Prognostic value of brachioradialis muscle oxygen saturation index and vascular occlusion test in septic shock patients

J. Marin-Coral, L. Claverias, M. Bodí, S. Pascual, A. Dubin, J. Gea, A. Rodríguez

A Critical Care Department – Joan XXIII Hospital – ISPV-URV, Tarragona, Spain
b Respiratory Department – Hospital del Mar – IMIM. Department CEXS, UPF, Barcelona, Spain
c CIBERES (CIBER Enfermedades Respiratorias), ISC III, Bunyola, Palma de Mallorca, Spain
d Sanatorio Otamendi y Miroli, Servicio de Terapia Intensiva, Buenos Aires, Argentina
e Cátedra de Farmacología Aplicada, Facultad de Ciencias Médicas, Universidad Nacional de La Plata, La Plata, Argentina

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Abstract

Objectives: To compare rSO2 (muscle oxygen saturation index) static and dynamic variables obtained by NIRS (Near Infrared Spectroscopy) in brachioradialis muscle of septic shock patients and its prognostic implications.

Design: Prospective and observational study.

Setting: Intensive care unit.

Subjects: Septic shock patients and healthy volunteers.

Interventions: The probe of a NIRS device (INNOS 5100) was placed on the brachioradialis muscle during a vascular occlusion test (VOT).

Variables: Baseline, minimum and maximum rSO2 values, deoxygenation rate (DeOx), reoxygenation slope (ReOx) and delta value.

Results: Septic shock patients (n=35) had lower baseline rSO2 (63.8 ± 12.2 vs. 69.3 ± 3.3%, p < 0.05), slower DeOx (−0.54 ± 0.31 vs. −0.91 ± 0.35%/s, p = 0.001), slower ReOx (2.67 ± 2.17 vs. 9.46 ± 3.5%/s, p < 0.001) and lower delta (3.25 ± 7.1 vs. 15.1 ± 3.9%, p < 0.001) when compared to healthy subjects (n=20). Among septic shock patients, non-survivors showed lower baseline rSO2 (57.0 ± 9.6 vs. 69.8 ± 11.3%, p = 0.001), lower minimum rSO2 (36.0 ± 12.8 vs. 51.3 ± 14.8%, p < 0.01) and lower maximum rSO2 values (60.6 ± 10.6 vs. 73.3 ± 11.2%, p < 0.01). Baseline rSO2 was a good mortality predictor (AUC 0.79; 95%CI: 0.63–0.94, p < 0.01). Dynamic parameters obtained with VOT did not improve the results.
Conclusion: Septic shock patients present an important alteration of microcirculation that can be evaluated by NIRS with prognostic implications. Monitoring microvascular reactivity in the brachioradialis muscle using VOT with our device does not seem to improve the prognostic value of baseline rSO2.

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Introduction

Septic shock remains the most frequent cause of death in non-coronary intensive care units. It is characterized by hemodynamic alterations associated with organ dysfunction. Although systemic oxygen transport is usually preserved after the resuscitation of septic shock, multiorgan failure frequently develops as a probable consequence of an imbalance between oxygen delivery and consumption (DO2 and VO2) at tissue level. Microcirculatory dysfunction could be involved in this phenomenon.

The microcirculatory derangements caused by sepsis consist in decreased functional vascular density and heterogeneity of capillary transit-time. They may persist despite the normalization of systemic hemodynamics and oxygen transport in the large blood vessels, having relevant prognostic implications. It is well known that recovery of macrohemodynamic stability does not necessarily involve a parallel enhancement in microcirculation, organ function restoration, and a subsequent better prognosis. Therefore, some macrohaemodynamical markers such as blood pressure, cardiac output, and other systemic cardiovascular variables are not reliable predictors of the evolution of septic shock. In contrast, the assessment of oxygen release to the peripheral tissues would better reflect the microcirculation status.

However, peripheral oxygenation depends on many different factors including the ensemble of small vessels, local blood flow, hemoglobin content and oxygen partial pressure, among others. This complexity has meant that clinicians have not been able to assess the status of microcirculation and peripheral tissue oxygenation at the bedside until last years. Nevertheless, both can be easily approximated with Near Infrared Spectroscopy (NIRS) through...
determination of skeletal muscle oxygen tissue saturation (StO$_2$) or skeletal muscle oxygen saturation index (rSO$_2$) depending on the device used. StO$_2$ is a measure of oxygen saturation in the microcirculation where oxygen is exchanged with tissue and it is usually measured in the thenar eminence. On the other hand, rSO$_2$ ("regional") value is an index of the OxyHb present within a volume of tissue (expressed as the percentage of oxygenated hemoglobin relative to total) and it can be easily assessed in other locations.

In this regard, both have demonstrated its prognostic value in septic shock. In addition to simple determination of StO$_2$, several studies have evaluated the behavior of this variable during an ischemic challenge (vascular occlusion test, VOT) in septic shock patients. This test assesses the reactivity of small vessels and appears to improve the predictive ability of simple StO$_2$ determination.

We have previously showed the relevance of measuring rSO$_2$ at the brachioradialis muscle as an outcome predictor in septic shock. The behavior of skeletal brachioradialis rSO$_2$ in response to VOT and its relationship to mortality in such patients has not been assessed yet. We hypothesized that this test can further improve the predictive value of simple rSO$_2$ measurement in the brachioradialis muscle of septic shock patients at StO$_2$ in the thenar eminence. Accordingly, the aim of the present study was to compare the prognostic implications relate to mortality of rSO$_2$ static and dynamic variables in the brachioradialis muscle of septic shock patients.

Materials and methods

The investigation was conducted according to the principles outlined in the Declaration of Helsinki for studies in humans. The study protocol was approved by the Ethics Committee at our institution, and informed consent was given by each patient or their next of kin.

Study protocol

Patients were always enrolled within the first 24 h after the onset of severe sepsis, during an episode of septic shock. Information collected comprised: demographic characteristics including age and sex, the Acute Physiology and Chronic Health Evaluation (APACHE) II score, the Sequential Organ Failure Assessment (SOFA) score, the primary site and type of infection, as well as hemodynamic and respiratory variables including heart rate (HR), mean arterial pressure (MAP), temperature, arterial blood gases and acid–base balance, hemoglobin concentration, norepinephrine use and dose, mechanical ventilation and PaO$_2$/F$_{O_2}$.

All patients were treated with fluid resuscitation and norepinephrine to maintain MAP above 65 mm Hg (maximum dose, 2 $\mu$g/kg/min). Fluid resuscitation was administered by a fluid bolus challenge with crystalloids to increase stroke volume and/or allow the vasopressor doses to be decreased when required. In accordance with our local guidelines, each subject was monitored through the entire process. All the NIRS parameters were studied related to ICU mortality.

Measurements

Values of rSO$_2$ were obtained with updates every 6 s using a NIRS spectrometer (INVOS 5100C Oximeter and adult Somasensor model SAFB-SM, Somanetics Corporation, Troy, MI, USA), coupled to a skin surface probe. The probe was placed on the medial forearm, 5 cm distal to the elbow, in the brachioradialis muscle. To ensure the validity of measurements in septic shock patients, rSO$_2$ measurements were only performed when MAP > 60 mm Hg and the vasopressor infusion rate remained unchanged for at least the preceding 2 h.

Vascular occlusion test (VOT)

The VOT consisted in stopping the blood flow of the brachial artery by wrapping a sphygmomanometer cuff around the arm and inflating it until 200 mm Hg. Briefly, after the stabilization of the baseline NIRS signal (defined as a rSO$_2$ variation < 2% over 30 s), baseline rSO$_2$ was recorded (defined as the average of the three first values of rSO$_2$). Afterwards, arterial inflow was stopped. After 3 min of ischemia the cuff pressure was released and arterial blood flow returned. The rSO$_2$ signal was continuously recorded through the entire procedure and until the final signal stabilization. Only one vascular occlusion test was made in every subject and all the parameters were included without known the final patient outcome.

The parameters obtained during VOT were: (1) the deoxygenation rate (DeOx), which indicates the velocity of the rSO$_2$ decrease during the ischemia and is believed to reflect the status of the local aerobic metabolism including oxygen consumption in the NIRS-assessed area; (2) the reoxygenation rate, which is the velocity of the rSO$_2$ recovery following VOT, which would reflect the time required to wash out stagnant blood and it is thought to be determined by the reserve capacity and functionality of the microvascular system. In this regard we calculated the reperfusion rate in the first 12 s (slope 12 s) and in the entire reperfusion time...
Table 1  Demographics characteristics of the study groups. SOFA, sequential organ failure assessment; APACHE, acute physiology and chronic health evaluation.

<table>
<thead>
<tr>
<th></th>
<th>Septic shock (n = 35)</th>
<th>Survivors (n = 19)</th>
<th>Non-survivors (n = 16)</th>
<th>p*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>68 ± 11</td>
<td>64 ± 11</td>
<td>72 ± 10</td>
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</tr>
<tr>
<td>Gender</td>
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<td>17 (48.6)</td>
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<td></td>
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<tr>
<td>Female</td>
<td>18 (51.4)</td>
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<tr>
<td>Etiology</td>
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</tr>
<tr>
<td>Respiratory</td>
<td>9 (25.7)</td>
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<td>4</td>
<td></td>
</tr>
<tr>
<td>Urinary tract</td>
<td>5 (14.3)</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>8 (22.9)</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>SOFA</td>
<td>8 ± 3</td>
<td>7 ± 3</td>
<td>9 ± 2</td>
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</tr>
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<td>APACHE</td>
<td>21 ± 7</td>
<td>19 ± 7</td>
<td>24 ± 7</td>
<td>0.039</td>
</tr>
</tbody>
</table>

Data are shown as mean ± SD or n (%).                               
* Differences between survivors and non-survivors.

(ReOx); (3) the difference (delta) between the baseline rSO2 and its maximum value during the hyperemic phase. This variable would represent the tissue’s ability to regulate local blood flow and oxygenation; (4) the lowest rSO2 value at the end of the ischemic period; and (5) the highest rSO2 value during the reperfusion phase.

Statistical analysis

Sample size was calculated based on previous study.17 It was estimated that the rSO2 standard deviation between the survivors and non-survivors septic shock patients would be 8.5%, and a 50% of mortality was assumed. With a statistical power of 80% and an alpha error of 0.05, at least 16 patients would be needed in both survivors and non-survivors groups, to detect a difference of 1 standard deviation, considered as the lowest clinical relevance. A descriptive analysis was performed. Normal distribution of the studied variables was confirmed using the Kolmogorov–Smirnov test. Discrete variables were expressed as counts (percentage) and continuous variables as mean ± standard deviation (SD) or median (25th–75th percentiles) as appropriate. Differences between groups were assessed using a Fisher’s exact test and Student’s t-test, Mann–Whitney U-test and Chi-square test, as appropriate. The signal slopes were determined by linear regression analysis. Pearson’s correlation coefficient was used to assess the association between rSO2 and VOT with other variables.

The predictive value of the baseline rSO2 and slopes were calculated using a receiver operator characteristic curve (ROC), and the area under the curve (AUC) was also computed. A p < 0.05 was considered significant. Data were analyzed using the SPSS Statistics package 20 version (IBM, Armonk, NY, USA).

Results

Thirty-five patients with septic shock (68 ± 11 years of age, 48.6% males) and twenty healthy volunteers (55 ± 8 years of age, 45% males) were finally included. Only three patients were not included because exclusion criteria: two patients with diabetes requiring insulin therapy and one patient with chronic renal insufficiency requiring hemodialysis. The main characteristics of patients are shown in Tables 1 and 2. Abdomen was the most common source of infection (37.1%), followed by community-acquired pneumonia (25.7%), urinary tract infections (14.3%) and others. Even though the differences did not reach statistical significance, non-survivors had more tachycardia, hyperlactatemia, acidosis and norepinephrine dosing compared with survivors.

NIRS measurements

The main results obtained with NIRS are shown in Fig. 1. Briefly, septic shock patients showed lower baseline rSO2 compared with healthy controls (63.8 ± 12.2 vs. 69.3 ± 3.3%, p < 0.05). Moreover, the DeOx obtained in the ischemic phase and the ReOx slopes obtained in the reperfusion phase (total ReOx and at 12s) were slower in septic shock patients (−0.54 ± 0.31 vs. −0.91 ± 0.35%/s, p = 0.001; 2.67 ± 2.17 vs. 9.46 ± 3.5%/s, p < 0.001; and 3.64 ± 3.32 vs. 13.15 ± 6.07%/s, p < 0.001). The same accounted for the delta value (3.25 ± 5.71 vs. 15.1 ± 3.9%, p < 0.001) being the maximum rSO2 post-reperfusion greater in the control group (67.48 ± 12.55 vs. 84.45 ± 3.92, p < 0.001). No differences were found in the minimum rSO2 between groups.

We just observed significant correlation between the SOFA score at ICU admission and DeOx slope at 12 s (−0.369, p = 0.034). No other correlations with significant values were observed.

Survivors vs. non-survivors

The ICU mortality in septic shock patients was 46%, and the comparison between values obtained with NIRS in survivors and non-survivors is shown in Table 3. It is worth noting that baseline rSO2 was significantly greater in the former group. Minimum rSO2 and maximum rSO2 post-reperfusion were lower in non-survivors. There were no differences in
Table 2  Clinical characteristics of the study groups. MAP, mean arterial pressure; NE, norepinephrine; PaO₂; partial pressure of oxygen in arterial blood; PaCO₂, partial pressure of carbon dioxide in arterial blood; BD, base deficit.

|                      | Septic shock (n = 35) | Survivors (n = 19) | Non-survivors (n = 16) | p*  
|----------------------|------------------------|--------------------|------------------------|-----
| Temperature (°C)     | 36.0 ± 0.9             | 36.2 ± 0.6         | 35.8 ± 1.2             | 0.371  
| MAP (mm Hg)          | 71 ± 11                | 73 ± 10            | 70 ± 12                | 0.423  
| Heart rate (beats/min) | 97 ± 20               | 94 ± 20            | 101 ± 21               | 0.325  
| NE use               | 35 (100)               | 19 (100)           | 16 (100)               |       
| NE dose (μg/kg/min)  | 0.72 ± 0.63            | 0.56 ± 0.49        | 0.90 ± 0.74            | 0.134  
| Hemoglobin (g/dL)    | 10.2 ± 2.4             | 10.3 ± 1.9         | 10.0 ± 2.9             | 0.784  
| Lactate (mmol/L)     | 1.9 (1.4–4.6)          | 1.7 (1.3–3.9)      | 2.8 (1.7–7.2)          | 0.075  
| Mechanical ventilation| 25 (43.1)             | 14 (56)            | 11 (44)                | 0.062  
| PaO₂/FiO₂ (n = 25)   | 307.88 ± 143.54        | 339.08 ± 155.02    | 274.09 ± 127.82        | 0.263  
| pH                   | 7.31 ± 0.11            | 7.33 ± 0.06        | 7.27 ± 0.14            | 0.329  
| PaO₂ (mm Hg)         | 107 ± 46               | 115 ± 54           | 98 ± 33                | 0.302  
| PaCO₂ (mm Hg)        | 39 ± 14                | 40 ± 17            | 38 ± 9                 | 0.796  
| Bicarbonate (mmol/L) | 19 ± 5                 | 19 ± 4             | 18 ± 5                 | 0.517  

Data are shown as mean ± SD, median (IR) or n (%).

* Differences between survivors and non-survivors.

Figure 1  rSO₂ curve variables in septic shock patients (n = 35) and healthy volunteers (n = 20). (a) Baseline rSO₂; (b) maximum rSO₂ during the reperfusion; (c) deoxygenation rate; (d) reoxygenation rate; (e) slope in the firsts 12 s; (f) difference between baseline rSO₂ and its maximum value.

Table 3  rSO₂ curve variables in survivors (n = 19) and non-survivors (n = 16). Minimum rSO₂, minimum rSO₂ post-ischemia; Maximum rSO₂, maximum rSO₂ during the reperfusion; DeOx, deoxygenation rate; ReOx, reoxygenation rate; Slope 12 s, slope in the firsts 12 s; Delta rSO₂, difference between baseline rSO₂ and its maximum value.

|                    | Healthy volunteers (n = 20) | Survivors (n = 19) | Non-survivors (n = 16) | p*  
|--------------------|-----------------------------|--------------------|------------------------|-----
| Baseline rSO₂ (%)  | 69.35 ± 3.36                | 69.83 ± 11.33      | 57.06 ± 9.65           | 0.001  
| Minimum rSO₂ (%)   | 41.55 ± 8.89                | 51.31 ± 14.83      | 36.06 ± 12.87          | 0.003  
| Maximum rSO₂ (%)   | 84.45 ± 3.92                | 73.26 ± 11.27      | 60.62 ± 10.60          | 0.002  
| DeOx (%/s)         | −0.91 ± 0.35                | −0.48 ± 0.25       | −0.62 ± 0.37           | 0.211  
| ReOx (%/s)         | 9.46 ± 3.50                 | 2.56 ± 2.11        | 2.8 ± 2.31             | 0.760  
| Slope 12 s (%/s)   | 13.15 ± 6.07                | 4.10 ± 3.66        | 3.09 ± 2.88            | 0.777  
| Delta rSO₂         | 15.10 ± 3.90                | 3.00 ± 5.74        | 3.56 ± 5.85            | 0.368  

Data are shown as mean ± SD.

* Differences between survivors and non-survivors.
any of the slopes neither in the delta value between two groups.

Finally, the baseline rSO₂ ROC curve confirmed a good discriminatory power for mortality (Table 4). In contrast, none of the dynamic parameters obtained with the VOT showed a significant AUC value (Table 3). The baseline rSO₂ cutoff value of 60% showed a sensitivity of 83%.

Discussion

The study suggests that among septic shock patients, baseline rSO₂ differed between survivors and non-survivors and was able to predict mortality. On the contrary and against our hypothesis, dynamic variables obtained with our device did not differ between survivors and non-survivors. To our knowledge this prospective study is the first to assess the microcirculatory dysfunction in this muscle after an ischemic challenge and to study its association with mortality.

Although NIRS rSO₂ is a measure of muscle tissue oxygenation and not a direct marker of microcirculatory perfusion, it permits the quantification of the microcirculatory dysfunction. NIRS during a VOT might give additional information about local VO₂, reactive hyperemia, and microcirculation recruitment and it seems to be sensitive to the progress and outcome of sepsis in clinical illness. Several studies have assessed the microvascular reactivity in the thenar eminence in sepsis with other NIRS devices. Most of them found differences in the baseline StO₂ between septic patients and healthy volunteers. In this sense, Leone et al. found that StO₂ static values were significantly lower in the non-survivors than in survivors septic shock patients. In contrast, some of them did not show differences between both groups. However, in these studies dynamic NIRS improved the discrimination power between normal and abnormal states of microcirculation. Furthermore, a recent meta-analysis that included twenty articles dealing with the prognostic implications of StO₂, showed that the static value is lower in septic patients than in control subjects. Our group have recently demonstrated that in septic shock throughout the first 24h after ICU admission, the patients with brachioradialis skeletal muscle rSO₂ < 60% had significantly greater mortality than patients with rSO₂ > 60% in the same location. Accordingly to these data, in the present study we confirm that brachioradialis baseline rSO₂ is a good prognostic predictor in this group of patients and that the cut-off value of 60% presents a good sensitivity for mortality prediction. Furthermore, in this study we improved the methodology of our previous work using a dynamic test.

Most of the studies that analyze the association between static and dynamic NIRS variables and mortality in septic shock patients were conducted in the thenar eminence with other NIRS devices. In one hand, in these studies static thenar StO₂ was variably reported as associated or not associated with mortality. On the other hand, some of these studies demonstrated that the recovery slope outperformed the other NIRS-derived variables because it was more strongly associated with organ dysfunction and mortality.

In this sense, Creteur et al. showed a significant association between a reduced reperfusion slope after VOT and mortality in septic shock patients while there were no differences in the static parameters between patients and control subjects neither in mortality. Payen et al. also showed a depressed reperfusion slope in non-survivors septic shock patients compared with survivors with a significant ROC curve for the prediction of mortality. They also showed a lower static StO₂ in patients than in healthy subjects but without any difference between survivors and non-survivors. In the same way, Shapiro et al. observed that baseline StO₂ did not discriminate between septic shock patients and control subjects, while the deoxygenation and recovery slope distinguished them. Non-survivors presented slower slopes than survivors with a relevant ROC curve.

Mesquida et al. also reported that in a population of septic shock patients impaired DeOx was associated with no improvement in organ failures after 24h. They did not found differences in baseline StO₂ between SOFA improvers and SOFA non-improvers patients.

Finally, Neto et al. in the meta-analysis above mentioned, concluded that static StO₂ distinguish between survivors and non-survivors septic shock patients, just like reoxygenation slope.

More recently, different groups have evaluated the microcirculation by NIRS in other locations in order to find better anatomic sites with different results. Alt-Oufella et al. evaluated the prognostic value of StO₂ measured around the knee in septic shock patients and compared it with thenar eminence StO₂. They concluded that after initial septic shock resuscitation, StO₂ measured around the knee is a strong predictive factor of 14-day mortality. In the same way, Colin et al. demonstrated that masseter and deltoid StO₂, but not thenar StO₂ were strong predictors of 28-day mortality.

We recently have assessed and compared rSO₂ obtained simultaneously in two different muscles, brachioradialis and deltoid. Our results showed that both measurements present a strong correlation and adequate consistency and both muscles also showed consistent discriminatory power for mortality.

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Discriminative power of rSO₂ and other VOT-derived variables relate to mortality in septic shock patients.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area under the ROC curve</td>
<td>95% Confidence intervals</td>
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<tr>
<td>Baseline rSO₂</td>
<td>0.790</td>
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<tr>
<td>DeOx</td>
<td>0.641</td>
</tr>
<tr>
<td>ReOx</td>
<td>0.477</td>
</tr>
<tr>
<td>Slope 12 s</td>
<td>0.577</td>
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<tr>
<td>Delta rSO₂</td>
<td>0.452</td>
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</table>
Our present results are in accordance with these data, showing that static rSO2 measurements in the brachioradialis muscle are good predictors of mortality. Although some articles showed that dynamic tests improve the prognostic value of the static parameters in the thanar eminence, our results show that VOT test in brachioradialis muscle of septic shock patients is not better to assess the microcirculatory alterations. Static NIRS data in this location is easier to obtain and better mortality predictor than dynamic parameters. However, it has to be taken into account that the studies without differences in dynamic tests between survivors and non-survivors included a small sample size. Future studies with a large number of patients will be necessary to elucidate this debate.

Although skeletal muscle StO2 may be equivalent to rSO2, they are obtained with different devices and the values are calculated with different algorithms. For this reason it is difficult to compare both parameters between them. However, further studies will be necessary to compare the prognostic value of the static NIRS measurements in the thanar eminence and in the other muscles. Muscle myofiber composition, oxygen consumption and metabolism may differ between these muscles and it may contribute to these differences. In addition, thanar muscle may be more influenced by abnormal peripheral perfusion than the other territories,32 a major confounder in assessing StO2.33

In other way and in contrast with the reported in the literature, we did not found differences in SOFA Score at admission between survivors and non-survivors due to the small sample size. Even though some differences did not reach statistical significance, non-survivors patients had more tachycardia, hyperlactatemia and norepinephrine dosing. These results are in accordance with Edul et al.35 who recently demonstrated the association of microcirculatory alterations with these three variables in septic shock patients.

This study and the NIRS technology have some limitations that should be taken into account. First of all, the methodologies for assessing the microcirculation by NIRS are very inconsistent in the literature, and consequently, results vary from study to study, making data comparison difficult and potentially inadequate. Two major aspects concerning the inconsistent methodology are measurement site and probe spacing. The measurement site is important because differences may exist in the sensitivity of muscle groups and/or other anatomical structures to the VOT during health and/or pathophysiological conditions. Probe spacing, on the other hand, will determine the depth of measurement within the respective muscle group. To address these issues, Bezemer et al.36 demonstrated in healthy subjects that although not apparent at baseline, the probe spacing and measurement site significantly influenced VOT-derived StO2 variables. In addition, the optimal way of performing VOT is a matter of debate.37,38 Second, we have assessed microvascular dysfunction within the firsts 24h of the septic shock diagnosis, but the time of measurement also varies between the different studies and it could be a confounding factor. Further studies will be necessary to check the utility of NIRS parameters along the time and their changes with the treatment. Third, to our knowledge, this is the first study that evaluates every NIRS-derived variable in the brachioradialis muscle. Although increased thickness of the subcutaneous layer due to edema may reduce the muscle layer assessed, this was not a major problem in our study, since the tissue edema was an exclusion criteria. In any case, we evaluated the NIRS variables in the early phase of septic shock before the development of significant edema.

We conclude that baseline rSO2 obtained at the brahioradialis muscle is a good predictor of mortality in septic shock. In our population, VOT-derived variables in this muscle does not seem to improve the prognostic value of the static parameters. Future studies will be necessary to confirm our results and to evaluate the usefulness of these parameters to evaluate the microcirculatory response to treatment.

Conflicts of interest

None.

Acknowledgments

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References

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