Forearm and Calf Tissue Oxygenation in Term Neonates
Measured with Near-Infrared Spectroscopy

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Abstract: Peripheral tissue oxygenation has been studied with near-infrared spectroscopy (NIRS) on either the forearm or calf with questionable comparability. The aim was to compare forearm and calf tissue oxygenation in healthy term neonates measured with NIRS. Fractional oxygen extraction, tissue oxygenation index, and mixed venous oxygenation were similar in both extremities, whereas oxygen delivery and oxygen consumption of calf tissue were higher.

Key words: near-infrared, peripheral, forearm, calf.

Near-infrared spectroscopy (NIRS) in combination with venous occlusion enables the measurement of peripheral tissue oxygenation and perfusion [1–5]. Studies of neonates were performed on either forearm [1–4] or calf [5] and reported rather different results. The influence of these different locations of measurements, i.e., forearm versus calf, on these results remains unclear.

Therefore the aim of the present study was to make these measurements with NIRS and the venous occlusion method in both locations in the same neonate to compare oxygen delivery (DO₂), oxygen consumption (VO₂), fractional oxygen extraction (FOE), tissue oxygenation index (TOI), and mixed venous oxygenation (SvO₂) of the forearm tissue and the calf tissue.

Methods
NIRS measurements (NIRO 300, Hamamatsu Photonics, Japan) and venous occlusions were carried out on 20 healthy term neonates without any pathological cardiocirculatory or respiratory signs within the first 3 days of life. The local ethical committee approved the study, and informed consent was obtained from the parents.

Measurements were performed during supine sleep, after feeding and a 3-min rest period without body movements. The NIRS optodes were placed over the left forearm and the left calf with a distance of 3.5 cm between the light source and the detector. Each measurement consisted of at least three venous occlusions lasting 20 s without movement obtained with a pneumatic cuff placed around the upper arm and one around the thigh. Between measurements on the forearm tissue and the calf tissue there was a rest period of 5 min. The order of forearm and calf was randomized.

Heart rate and oxygen saturation (SaO₂) were measured by pulse oximetry on the wrist and the ankle. The central and peripheral temperatures of forearm and calf were measured continuously. Mean arterial pressure (MAP) was measured before and after venous occlusions.

NIRS measures any change in oxygenated hemoglobin, deoxygenated hemoglobin, total hemoglobin, and TOI. Hb flow/min was calculated from the linear increase of total hemoglobin within the 20 s of venous occlusion. Further parameters were calculated as follows: DO₂ = Hb flow × 4 × SaO₂; VO₂ = Hb flow × 4 × (SaO₂ – SvO₂); whereby the SvO₂ was oxygenated hemoglobin/total hemoglobin; FOE = VO₂/DO₂.

DO₂, VO₂, FOE, TOI, and SvO₂ for each neonate were determined as mean values of the three venous occlusions in each measurement. Data of the forearm and calf were compared by a paired t-test. DO₂, VO₂, FOE, TOI, and SvO₂ were correlated to circumferences by linear regression analysis. The differences of DO₂ and VO₂ were analysed according to Bland and Altman, and the data are represented as mean ± SD.

Results
The 20 healthy term neonates had a gestational age of 39.5 ± 0.69 weeks, birth weight of 3,480 ± 309 g, actual weight of 3,341 ± 317 g, postnatal age of 38.7 ± 27.0 h, and Apgar scores of 1/9 to 5/10. The male-to-female ratio was 10/10.
Table 1. Details of 20 healthy neonates.

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Forearm</th>
<th>Calf</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference (cm)</td>
<td>9.3 ± 0.7</td>
<td>11.8 ± 0.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mean arterial pressure (mmHg)</td>
<td>54.6 ± 5.9</td>
<td>54.6 ± 5.9</td>
<td>ns</td>
</tr>
<tr>
<td>Heart rate (min⁻¹)</td>
<td>115 ± 14</td>
<td>115 ± 14</td>
<td>ns</td>
</tr>
<tr>
<td>Arterial oxygen saturation (%)</td>
<td>96.4 ± 1.4</td>
<td>96.7 ± 1.5</td>
<td>ns</td>
</tr>
<tr>
<td>Temperature rectal (°C)</td>
<td>36.9 ± 0.3</td>
<td>36.9 ± 0.3</td>
<td>ns</td>
</tr>
<tr>
<td>Temperature peripheral (°C)</td>
<td>34.1 ± 1.1</td>
<td>34.5 ± 0.7</td>
<td>ns</td>
</tr>
</tbody>
</table>

Table 2. Forearm and calf oxygenation in 20 healthy term infants.

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Forearm</th>
<th>Calf</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen delivery (DO2) (µM/100 ml/min)</td>
<td>25.6 ± 7.5</td>
<td>32.8 ± 9.7</td>
<td>0.0027</td>
</tr>
<tr>
<td>Oxygen consumption (VO2) (µM/100 ml/min)</td>
<td>7.9 ± 2.1</td>
<td>9.7 ± 2.2</td>
<td>0.0044</td>
</tr>
<tr>
<td>Fractional oxygen extraction (FOE)</td>
<td>0.32 ± 0.07</td>
<td>0.32 ± 0.07</td>
<td>ns</td>
</tr>
<tr>
<td>Mixed venous oxygenation (SvO2)</td>
<td>0.66 ± 0.07</td>
<td>0.66 ± 0.07</td>
<td>ns</td>
</tr>
<tr>
<td>Tissue oxygenation index (TOI) (%)</td>
<td>63.9 ± 4.9</td>
<td>63.8 ± 11.7</td>
<td>ns</td>
</tr>
</tbody>
</table>


Table 1 summarizes descriptive data. Only the forearm and calf circumferences were significantly different.

Table 2 summarizes the data of NIRS measurements. There were no differences of FOE, TOI, and SvO2 between forearm and calf. The DO2 and VO2 of calf were significantly higher compared to the DO2 and VO2 of forearm.

The FOE, TOI, and SvO2 of forearm and calf did not correlate significantly with circumferences. DO2 increased with increasing circumference, and correlation was weak but significant ($r = 0.37$, $p = 0.02$). VO2 tended to increase with increasing circumference, but correlation did not reach significance.

Figures 1 and 2 illustrate the differences (Bland and Altmann) of DO2 and VO2 between the forearm tissue and calf tissue.

Discussion

The present study is the first that compared forearm and calf oxygenation measured by NIRS and the venous occlusion method in healthy term neonates. The main finding was that FOE, TOI, and SvO2 of forearm tissue and calf tissue were similar.

The DO2 and VO2 of calf tissue were higher than the DO2 and VO2 of forearm tissue, whereby a Bland-Altmann analysis of these differences in DO2 and VO2 illustrated wide ranges. The similar FOE, TOI, and SvO2 in both limbs suggest a similar tissue composition of both limbs. Therefore the differences of DO2 and VO2 seem to be due to the increasing limb size and not to different tissue compositions of both limbs. With the present study design, however, the influence of limb size and tissue composition cannot be differentiated clearly.

The observed differences of forearm and calf in the present study are one reason for the difficulty in compar-
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ing different studies. Other reasons are technical differences, e.g., different devices [1]; different patient groups; term infants [1, 2, 5] and preterm infants [3, 4]; different measurement protocols; and different methods of analysis. In the present study, measurements were performed after a 3-min rest period. This makes comparisons to recent studies difficult, where the period and level of activity before and during measurements are not clearly defined [1, 3–5]. Furthermore, the periods of linear changes during venous occlusion were analyzed to exclude artefacts. This makes comparisons to recent studies difficult, where the first seconds after venous occlusion were analyzed [3, 5]. With the present study we were able to show that a comparison of forearm and calf FOE, TOI, and SvO2 is possible. However, we should be aware of differences in DO2 and VO2 of forearm and calf, whereby the influence of circumference and tissue composition should be of interest in further investigations.

REFERENCES