the above-mentioned parameters, they have limited predictive ability for microcirculation. The current approach focuses on monitoring tissue perfusion at the microcirculatory level. Evaluating microcirculation is crucial for specific patient groups, including hypertensive patients,[22] diabetic patients,[23] patients with congestive heart failure,[24] those undergoing long and bleeding operations,[25] and open-heart surgery patients with ECC.[9]

Plasma lactate elevation, known as hyperlactatemia, is monitored to assess microcirculation and may indicate inadequate tissue perfusion under certain clinical conditions.[7,8] While the relationship between macrocirculation and microcirculation is believed to be weakened, studies have shown a positive correlation between hemodynamic instability and serum lactate levels.[26] Persistent hyperlactatemia, despite resuscitation, is even more strongly associated with morbidity and mortality.[27,28] Research on critically ill patients has demonstrated that changes in hemodynamics can impact serum lactate levels, and even a slight increase in plasma lactate levels is linked to higher mortality.[29] An experimental study on volunteers found that the rate of lactate accumulation increased with higher acceleration during physical activity above the 'Lactate Threshold Level', which is the point at which anaerobic metabolism begins.[30]

This study aimed to demonstrate the relationship between plasma lactate and DP and plasma lactate and SI in patients undergoing open-heart surgery after the termination of ECC, the period when the macro-micro circulation relationship is disrupted. The study also aimed to investigate whether DP and SI parameters can indicate the adequacy of microcirculation.

As per the examination of the results, no significant relationship was found between plasma lactate level

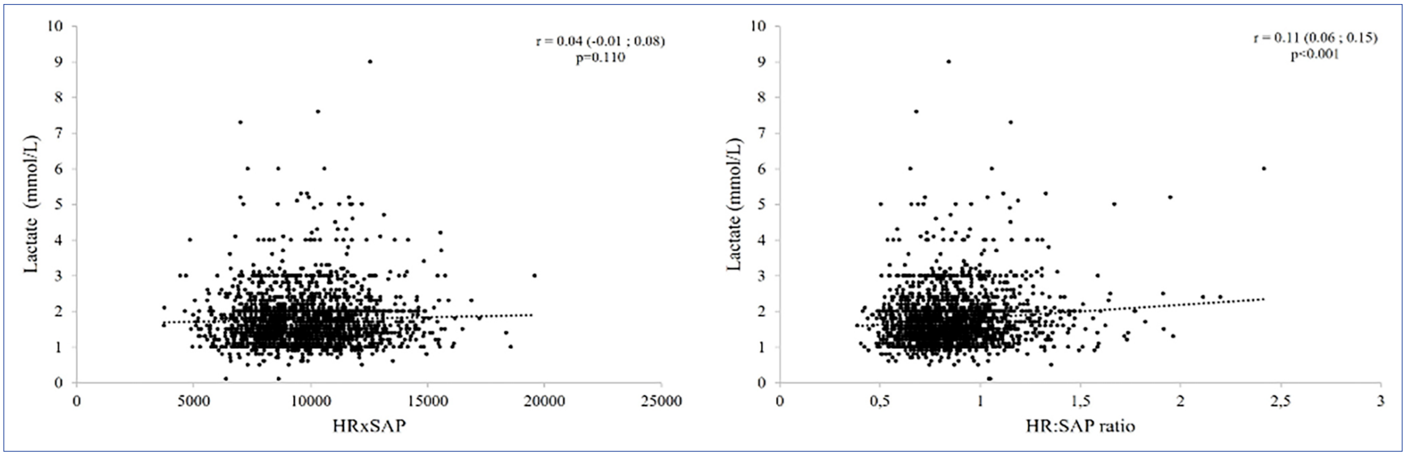

Figure 1. Correlations between HRxSAP, HR:SAP ratio and lactate levels in post-ECC periot.

HR: Hearth rate; SAP: Systolic arterial pressure; ECC: Extracorporeal circulation.

and DP (p=0.11, r=0.04 (-0.01;0.08)). However, a weak correlation was observed between plasma lactate and SI at the same time point (p<0.001, r=0.11 (0.06;0.15)) (Fig. 1).

In the subgroup analysis conducted with patients having a DP value >12000 in the post-ECC period, no significant correlation was found (p=0.643, r=0.03 (-0.09;0.14)) (Fig. 2).

Unfortunately, our data did not support our initial hypothesis that microcirculation would be worse in patients with high diastolic pressure (DP) compared to those with low DP and that there would be a significant relationship in this patient group. Upon examining the limitations of our study to understand the reason for this, we first considered that it was a retrospective data analysis study. Additionally, the low number of patients for subgroup analysis was another limitation. Although the upper limit for DP is 12000, higher DP values indicate a higher cardiac workload. In our study, even the highest DP value measured was below 20000, and there were only three patients with DP values above 18000. When we examined the high DP subgroup values, we found that DP in most patients accumulated just above the physiological limit, in the range of 12000–14000. Another possible reason for not finding a significant relationship could be that, as shown in Table 2, plasma lactate values ranged from 1.3 to 2.0 mmol/L in the post-ECC period and did not exceed 2 mmol/L in any patient.

Conclusion

The measurements of both DP and SI are essential indicators for macrocirculation. However, the results of this study showed that relying solely on vital parameters to assess macrocirculation or combining them using multipliers and ratios may not provide adequate information about microcirculation. Vital parameters do not reflect all circulatory disorders. Combining them using multipliers or ratios can obscure isolated changes in one variable with another. It would be more appropriate for critically ill patients to assess microcirculation directly using parameters such as plasma lactate. Therefore, further studies are necessary to evaluate microcirculation and develop independent parameters.

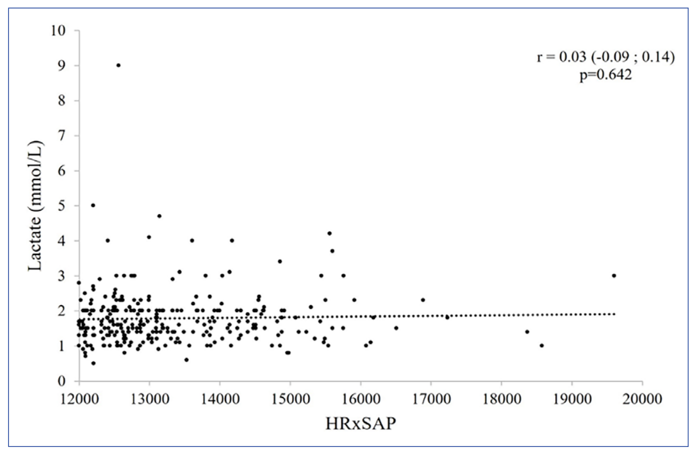

Figure 2. Correlations between HRxSAP and lactate levels in patients with HRxSAP >12000 in post-ECC period.

HR: Hearth rate; SAP: Systolic arterial pressure; ECC: Extracorporeal circulation.

Disclosures

Ethics Committee Approval: The study was approved by The Acıbadem Mehmet Ali Aydınlar University Ethics Committee (no: 2024-10/431, date: 18/07/2024).

Authorship Contributions: Concept – M.T., B.G., F.T.; Design – M.T., B.G., F.T.; Supervision – M.T., B.G., F.T.; Materials – F.T.; Data collection &/or processing – M.T., B.G.; Analysis and/or interpretation – B.G.; Literature search – M.T.; Writing – M.T., F.T.; Critical review – M.T., B.G., F.T.

Informed Consent: Written informed consent was obtained from all patients.

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