Tissue oxygen saturation levels from fetus to neonate

Mari Mukai¹, Toshiyuki Uchida¹, Hiroaki Itoh¹, Hikaru Suzuki², Masatsugu Niwayama³,⁴ and Naohiro Kanayama¹

¹Department of Obstetrics and Gynecology, Hamamatsu University School of Medicine, Hamamatsu Shizuoka, ²ASTEM, Kawasaki, Kanagawa, and ³Department of Electrical and Electronics Engineering and ⁴Research Institute of Electronics, Shizuoka University, Shizuoka, Japan

Abstract

Aim: Oxygen saturation during the term of delivery to the first cry, when fetal circulation dynamically changes, has not yet been examined. The aim of this study was therefore to determine whether the continuous measurement of regional tissue oxygen saturation (rSO2) from crowning until 5 min after delivery is possible using fetal tissue oximetry with a sensor attached to the examiner’s finger.

Methods: Oxygen saturation levels in fetal cranial tissue between the second stage of delivery to crowning and up to 5 min after delivery were measured using fetal tissue oximetry with a sensor attached to the examiner’s finger. Thirty-five deliveries were examined, and oxygen saturation was measured in seven infants from delivery of the head until 5 min after birth. Umbilical cord blood gas was measured in all cases. This clinical test was performed under the permission of the Ethics Committee of Hamamatsu University School of Medicine.

Results: Average tissue oxygen saturation in the second stage of delivery and at 5 min after delivery were 50.3 ± 16.3% and 56.8 ± 8.46%, respectively. In cases of continuous measurement, average rSO2 for crowning, immediately after delivery, and the first cry was 32.7 ± 9.5%, 30.0 ± 6.6%, and 31.6 ± 5.5%, respectively.

Conclusion: We herein successfully measured oxygen saturation levels in fetal cranial tissue during crowning, delivery of the head, the first cry, and 5 min after delivery using fetal tissue oximetry with a sensor attached to the examiner’s finger.

Key words: fetal tissue oximetry, fetal tissue oxygen saturation, near-infrared spectroscopy, newborn, parturition.

Introduction

Approximately 10% of neonates require some assistance to begin breathing at birth, with <1% needing extensive resuscitation.¹,² Prompt diagnosis and treatment are essential for fetuses with severe neonatal asphyxia and fetal hypoxic encephalopathy. Apgar score is currently the most common method used to evaluate the condition of newborns at birth. Although Apgar score is simple and easily available, its accuracy for neonatal asphyxia is limited because it depends on the examiner’s decision. The guidelines of the International Liaison Committee on Resuscitation (ILCOR), European Resuscitation Council (ERC), and American Heart Association (AHA) recommend that assessments of ventilation or supplementary oxygen be based on three vital characteristics: heart rate; respiration; and oxygen saturation.¹³–⁵ Pulse oximetry (in the assessment of arterial blood oxygen saturation), however, has sometimes been normal even in the case of cerebral hypoxia–ischemia, indicating that it does not show the brain condition of perfusion resulting from hypoxic encephalopathy or metabolic changes. Therefore, the development of a measurement method that evaluates hypoxia at the tissue level and measures oxygen saturation immediately after birth is needed.

Previous studies measured oxygen dynamics using a pulse oximetry probe applied to the fetal head.⁶–⁸
Furthermore, in some studies the fetal oximetry measurements were collected using an intravaginal probe with near-infrared spectroscopy (NIRS)\(^9,10\). Oxygen saturation in newborn infants transitioning from intrauterine to extrauterine life, however, has not yet been investigated.

We recently developed a NIRS monitoring device, which is used by attaching a sensor to the examiner’s finger, in order to measure fetal oxygen dynamics during delivery.\(^11,12\) It enables quick measurements of regional tissue oxygen saturation (rSO2) in areas touched by the examiner’s finger. This rSO2 reflects approximately 50% of the scalp and 50% of the brain. We evaluated the potential of this device to perform non-invasive and prompt assessment of the fetal brain oxygen condition, and oxygenation monitoring, by measuring fetal cranial tissue oxygenation saturation as well as its ability to clarify fetal brain oxygen dynamics after delivery.

**Methods**

**Probe**

A probe that non-invasively measures tissue oxygen saturation in blood using spatially resolved NIRS, with wavelengths 770 nm and 830 nm, was used in the present study (KN-15; ASTEM, Kawasaki, Japan). The sensor probe was attached to the examiner’s finger. Light receivers were located 6 mm and 8 mm from the light emitter (LED). The receivers enable to determine the absolute value of hemoglobin concentration and tissue oxygen saturation, at approximately 5 mm below the body surface (Fig. 1a).

The positioning of the probe on the examiner’s finger enabled the measurement of regional tissue oxygen saturation non-invasively and immediately by touching the target region with the finger.

**Participants**

We recruited pregnant women who had normal vaginal deliveries at the Perinatal Center, Hamamatsu University School of Medicine. The inclusion criteria were as follows: delivery after 37 weeks 0 days of gestation; no fetal malformations or maternal complications before delivery; and measurement possible for >10 min before delivery.

Written informed consent was acquired from all pregnant women with the approval of the Ethics Committee of Hamamatsu University School of Medicine.

**Measurement protocol**

Measurements of fetal forehead tissue oxygen saturation were performed in the second stage of labor >10 min before delivery and 1, 3, and 5 min after delivery (Fig. 1b). Measurements were taken for at least 30 s until the value become stable.

Continuous monitoring was performed from crowning to 5 min after delivery in seven of the 35 subjects.

**Statistical analysis**

Data are expressed as mean ± SD. The significance of differences between two means was assessed using the Steel–Dwass test, where appropriate. \( P < 0.05 \) was regarded as significant.
Approval

The Ethics Committee of the Hamamatsu University School of Medicine approved all the procedures of this study (Registration no., 19–048).

Results

We examined 35 normal vaginal deliveries in the Perinatal Center in Hamamatsu University School of Medicine between July and September, 2015.

The average age of the mothers and gestational age were 31.3 ± 5.5 years and 39.3 ± 1.2 weeks, respectively. Twenty-two mothers were primipara (62.9%). Average umbilical cord arterial pH was 7.297 ± 0.09 (Table 1).

Average fetal cranial tissue oxygen saturation during the second stage of delivery, 1 min after delivery, 3 min after delivery, and 5 min after delivery were 50.3 ± 16.3%, 50.6 ± 10.5%, 54.4 ± 8.4%, and 56.8 ± 8.4%, respectively. Tissue oxygen saturation increased with time after delivery. Moreover, in most cases, tissue saturation reached a plateau 5 min after delivery. In eight cases, continuous monitoring was performed from crowning until 5 min after delivery. In these cases, oxygen saturation decreased the most between after delivery and the first cry (Table 2).

A gradual increase in tissue oxygen saturation from the first cry to several min after delivery was the dominant pattern (Fig. 2a). In these cases, fetal breath condition was relatively good after delivery. In contrast, one infant had nasal flaring 3 min after delivery. Oxygen saturation varied between 30 and 40%. When the newborn started grunting, it was diagnosed with transient tachypnea, and moved to the neonatal intensive care unit (Fig. 2b). In this case, continuous positive airway pressure was started 3 min after delivery and oxygen was given. On pulse oximetry, oxygen saturation varied between 85 and 89%. Umbilical cord arterial pH, Apgar score at 1 min, and Apgar score at 3 min were 7.227, 8, and 8, respectively. In this case, variable deceleration was detected during labor and the mother was given oxygen. While postnatal Apgar score and umbilical blood arterial pH was normal, this infant developed respiratory disorder after birth. Compared with normal infants, in this infant the increase in postnatal tissue oxygen saturation was slow.

Discussion

In the present study, we successfully measured fetal cerebral tissue oxygen saturation during crowning and the first cry using tissue oximetry with a sensor attached to the examiner’s finger. A previous study measured fetal cerebral tissue oxygen saturation 2 min after delivery, while two previous studies examined cerebral oxygen saturation in the first minutes of life using NIRS. In the present study fetal cerebral tissue oxygen saturation decreased the most during the appearance of the head to the first cry. Neonatal cerebral tissue oxygen saturation is lowest at crowing and at the first cry. It is thought that this change is caused by the transient anoxia in the interval between the shift from oxygenation with the umbilical blood to pulmonary respiration.

The time at which tissue oxygen saturation reached a plateau after delivery varied among fetuses. In most infants with continuous monitoring, tissue oxygen saturation reached >50% within 5 min of delivery, whereas that in the infant with respiratory disorder was 40–50%. The difference in time to reach a plateau in

Table 1 Subject characteristics

<table>
<thead>
<tr>
<th>Maternal age (years)</th>
<th>31.3 ± 5.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parity (n)</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>22</td>
</tr>
<tr>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>≥3</td>
<td>1</td>
</tr>
<tr>
<td>Gestational weeks</td>
<td>39.3 ± 1.2</td>
</tr>
<tr>
<td>Birthweight (g)</td>
<td>3076 ± 364</td>
</tr>
<tr>
<td>Umbilical artery pH</td>
<td>7.297 ± 0.071</td>
</tr>
<tr>
<td>Apgar score</td>
<td></td>
</tr>
<tr>
<td>1 min</td>
<td>8 (5–10)</td>
</tr>
<tr>
<td>5 min</td>
<td>9 (7–10)</td>
</tr>
</tbody>
</table>

rSO2 (%)

Table 2 rSO2 of the head (mean ± SD)

<table>
<thead>
<tr>
<th>rSO2 (%)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Second stage of labor (n = 35)</td>
<td>50.3 ± 16.3</td>
</tr>
<tr>
<td>Crowning (n = 7)</td>
<td>32.7 ± 9.5</td>
</tr>
<tr>
<td>Immediately after birth (n = 6)</td>
<td>30.0 ± 6.6</td>
</tr>
<tr>
<td>After the first cry (n = 5)</td>
<td>31.6 ± 5.5</td>
</tr>
<tr>
<td>After delivery</td>
<td></td>
</tr>
<tr>
<td>1 min (n = 35)</td>
<td>50.6 ± 10.5</td>
</tr>
<tr>
<td>3 min (n = 35)</td>
<td>54.4 ± 8.4</td>
</tr>
<tr>
<td>5 min (n = 35)</td>
<td>56.8 ± 8.4</td>
</tr>
</tbody>
</table>

rSO2, regional tissue oxygen saturation.
tissue oxygen saturation may become a new index for evaluating fetal tissue oxygen saturation.

We examined cerebral tissue oxygen saturation of the fetus from the second stage of labor to 5 min after birth continuously with fetal tissue oximetry, using a sensor attached to the examiner’s finger. Using this oximeter it would be possible to measure tissue oxygen saturation in cases of severe neonatal asphyxia, in which oxygen saturation measurements have previously been considered difficult, and, hence, hypoxia states may now be able to be quickly evaluated.

The limitations of the present study were as follows: data were collected in only 35 cases; premature infants, patients with maternal complications, and infants with intrauterine growth retardation were excluded. Fetal condition prior to delivery has been strongly associated with poor oxygenation after delivery. Therefore, more data are needed on fetal brain tissue oxygen saturation in cases of non-reassuring fetal state, intrauterine infection with maternal fever, and intrauterine fetal growth restriction. Moreover, an efficient and non-invasive evaluation of fetal tissue oxygen saturation, and delivery of potential treatment and oxygen medication, may be facilitated by selection of an abnormal cut-off after comparison of hypoxic and normal deliveries, in addition to retrospective analyses.

We successfully measured fetal brain tissue oxygen saturation levels after delivery using fetal tissue oximetry.

Figure 2 Representative examples of (a) normal and (b) low regional tissue oxygen saturation (rSO2). (a) The mother was a 34-year-old primigravida woman who delivered at 38 gestational weeks. The infant had an Apgar score of 7 at 1 min and 8 at 5 min, and weighed 3050 g. Umbilical artery pH was 7.037. (b) The mother was a 31-year-old parous woman who delivered at 41 gestational weeks. The infant had an Apgar score of 8 at 1 min and 8 at 5 min. Umbilical artery pH was 7.227. (arrow) Delivery; (→) first cry.
oximetry with a sensor attached to the examiner’s finger. Oximetry will provide a clearer understanding of the fetal oxygen condition, compared with other evaluation methods.

Acknowledgments

The authors thank Mrs Naoko Hakamada, Mrs Yumiko Yamamoto, Mrs Naoko Kondo, Mrs Miuta Sawai, and Mrs Kazuko Sugiyama for assistance with the manuscript or technical assistance.

Disclosure

The authors declare no conflict of interest.

References
