



## Original Article

# Measurement of brain tissue oxygen saturation in term infants using a new portable near-infrared spectroscopy device

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**Abstract** **Background:** A small oximeter with the probe attached to the examiner's finger has been developed. The aim of this study was to determine the feasibility of measuring regional oxygenation of the brain tissue using this device in healthy term infants immediately after birth.

**Methods:** We conducted a prospective observational study. Using a new near-infrared spectroscopy (NIRS) device, we measured changes in regional cerebral tissue oxygen saturation (crSO<sub>2</sub>) during the first 10 min of life in 32 healthy term infants after delivery. Arterial oxygen saturation (SpO<sub>2</sub>) was also simultaneously measured.

**Results:** Median crSO<sub>2</sub> increased from 43% (1 min after birth) to 49% (4 min after birth); thereafter, no significant changes were observed. Median SpO<sub>2</sub> increased constantly from min 3 to min 7, from 77% to 92% and did not change significantly after 8 min. A stable oxygen saturation signal was measured in 59% of infants (crSO<sub>2</sub>) and in 0% of infants (SpO<sub>2</sub>) at 1 min, and in 97% (crSO<sub>2</sub>) and in 78% (SpO<sub>2</sub>) at 3 min.

**Conclusions:** During the transition after birth, crSO<sub>2</sub> can be more easily and quickly measured in healthy newborn infants using the novel NIRS device than SpO<sub>2</sub>.

**Key words** arterial oxygen saturation, near-infrared spectroscopy, oximetry, regional cerebral tissue oxygen saturation, term infant.

The seventh edition of the Neonatal Resuscitation Program states that pulse oximetry should be used when resuscitation can be anticipated, positive pressure ventilation is administered, central cyanosis persists beyond the first 5–10 min of life, or supplementary oxygen is given.<sup>1</sup> It provides arterial oxygen saturation (SpO<sub>2</sub>) targets that resuscitation teams should achieve. There is ongoing discussion, however, about the use of supplemental oxygen during neonatal resuscitation because the appropriate oxygen concentration during resuscitation in newborns remains unknown.<sup>2</sup> Because the brain is one of the most vulnerable organ systems to hypoxia–ischemia during neonatal transition, a more direct, simple, non-invasive way to assess oxygenation would be useful. One approach to measuring cerebral oxygenation is to measure regional cerebral tissue oxygen saturation (crSO<sub>2</sub>) using near infrared spectroscopy (NIRS), which is a well-described non-invasive technique that uses the transparency of biological tissue to light in the near-infrared spectrum to measure cerebral tissue oxygenation.<sup>3–6</sup> Studies have already been performed during the neonatal transition,<sup>7</sup> and several observational studies have described changes in crSO<sub>2</sub> during the first few minutes immediately after birth.<sup>8–10</sup>

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Recently, Kanayama and Niwayama developed a small oximeter with the probe attached to the examiner's finger (KN-15; ASTEM, Kawasaki, Japan).<sup>11</sup> This medical instrument consists of a probe with NIRS and a numerical display device. The size of the sensor in the probe is <1 cm<sup>2</sup>. This probe is attached to the examiner's finger. Examiners can measure any site in the human body, even the organs within a body cavity during surgery, because the device is small and portable. The same group has previously investigated the characteristics of this oximetry technique and obtained clinical data during labor; they concluded that the mean crSO<sub>2</sub> of the fetal head during labor significantly correlated with umbilical cord arterial pH immediately after delivery.<sup>12</sup> crSO<sub>2</sub> during the transition after birth, however, has not been evaluated in a large group of patients using this device. The aim of this study was therefore to measure crSO<sub>2</sub> during the immediate transition after birth to determine the safety of this new small portable device and its correlation with SpO<sub>2</sub>, as well as to define crSO<sub>2</sub> reference ranges within the first 10 min after birth in healthy term infants who do not need any medical support.

## Methods

This prospective observational study was conducted at a tertiary center, the Division of Neonatology, Department of Pediatrics, Saitama Medical Center, Saitama Medical University, Japan, from November 2015 to March 2016. We included newborn infants with gestational age (GA) ≥37 weeks after

uncomplicated pregnancy. This group of patients was selected because the study protocol would not alter the routine treatment of these infants. Term infants were observed routinely for 10 min on a resuscitation table. Infants requiring any respiratory support or additional inspired oxygen during the transition or with any suspected or known malformation were excluded. Infants delivered after vacuum-assisted delivery or forceps delivery were excluded. Only those infants who had an uncomplicated transitional period were included. The Ethics Committee of the Saitama Medical Center, Saitama Medical University approved the project. Written informed consent was obtained from the parents.

A KN-15 NIRS device was used to measure  $crSO_2$  (Fig. 1). The transducer contains near-infrared light-emitting diodes (LED) and photodiodes. The detectors were placed 6 and 8 mm away from the LED. The KN-15 NIRS device calculates  $crSO_2$ , which is expressed as percentage of oxygenated hemoglobin/total hemoglobin. The transducer was positioned on the left frontoparietal area of the forehead of each infant, regardless of mode of delivery. Arterial oxygen saturation was measured using a Neopulse device (Atom Medical, Tokyo, Japan). The transducer was placed on the right hand/wrist. All variables were continuously stored for subsequent analysis.  $crSO_2$  and  $SpO_2$  data were stored every 1 and 15 s, respectively.

Measurements were performed during the first 10 min after birth. A stopwatch was set off when the neonate was fully delivered. All infants were dried and wrapped with warmed towels. Immediately after arrival of the infant at the resuscitation table, two people applied the transducers. First, one sensor was placed on the left frontoparietal area of the forehead (to measure  $crSO_2$ ), and concurrently, transcutaneous pulse oximetry was initiated on a preductal level (right hand, to measure  $SpO_2$ ). The infants were positioned supine and were breathing room air. A neonatologist observed the transition of the newborn infants and recorded Apgar scores at 1 and 5 min. After 10 min and a clinical assessment, the newborn infant was handed to the parents.



**Fig. 1** The oximeter probe attached to the examiner's finger measuring regional cerebral tissue oxygen saturation on the head of a newborn (KN-15 NIRS; ASTEM, Kawasaki, Japan). Photo courtesy of ASTEM.

### Statistical analysis

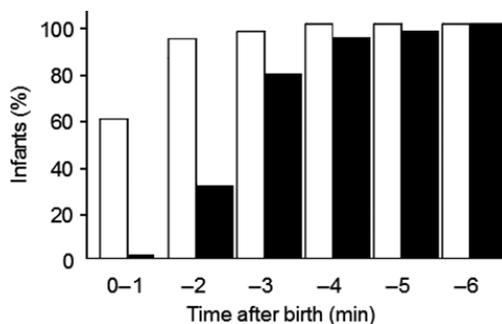
Median  $SpO_2$  and  $crSO_2$  were calculated for each minute after birth. Data are presented as median (IQR). Infant characteristics are presented as numbers and proportions for categorical variables and as mean  $\pm$  SD for continuous variables. To compare patient characteristics, Student's *t*-test was used. Changes by minute were evaluated using Friedman's analysis of variance and Holm's post-hoc test of variance for repeated measures.  $P < 0.05$  was considered to be significant. Statistical analysis was performed using EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan).

### Results

Of 46 neonates, 14 were excluded because of a lack of recorded  $SpO_2$  data. Both  $crSO_2$  and  $SpO_2$  data for 32 neonates, who were delivered between November 2015 and March 2016, were analyzed (GA,  $38 \pm 1$  weeks; birthweight,  $2771 \pm 314$  g; Apgar score, 8/9; Table 1). By 1 min, the  $crSO_2$  signal could be measured for approximately 60% of infants. Therefore, the data presentation begins at 1 min. The data presentation of  $SpO_2$  begins at 3 min, because the  $SpO_2$  signal could be measured for at least 70% of infants by 3 min. A stable oxygen saturation signal was measured in 59% of infants ( $crSO_2$ ) and in 0% of infants ( $SpO_2$ ) at 1 min, and in 97% ( $crSO_2$ ) and in 78% ( $SpO_2$ ) at 3 min. After 2 min, a  $crSO_2$  signal could be measured in >90% of infants, and after 4 min, an  $SpO_2$  signal could be measured in >90% of infants (Fig. 2). Median  $crSO_2$  increased from 43 in 1 min to 49 in

**Table 1** Subject characteristics

Characteristics	Term infants ( $n = 32$ ) Mean $\pm$ SD or $n$ (%)
Gestational age (weeks)	$38 \pm 1$
Vaginal delivery	4 (13)
Birthweight (g)	$2771 \pm 314$
Head circumference (cm)	$33.3 \pm 1.2$
Apgar scores at 1 min	$8 \pm 0.45$
Apgar scores at 5 min	$9 \pm 0.44$
pH umbilical artery	$7.32 \pm 0.04$



**Fig. 2** Cumulative proportion of infants with measurement of (□) regional cerebral tissue oxygen saturation and (■) arterial oxygen saturation.

4 min with no further statistical change. SpO<sub>2</sub> increased from 77 in 3 min to 92 in 7 min (Fig. 3).

## Discussion

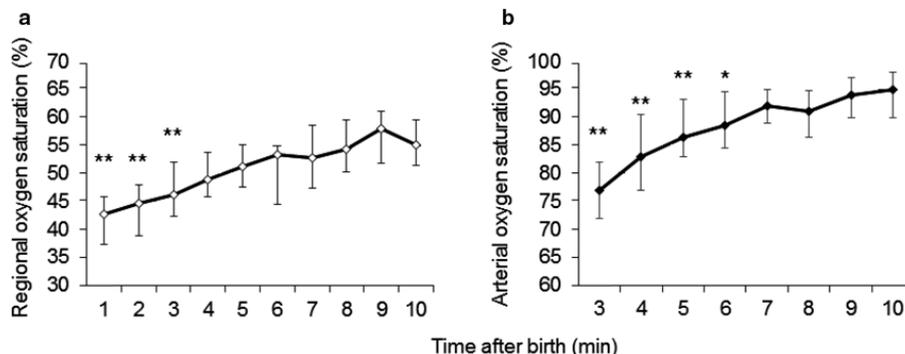
We analyzed changes in crSO<sub>2</sub> using a novel NIRS system and simultaneous changes in SpO<sub>2</sub> during the transition after birth in a group of healthy term infants. The range of crSO<sub>2</sub> in term infants was between 43% and 58%, and reached a plateau after 4 min. Previous studies have reported crSO<sub>2</sub> range in term and preterm infants between 57% and 79% during the first few days of life.<sup>8,10,13–17</sup> Fauchere *et al.*<sup>10</sup> published data on crSO<sub>2</sub> in 20 newborn term infants after cesarean section (CS), with a different NIRS device (NIRO 300, Hamamatsu, Japan). Urlesberger *et al.*<sup>18</sup> conducted a prospective observational study in 61 term infants and measured crSO<sub>2</sub> using an INVOS 5100 near-infrared spectrometer (Somanetics, Troy, MI, USA). They reported a very similar trend for crSO<sub>2</sub>, but their crSO<sub>2</sub> data were higher than the present ones. A possible reason for this difference in crSO<sub>2</sub> may be the use of different NIRS devices. NIRS measurement in healthy term infants during the transition after birth using the present new device, KN-15, was safe and feasible.

Several studies have evaluated normal SpO<sub>2</sub> immediately after birth. Kamlin *et al.*<sup>19</sup> studied SpO<sub>2</sub> after birth in healthy infants with GA  $\geq$ 31 weeks and obtained SpO<sub>2</sub> readings by 1 min of life in 53% of their cohort. Rabi *et al.*<sup>20</sup> documented SpO<sub>2</sub> in healthy newborns with GA  $\geq$ 35 weeks during unassisted transition in the delivery room and found that the median time to obtain stable SpO<sub>2</sub> readings after probe placement was 82 s. Nuntnarumit *et al.*<sup>21</sup> studied 75 newborns with median GA 35 weeks and birthweight 2390 g, and found that the median time from birth to obtain reliable SpO<sub>2</sub> and heart rate values was 160 s. We recorded SpO<sub>2</sub> every 15 s in healthy newborn infants with GA  $\geq$ 37 weeks during the transition after birth, and obtained SpO<sub>2</sub> readings by 1 min and 2 min of life in 0% and in 31% of the cohort, respectively (Fig. 2); furthermore, the median time from birth to obtain SpO<sub>2</sub> was 150 s (IQR, 116–169 s), which is very similar to the Nuntnarumit *et al.* data. In contrast, a stable crSO<sub>2</sub> signal was measured relatively quickly. Urlesberger *et al.*<sup>18</sup> were able to

measure crSO<sub>2</sub> in 92% of 59 healthy term infants by 3 min after elective CS delivery using an INVOS 5100 near-infrared spectrometer. Fauchere *et al.*<sup>10</sup> reported crSO<sub>2</sub> during immediate postnatal adaptation in 20 healthy newborn infants delivered at term by elective CS, and the median age at the initiation of NIRS measurement was 2 min after birth (range, 1–4 min). In the present study, after the infant was placed on a radiant warmer, crSO<sub>2</sub> was detected immediately when the sensor was placed on the left frontoparietal area of the forehead. The crSO<sub>2</sub> readings were obtained by 1 and 2 min of life in 59% and in 94% of the cohort, respectively, and the median time from birth to obtain crSO<sub>2</sub> was 57 s (IQR, 50–78 s), which was much shorter than for SpO<sub>2</sub> (i.e. 150 s; IQR, 116–169 s).

The sector of wearable health technology is generating, apparently, endless interest. The use of low-cost, wearable monitoring devices or wearable biosensors that allow constant monitoring of physiological signals is essential for the advancement of both the diagnosis and treatment of disease as well as for monitoring in active lifestyles. Wearable, wireless fingertip pulse oximetry devices for arterial saturation measurement are already available for smart phones, and fetal/neonatal crSO<sub>2</sub> can now be measured via finger-mounted oximeter.<sup>11</sup> In the present study, we have confirmed the safety and feasibility of this novel device to measure crSO<sub>2</sub> in healthy newborn infants. There is a concern, however, about its use in newborn infants at the resuscitation table, particularly in those requiring resuscitation. Because this finger-mounted tissue oximetry probe was first developed to be attached to the physician's finger to obtain tissue oxygen saturation of the fetal head during the second stage of labor,<sup>12</sup> at least one physician or midwife is needed to measure crSO<sub>2</sub> for one resuscitated newborn baby. Therefore, a new probe, such as an SpO<sub>2</sub> probe or electrocardiogram electrode, should be developed for this device so that it can also be placed directly on the head of newborn babies.

The present study was limited only by its small size, particularly because only a small proportion of neonates were vaginally delivered (only 13%). This is due to the characteristics of the present institute, one of the largest Japanese tertiary neonatal units, where the rates of normal vaginal delivery are



**Fig. 3** (a) Regional cerebral tissue and (b) arterial oxygen saturation. \* $P < 0.05$ , \*\* $P < 0.01$  compared with the endpoint (min 10).

very low. Despite these limitations, the present study has confirmed the ease, simplicity, and safety of this finger-based device to obtain quick and reliable crSO<sub>2</sub> measurements. We believe that this novel oximetry probe will provide new information for the management of newborns during the transition after birth.

In conclusion, crSO<sub>2</sub> can be measured in healthy term newborn infants during the transition after birth using this novel NIRS device even more easily and quickly than SpO<sub>2</sub>. There was an increase in crSO<sub>2</sub> during the first 4 min of life. This new NIRS instrument could be used as an alternative to or in combination with pulse oximetry during neonatal resuscitation.

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## Disclosure

A KN-15 NIRS device was leased from ASTEM (Kawasaki, Japan).

## Author contributions

M.T. and F.N. designed the study; T.W., M.I., F.M., R.O., and F.N. collected and analyzed data; T.W. and F.N. drafted the manuscript; M.I., F.M., R.O., and M.T. critically reviewed the manuscript; all authors read and approved the final manuscript.

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