Monitoring of Fetal Arterial Oxygen Saturation during Labour Analgesia

Kan Amano, Masahiro Nishijima, Kenji Suzuki*

Our purpose was to evaluate the clinical usefulness of intrapartum fetal pulse oximetry during labour analgesia.

Sixty-eight cases under various types of analgesia were enrolled. Fetal arterial oxygen saturation (F-SpO2) was continuously monitored with simultaneous FHR monitoring by means of a Nellcor N-400 oximetry with an FS-14 fetal sensor (Mallinckrodt Inc.) which had a light wavelength of 735/890 nm. The relationship between F-SpO2 values and umbilical arterial blood gas analysis was studied.

Adequate F-SpO2 signals were obtained in 73% of the monitoring time (mean 220 min) without any remarkable feto-maternal side effects. The mean F-SpO2 value throughout the first stage of labour in fetuses with normal outcome was 50.1 ± 8.1% (mean ± SD; n = 43). No significant difference of F-SpO2 value was noted among various types of analgesia. In case of fetal distress (n = 8) F-SpO2 value during 10 min before delivery was 30.0 ± 11.1%, which was significantly lower than 45.5 ± 10.4% of the cases without fetal distress. When the final F-SpO2 was below 30%, a more acidotic tendency was noted than in the cases above 30% (p < 0.005) irrespective of the types of labour analgesia.

In combination with FHR monitoring, fetal pulse oximetry promises greatly improved detection of fetal status during labour analgesia. The critical threshold of F-SpO2 for the development of fetal acidemia secondary to hypoxemia seemed to be around 30% although more studies are needed to clarify the threshold point and its duration.

Key words: fetal surveillance, fetal pulse oximetry, labour analgesia, fetal distress

Cardiotocogram (CTG) monitoring has been used as an essential means for early diagnosis of fetal hypoxia during labour since 1970's. Though CTG monitoring appears to have contributed to an improved fetal prognosis, it remains doubtful whether it has contributed to the improvement in long-term prognosis14. There are great concerns over the fact that it also contributes to a fair amount of unnecessary obstetric intervention.

Pharmacological analgesia given to a mother during labour may alter the fetal heart rate (FHR) patterns such as baseline variability12,18. The combination of CTG monitoring with fetal scalp blood sampling (FBS) has conventionally been considered to be the "gold standard" of fetal diagnosis, but the practice of FBS is almost nil in Japan because of its invasiveness. In recent years, monitoring of fetal arterial oxygen saturation (F-SpO2) using a pulse oximetry has become possible7, and the clinical usefulness of this method may one day become the preferred alternative to FBS.
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In this manuscript, we present the data from our assessment of the safety and usefulness of F-SpO2 monitoring during labour analgesia.

**Subjects and Methods**

This study included 68 subjects with a mean age of 30 years, all of whom had given their signed informed consent and was approved by our hospital's investigation committee on ethics. Fifty were nulliparous and 18 were multiparous, sixty five had term delivery (2 had twins), and 3 had preterm delivery (1 had twins at 33 weeks of gestation and 2 others had babies at 35 weeks of gestation). Maternal complications were observed in 4 subjects (toxemia of pregnancy in 3 and oligohydranmni in 1), and fetal complications were observed in 3 (intrauterine growth retardation (UGR) in 1, Ebstein's anomaly in 1, and sinus bradycardia in 1).

Thirty-eight subjects, including those with the maternal and fetal complications, had elective labour induction, and the remaining 30 had spontaneous labour onset or spontaneous rupture of the membranes. Labour was induced or augmented by intravenous instillation of oxytocin in all subjects. Delivery was accomplished under epidural analgesia ("top-up" with 0.375% bupivacaine) in 42 including high risk cases. Balanced anesthesia was performed on patient request in 12 cases; 10 mg diazepam IM at the end of latent phase, inhalation of intermittent 0.25% enflurane and 50 mg pethilfan IM at the phase of maximal slope of Friedman curve and 30 mg ketamin IV just before delivery. Two cases were under spinal anesthesia (0.3 mg morphine) and 13 cases were without analgesia.

F-SpO2 was serially monitored with a fetal oxygen saturation monitoring system developed by Mallinckrodt Inc., simultaneously with conventional CTG monitoring. In the subjects with intact membranes, the sensor was applied to a site of the fetus when the mean cervical dilation was 5.3 (3-10) cm after artificial rupture of the membranes and the degree of descent of the fetal head was not higher than the level of the ischial spines –2 cm. F-SpO2 was determined with a N-400 pulse oximeter calibrated specifically for fetuses, and the data were serially recorded on the uterine contraction curve. The sensor was a FS-14 reflective sensor which had a light wavelength of 735/890 nm. Distance between the light-emitting diodes and photo detector is 14 mm. It was placed transvaginally between the area from the buccal to temporal region of the fetus and uterine wall under guidance of the surgeon’s examining hand fingers in the vagina.

Diagnosis of fetal distress and operative delivery was performed based on the FHR patterns such as late deceleration, sever/prolonged deceleration and/or decreased variability. Relationship between the value of F-SpO2, FHR findings and umbilical arterial blood gas analysis after delivery were studied.

In the statistical analysis, difference at p<0.05 determined by the Student's t-test, χ²-test, Fisher's exact probability test were considered significant.

**Results**

Thirty-seven subjects had spontaneous delivery, 17 vacuum extraction, 7 forceps delivery, 7 cesarean delivery. Operative deliveries were performed in 8 cases due to fetal distress (cesarean delivery in 3, forceps delivery in 3, and vacuum delivery in 2). The mean birth weight was 2,915 g (1,300~3,954 g). The Apgar score was lower than 7 in 9 (13.2%) of the subjects. The pH level in the umbilical artery (Ua-pH) was less than 7.20 in 11 (16.2%) of the subjects. Preterm infants and asphyxiated infants were managed in the neonatal intensive care unit, and all of them showed a favorable prognosis with the exception of one infant who showed Ebstein's anomaly.

Marking from pressure and redness was observed at the site to which the sensor was applied in 8 subjects (12.7%), but it disappeared spontaneously within 12 hours in all cases. No subject had pyrexia of 38°C or over during the course of labour and there was no adverse reaction to the monitoring, i.e., damage or hemorrhage, accompanying the sensor application.

F-SpO2 measurement was performed for a mean
of 220 minutes (12~510), and evaluable data were recorded in 72.8±18.1% (mean (M)±standard deviation (SD)) of the total measurement time. However, the sensor slipped out of position because of uterine contraction, turning of fetal head, and maternal movement. Thus, the sensor had to be repositioned several times during monitoring. According to analgesic methods, more evaluable signals were obtained in subjects who were delivered under epidural analgesia than balanced anesthesia (p<0.0002, Table 1). In 4 subjects of 13 (30.7%) who were delivered without analgesia, well-evaluable data were obtained for only 50% or less of the total measuring time due to signal loss, with higher frequency than that shown in the 2 of 42 (4.9%) subjects who were delivered under epidural analgesia (p<0.02).

Whenever the FHR was reassuring; that is normocardia with variability and no decelerations, the

Table 1   Methods of analgesia and qualified monitoring time of F-SpO2.

<table>
<thead>
<tr>
<th>Number of cases</th>
<th>% of time M±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>epidural</td>
<td>42</td>
</tr>
<tr>
<td>balance</td>
<td>11</td>
</tr>
<tr>
<td>spinal</td>
<td>2</td>
</tr>
<tr>
<td>no-analgesia</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>68</td>
</tr>
</tbody>
</table>

§: ratio of qualified monitoring time and total monitoring time
*: p<0.0002

Fig. 1   Effect of diazepam on FHR pattern and F-SpO2.

a: Whenever the FHR pattern was reassuring the value of F-SpO2 was stable between 30~70%. In this case F-SpO2 was 60~70%.

b: In this case labour was induced under balanced anesthesia. After 10 mg intramuscular administration of diazepam FHR baseline variability decreased, however, F-SpO2 was stable between 50~60%. 

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Fig. 2 Case K.Y., 32 y/o, 40 wks, Para 0.
Labour was induced due to oligohydramnios; after epidural block (0.375% bupivacaine 7 ml) prolonged deceleration was noted without maternal hypotension in the spine position (a).
Amniotic fluid index was 3 cm and F-SpO₂ value was between 20~35% (b).
After turning to the lateral position and amnioinfusion (250 ml saline), deceleration disappeared with the increase of F-SpO₂ value (40~50%)(c).
Three hours later a vigorous male baby was delivered by vacuum extraction (3078 g, Ap 9/9, Ua-pH 7.34).
range of F-SpO2 was stable within 30–70% (Fig. 1). Variation of F-SpO2 values was noted during decelerative FHR patterns (Fig. 2).

In the 43 subjects with normal term delivery, F-SpO2 in the first stage of labour was 50.1 ± 8.0%. There was no significant difference in F-SpO2 among the different analgesic groups (Table 2).

In 8 subjects who had operative delivery under the diagnosis of fetal distress based on FHR findings, Ua-pH and F-SpO2 were 7.11 ± 0.10 and 30.0 ± 11.1%, respectively (Table 3). These values were significantly less than the corresponding values in the 60 subjects without evidence of fetal distress (7.29 ± 0.06 and 45.5 ± 10.4%, p < 0.002, respectively).

When the F-SpO2 during the 10-minute period before delivery was below 30%, Ua-pH was 7.15 ± 0.01, showing a significant tendency of acidosis compared to the subjects with F-SpO2 values of 31 ~ 40% (7.29 ± 0.04), 41 ~ 50% (7.29 ± 0.07), 50% < (7.29 ± 0.06) (Fig. 2). There were slight correlations of F-SpO2 with oxygen tension pressure (PO2), arterial oxygen saturation (SaO2), and base excess (BE) of umbilical artery (coefficient of rank correlation r = 0.55, r = 0.55, and r = 0.43, respectively, p < 0.01).

With regard to prediction of Ua-pH < 7.20, when the cutoff value of F-SpO2 was 30%, the sensitivity, specificity, positive and negative predictive values were 55%, 95%, 67%, and 92%, respectively.

**Discussion**

CTG monitoring is a conventional method for evaluating fetal status during labour, but it is an indirect method for evaluating fetal hypoxia. Pharmacological analgesia such as narcotics and sedatives may alter the FHR patterns, especially baseline variability[12,13]. Changes in FHR patterns have been observed in the 30 minutes after an epidural loading dose[16]. The method is not always specific[19], and false-positive findings have become an issue. Thus, efforts are underway to combine CTG monitoring with a new method for fetal surveillance, and the clinical application of F-SpO2 monitoring using a pulse oximetry is awaited[7].

F-SpO2 monitoring has been difficult due to the smallness of the fetal pulse signal, the limited measurement area, difficulty in applying the sensor, and the problem with calibration. The principle of fetal pulse oximetry is similar to that have already been used in other fields: oxygen saturation by pulse oximetry (SpO2) is determined from the absorption ratio of red light (660 nm) and infrared.

**Table 2** Methods of analgesia and F-SpO2 during first stage of labour.

<table>
<thead>
<tr>
<th>method of analgesia</th>
<th>number of cases</th>
<th>F-SpO2 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>epidural</td>
<td>18</td>
<td>47.2 ± 9.1</td>
</tr>
<tr>
<td>balance</td>
<td>11</td>
<td>53.2 ± 7.0</td>
</tr>
<tr>
<td>spinal</td>
<td>2</td>
<td>55.62</td>
</tr>
<tr>
<td>no-analgesia</td>
<td>12</td>
<td>51.6 ± 5.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M ± SD</td>
</tr>
</tbody>
</table>

**Table 3** FHR, Ua-pH and F-SpO2 in cases of fetal distress.

<table>
<thead>
<tr>
<th>FHR</th>
<th>F-SpO2</th>
<th>mode of delivery</th>
<th>Ua-pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>I tachy (165 bpm)+V ↓</td>
<td>10</td>
<td>CS</td>
<td>7.17</td>
</tr>
<tr>
<td>II tachy (175 bpm)+sev.VD</td>
<td>25</td>
<td>CS</td>
<td>6.96</td>
</tr>
<tr>
<td>III VD→brady</td>
<td>47</td>
<td>VE</td>
<td>7.20</td>
</tr>
<tr>
<td>IV tachy (180 bpm)+sev.VD →brady</td>
<td>40</td>
<td>FCP</td>
<td>7.09</td>
</tr>
<tr>
<td>V sev. VD+V ↓ →brady</td>
<td>28</td>
<td>FCP</td>
<td>6.95</td>
</tr>
<tr>
<td>VI pseudo-sinusoidal →brady</td>
<td>35</td>
<td>FCP</td>
<td>7.22</td>
</tr>
<tr>
<td>VII sev.VD+PD</td>
<td>30</td>
<td>VE</td>
<td>7.07</td>
</tr>
<tr>
<td>VIII tachy (175 bpm)+sev.VD</td>
<td>25</td>
<td>CS</td>
<td>7.19</td>
</tr>
</tbody>
</table>

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![Fig. 3](image)

**Fig. 3** Relationship between F-SpO2 10 min before delivery and UA-pH.

light (920 nm) in pulsatile arterial components. Deoxyhemoglobin and oxyhemoglobin are readily absorbed by the red light and infrared light, respectively, if the ratio is high, SpO2 will be low. The conventional pulse oximetry using transmission type sensor has limited application and low accuracy when applied to fetal arterial oxygen saturation monitoring. Therefore, a reflectance type sensor is frequently used for the monitoring of fetuses.

The sensor was applied to the area from the buccal to temporal region of the fetal head. The arch-like design of the sensor tip contributed to the stable attachment between the area and the uterine wall. In addition, with electrical impedance technology, the correct sensor position can be further identified by optical signal waveform confirming whether the sensor was in contact with the skin of the fetus.

Dildy et al.\(^9\) reported that quality signals could be obtained at 49±23% of the total monitoring time. In the present study, quality recording time were obtained at 73% of the total measuring time. The data collected from the subjects who received epidural analgesia tended to be particularly stable and favorable because maternal movements were reduced by the effect of analgesia.

A sensor that was fixed beneath the scalp\(^6\) allows for long-term recording of quality data, but sensor is inevitably influenced by caput succedaneum and peripheral circulation. The SpO2 value varies with the site of sensor application, and there may be a 13.4% difference between the frontal region and the occipital region\(^6\). According to the report of dual sensor (FS-14) study, applying to the right and left buccal regions of the same fetus, no significant difference of mean F-SpO2 values was encountered\(^6\). F-SpO2 can be measured even before the rupture of the membranes. But it is often difficult to get accurate data. Therefore, artificial rupture of the membranes is required, even though the application of the sensor is invasive.

There were no adverse reactions to the monitoring due to sensor insertion, e.g., maternal pyrexia and trauma, but pressure marks and redness were observed at the application site in 8 (12.7%) of the subjects. The markings disappeared spontaneously within 12 hours after the onset, and no problematic symptoms remained. Thus, F-SpO2 monitoring was confirmed to be safe.

Calibration of the fetal pulse oximetry becomes an issue. It is impossible to investigate the relationship between F-SpO2 and SaO2 by a hemoximeter in human fetuses. The N-400 pulse oximetry used in the present study was calibrated specifically for fetuses based on the data from intraterine animal model and human neonates with severe cyanotic heart disease. The problem with the measurement accuracy of the fetal pulse oximetry which recorded in the lower range (<20~30%) remains unsolved.

What is the normal range of F-SpO2 during labour? Also, what is the threshold value of F-SpO2 to predict fetal acidosis?

A multicenter study using the N-400 pulse oximetry (FS-10, prototype) organized by Dildy et al.\(^9\) reported that the mean F-SpO2 values in the first and second stages were 59±10% and 53±10%, respectively, showing a tendency of a decrease in saturation value. According to the report, the normal lower limit (M-2SD) was 33%. Another study on 115 normal fetuses using FS-14 sensor by Chua et al.\(^5\) was reported that mean F-SpO2 in the first stage of normal fetus was 50±10%, and that there was no remarkable changes accompanying progression of labour. It was also reported that the F-SpO2 value was 30% or higher in all fetuses\(^5\). In our present study, F-SpO2 was 50.1±8.0% in the
normal subjects, which was similar to the values in the above-described studies.

F-SpO\textsubscript{2} has shown more-or-less constant changes in individual fetuses within the ranges from 30 to 70% when the FHR pattern was reassuring.

The frequency of variable deceleration and prolonged deceleration occurring from umbilical cord compression or sometimes after epidural block is relatively high during labour. However, there is no definite standard at which obstetrician will venture into emergency delivery. The combined use of F-SpO\textsubscript{2} monitoring will facilitate accurate fetal surveillance. When hypoxia is suspected due to variable or prolonged decelerations, normal oxygen saturation levels can still occur. Knowing the oxygen saturation in periods of variable or prolonged decelerations enables a better assessment of the extent of danger to the fetus.

Johnson et al.\textsuperscript{11} investigated the effect of uncomplicated epidural analgesia on F-SpO\textsubscript{2} by the use of N-400 pulse oximetry. They observed no measurable effect on F-SpO\textsubscript{2} following uneventful epidural "top-up" in cases without maternal hypotension. In case with decreased variability after maternal medication F-SpO\textsubscript{2} monitoring seemed to be a valuable tool to discriminate whether the fetus is hypoxic or not.

In this study safe vaginal delivery was performed in case of fetal sinus bradycardia (70 bpm) by the use of F-SpO\textsubscript{2} monitoring. F-SpO\textsubscript{2} monitoring is thought to be considerably significant as a method for fetal surveillance in case of arrhythmia, whose FHR findings are difficult to evaluate\textsuperscript{2}.

The data from animal experiments have suggested that the threshold for the transition from fetal hypoxia to metabolic acidosis is approximately 30%.\textsuperscript{15,17} Based on the results of umbilical cord arterial gas analysis in 1,101 subjects, Dildy et al.\textsuperscript{4} considered that it was valid to regard the cutoff value of F-SpO\textsubscript{2} to be 30% even in human fetus. In their study, 10.4% of subjects showed acidemia, and 86.2% of those with acidemia showed an SaO\textsubscript{2} of less than 30% when the theoretical value of arterial SaO\textsubscript{2} (0.8×Ua-SaO\textsubscript{2}+0.2×Uv-SaO\textsubscript{2}) was less than 30%.

There was no constant correlation between the FHR finding and F-SpO\textsubscript{2}, however, the mean F-SpO\textsubscript{2} during the 10-minutes period before delivery was 30.0±11.1% in the 8 subjects in whom emergency deliveries had been indicated by fetal distress. More significant tendency of acidosis was found in subjects with F-SpO\textsubscript{2} less than 30% than those with 30% or higher. With regards to the prediction of Ua-pH less than 7.20, the sensitivity, specificity, positive and negative predictive values were 55%, 95%, 67%, 92%, respectively. In a study by Kuhnert et al. analyzing the correlation between scalp pH and mean F-SpO\textsubscript{2} during 10-minutes period before FBS in the subjects with abnormal FHR, the sensitivity and specificity for prediction of pH less than 7.20 were 80% and 100%, respectively\textsuperscript{13}.

Furthermore, Carbone et al.\textsuperscript{14} compared the predictive value of fetal pulse oximetry with FBS for an abnormal neonatal outcome. They reported that receiver-operator characteristic curve showed similar performance of either technique for cutoff value ≤7.20 for FBS and ≤30% for F-SpO\textsubscript{2}.

On the other hand, Alshimmiri et al.\textsuperscript{1} investigated the threshold values for prediction of acidosis from the correlation of the mean F-SpO\textsubscript{2} during the 30-minute period before delivery with umbilical arterial base excess (BE) and pH in subjects who had either abnormal FHR, IUGR, or meconium-stained amniotic fluid. The mean F-SpO\textsubscript{2} averaged 42.1%±9.9% and the correlation with BE was somewhat weak (r=0.30, p<0.05), as was the correlation with pH (r=0.26, p=0.05). They concluded that intrapartum F-SpO\textsubscript{2} monitoring was of limited value as a diagnostic test for predicting acidosis at birth.

Even when the critical threshold of F-SpO\textsubscript{2} is less than 30%, the correlation between the duration and the shift to acidosis remains unknown. The measurement accuracy in the lower range (<30%) also remain unsolved and further improvements in the system are expected in the future.

References

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