J. Perinat. Med.
6 (1977) 252

Monitoring of transcutaneous P_O₂ in the fetus and mother during normal labor*

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The first report on oxygen and air diffusion through the skin was published in 1851 [9] and suggested that the direction of the diffusion was from the outside inwards. In 1951 BAUMBERGE and GOOD-FRIEND showed that oxygen diffused from the blood through artificially heated skin [1]. These latter findings were subsequently confirmed by ROTH in 1957 [21]. In 1956 CLARK published his construction of the membrane electrode [3] and in 1964, EVANS and NAYLOR reported that the rate of oxygen diffusion could be increased by the general warming of the subject or by the induction of inflammation at the site of measurement [6].

These observations together formed the prerequisites for the continuous measurement technique of transcutaneous P_O₂ (tcP_O₂) presented by HUCH and LÜBBERS in 1969 [10]. Their first electrode was subsequently modified so that arterialisation of the skin was produced by a heating element built into the electrode [13].

To date, methodological studies have primarily concerned the relationship between tcP_O₂ and arterial P_O₂, the relationship between these two variables typically being highly positive [5, 8, 17]. However, with some equipment and in some individual cases within several of the published series, a lower correlation has been observed between tcP_O₂ and central P_O₂ values, this being especially true in hypoxemia and hyperoxemia [4, 7, 22, 23].

* The material has been partly presented at the 5th European Congress of Perinatology (1976).

Curriculum vitae

OLOF LÖFGREN was born in 1943. He graduated from the University of Lund in 1971. At present he is research student at the Perinatal Laboratory at the Department of Obstetrics and Gynecology, General Hospital, Malmö. His research interests are respiratory gas exchange and blood flow in the placenta and fetal surveillance.

Since continuous recording of P_O₂ is apparently primarily of interest to pediatricians and anesthetists, the applicability of the method has been mainly tested on newborns and on adult surgical patients [11, 14, 16, 17, 18]. Reports on the use of the method with fetuses during labor are still both scanty and few in number, being restricted to case reports [12, 15, 18].

The aim of this paper is to report physiological and technical data obtained in a systematic study of intrapartum fetal and maternal tcP_O₂-monitoring.

1 Material and methods

1.1 Material

The material is comprised of 19 parturients, the majority being nulliparae. All fetal presentations were vertex. The tcP_O₂ recordings averaged one

Tab. I. Patients.

ntot.		19
nulliparae	n	17
multiparae	n	2
electrode attachment:		
tissue glue	n	12
suction	n	7
birth weight:		
$\bar{x}$	g	3,525
range	g	2,730–4,250
boy/girl	n	12/7
Apgar score at 1':		
9	n	18
8	n	1

hour in duration (Tab. I). All infants were full term, had a normal birth weight and had a one-minute APGAR score ≥ 8 . Intrapartal fetal heart rate was monitored, and was normal in all cases throughout labor.

1.2 Instrumentation

Two identical and separate sets of the Radiometer prototype equipment TCMI were used (Fig. 1). The central instrument digitally displays the values for tcPO₂, current electrode temperature and current energy supply to the heating element of the electrode. The electrode temperature can be maintained very steadily at any preset level between 35 and 50°C ($\pm 1/10^\circ\text{C}$). The instrument has an automatic alarm for adjustable lower and upper limits of tcPO₂. The instrument was connected to a two channel pen recorder (GOEZ RE 520). FHR was recorded with ROCHE equipment (CPM5F).

A schematic diagram of the electrode is seen in Fig. 2. A 12 μ cuprophane spacer and a 25 μ teflon membrane covers the Ag/AgCl anode and the platinum cathode. The maternal tcPO₂ electrode surface has a diameter of 9 mm; its total diameter, including the plastic ring surrounding the electrode, is 20 mm. The response time of the electrode

Fig. 1. The central instrument Radiometer TCMI. Three windows displays from left to right: tcPO₂, electrode temperature and energy supply in mW to keep the temperature at a constant level ($\pm 0.1^\circ\text{C}$).

Fig. 2. A schematic figure of the electrode. The retaining ring used in this study gave a distance between skin and membrane of 0.1 mm.

Fig. 3. The electrodes with the fetal suction electrode taken out of the suction device (to the right).

(95% response) was 12–18 sec. The electrode is attached to the skin with double adhesive tape. The same type of electrode, modified by mounting the wire on the top of the electrode was used for some (12/19) of the fetal recordings, glue being used for attachment. For the remaining fetal recordings (7/19), the electrode was modified to fit into a suction device, as shown in Fig. 3. This construction allowed the electrode to be removed and recalibrated with the suction device left on the scalp. The suction amounted to 0.5 kp/cm².

1.3 Recording procedure

The electrodes were calibrated against air in a thermostated water solution immediately before and after each recording. For hygienic reasons an

antiseptic solution (UROCID[®]) was used. Once a day, the zero point was checked against nitrogen.

The maternal electrode was affixed to the sub-clavicular area. The fetal electrode was affixed to the fetal scalp by one of the methods previously described. The fetal head was not shaved, but sparsely-haired fetuses were preferred for this study. The fetal tcPO₂ electrode was attached to the vertex by means of a glue (HISTOACRYL[®]) in 12 cases and by means of a suction device (Radiometer pat.) in 7 cases. The space between the electrode membrane and the skin was filled with a contact jelly. The temperature of the electrode was preset at 44.5°C, yielding a skin temperature of approximately 43.5°C. An ordinary fetal scalp coil electrode for FHR recording was attached next to the tcPO₂ electrode. The fetal electrodes were

Tab. II. Drift of the tcPO₂ electrodes at recalibration.Drift maternal tcPO₂ electrode:

$\bar{x}$ mm Hg	+ 2.9
range	- 5 → + 12
ascending n	11
descending n	5

Drift fetal tcPO₂ electrode:

$\bar{x}$ mm Hg	- 4.1
range	- 24 → + 7
ascending n	8
descending n	9

Duration of tcPO₂ recording:

$\bar{x}$ min	62
range	10 → 120

applied when the cervix was dilated to 4–6 cm and the head stationed at approximately the inter-spinous line. After an initial adaptation period of 5–10 min., the recordings were begun.

2 Results

2.1 Electrode drift

The drift of the electrodes during measurement, defined as the difference between the calibrated value before and after the recording, was, on the average, + 2.9 mmHg for the maternal electrode and - 4.1 mmHg for the fetal electrode (Tab. II). However, a few extreme drifts were observed.

2.2 Maternal tcPO₂

The group mean for maternal tcPO₂ was 90 mmHg, with a range of 80–110 mmHg, with mothers breathing air (Tab. III). The maternal tracings showed a more or less pronounced wave-like pattern, these variations being closely related to the periodic changes of respiration induced by the labor pains.

Fig. 4. Minute for minute registration of tcPO₂ from the fetal scalp during labor in 19 patients. The level of one of the registrations apparently differs from the others. The cause of this was unknown, the electrode seemed appropriate attached and no air leakage into the electrode chamber was diagnosed. Most of the registrations were oscillating and showed a declining tendency of tcPO₂ throughout the recording time.

Tab. III. Maternal tcPO_2 during labor (mm Hg).

	Air breathing	$\text{N}_2\text{O-O}_2$ breathing	Temporary 100% O_2 breathing
$\bar{x}$	92	158	366
range	80–110	140–180	170–515
n	10	4	14

The maximal amplitude of the waves was 30 mmHg during air breathing.

In 14 patients, temporary hyperoxia was induced by administering 100% oxygen to the mother during a number of consecutive contractions. Thus a steady state of PO_2 did not exist. The mean maximum tcPO_2 recorded in association with this hyperoxia was 366 mmHg (Tab. III).

In a few patients to whom $\text{O}_2/\text{N}_2\text{O}$ (50%) was similarly administered, a mean maximum tcPO_2 of 158 mmHg was observed.

The average response time of the maternal electrode when administering oxygen to the mother was found to be 15 sec.

2.3 Fetal tcPO_2

Fig. 4 presents a composite diagram of all the fetal tcPO_2 recordings. The majority of recordings were begun during the first stage of labor, starting at somewhat different times (see above 1.3). Thus, the zero-point of the time scale in Fig. 4 depicts the moment when the recording was started for each individual case. The curves do not include the adaptation period (5–10 min). Fig. 5 shows the mean tcPO_2 level minute for minute, as derived from Fig. 4. The shaded area represents the range of tcPO_2 scores. Over 90 min. of recording, the group mean tcPO_2 declined from 20 to 14 mmHg. There was no significant difference between the tcPO_2 recordings obtained with different electrode

Fig. 5. Same as Fig. 4 with mean and range, showing a slight declining tendency throughout the measuring time. One rather high registration (dotted line) is separated from the rest of the material. The drift of the electrode during this deviating registration was -15 mmHg after 43 min.

attachment techniques. The tcPO_2 levels did not systematically change during contractions. The temporary maternal hyperoxia induced by breathing 100% O_2 produced a mean fetal tcPO_2 increase of 3 mmHg, the range of increase being 0–9 mmHg.

3 Discussion

3.1 Electrode characteristics

The drift values of both the fetal electrodes and the maternal electrode were low throughout the study, but a few pronounced drifts were observed in the fetal electrodes. However, the tcPO_2 recordings associated with these relatively large drift values did not differ in any significant manner from the recordings not associated with large drifts. This fact would suggest that the drifts observed are most likely to be artefacts caused by mechanical factors such as incorrect pressure on the electrode membranes, either from the fetal head during the recording or at abrupt disattachment of the electrode.

3.2 Maternal tcPO_2

Previous studies have shown that tcPO_2 and arterial PO_2 are highly correlated but not identical entities. The present results concerning maternal tcPO_2 measurements are in good agreement with the results published by other authors [12, 15, 16, 17]. That the electrode is highly sensitive is suggested both by the high correlation between the wave pattern of the tracings and the respiratory changes, and by the fast response at experimentally induced hyperoxia.

3.3 Fetal tcPO_2

The most notable finding was the rather wide range of the fetal tcPO_2 levels, particularly during the first half hour of the monitoring period. In one case an extremely high tcPO_2 level was observed; the drift of the electrode was -11 mmHg in this case. However, within the wide range, the curves show a somewhat parallel course. All curves showed a tendency to decline slowly during the period of measurement, the mean decrease being 6 mmHg. Others (for review see 2), have also re-

ported such a tendency as observed through scalp blood measurements. In the present series the tcPO_2 values have not been studied in association with PO_2 from the fetal scalp blood; however, the mean tcPO_2 value was quite similar to the mean fetal blood PO_2 values published in the literature [2, 12, 14, 15, 19, 20]. Yet, the relevance of the very low tcPO_2 levels observed in a few of the present cases is unclear, and it is impossible to determine to what extent these tracings have true physiological relevance versus might be due to technical factors. The electrodes are undoubtedly somewhat sensitive to excessive mechanical pressure, a problem which might be overcome, i.e., by diminishing the diameter of the electrode.

It might be assumed that the uterine contractions would influence the fetal blood PO_2 level [12]. In the present series of normal cases, uterine contractions were not found to influence the tcPO_2 levels of the fetus.

The extent of influence of maternal hyperoxia on the fetal PO_2 is still the subject of debate. In the present series a maximum rise of 9 mmHg in fetal tcPO_2 was obtained at temporary maternal hyperoxia, the maternal tcPO_2 averaging 366 mmHg. The result is in good agreement with those published by e. g. MORISHIMA [20]. However, the material should be enlarged in order to allow more precise evaluation of the effect of maternal hyperoxia on fetal PO_2 .

One possible source of error in measuring tcPO_2 in the fetal scalp is decreased skin circulation caused, for example, by a caput succedaneum or a rigid cervix. One approximate indication of the extent of cutaneous circulation might be obtained through the study of the electrode heating element energy supply which was necessary to maintain a constant skin temperature; the energy supply decreases when the circulation is reduced. While the heat isolation of the electrode constitutes a certain methodological error, differences in energy supply could nevertheless provide an approximate measure of circulatory disturbances in the underlying skin.

4 Conclusions

The continuous recording of tcPO_2 from the fetal scalp during labor is a working method, although some technical and physiological problems remain.

Intermittent fetal scalp blood PO_2 measurements are generally considered of low value in fetal surveillance [19]. This could be due to rapid fluctuations of the blood PO_2 level. Accordingly tcPO_2 might better reflect the fetal status. To confirm this and to analyse the physiological and clinical importance of tcPO_2 , further investigations are

necessary. These studies should include, inter alia, the study of the correlation with intermittent blood PO_2 , pH and FHR measurements. Such extended systematic studies including also tcPO_2 monitoring in breech presentation are currently in progress at this department.

Summary

Transcutaneous PO_2 (tcPO_2) measurement is a non-invasive method which gives continuous information about central PO_2 . The method has previously been tested primarily on newborns and adults, and reports on the applicability of the method on the fetus during labor are still scanty and restricted to case reports.

This paper reports on a systematic study of intrapartum fetal and maternal tcPO_2 -monitoring. The material is comprised of 19 parturients, the majority being nulliparae. All fetal presentations were vertex. The tcPO_2 recordings averaged one hour in duration (Tab. I). FHR was recorded simultaneously. In 12 cases the electrode was affixed with

glue, and in 7 cases a suction device was used for fixation. The electrode was attached when the cervix was dilated 4 to 6 cm. The mean tcPO_2 was 20 mmHg in the beginning of the registration, and showed a small decline in level throughout labor reaching 14 mmHg at the end of the registration period (Fig. 5). These values are in good agreement with those found by other authors in previous investigations. In some of the present cases, very low tcPO_2 values were recorded. The relevance of these low tcPO_2 values is unclear, and it is impossible to determine to what extent these tracings have true physiological relevance versus might be due to technical factors.

Keywords: Fetus, fetal disease, labor, scalp, transcutaneous oxygen.

Zusammenfassung

Bestimmung des transkutanen PO_2 bei Fet und Mutter unter der Geburt

Die Bestimmung des transkutanen PO_2 (tcPO_2) ist eine nicht-invasive Methode, die eine ständige Information über den zentralen PO_2 ermöglicht. Die Methode ist kürzlich zunächst bei Neugeborenen und Erwachsenen erprobt worden; Berichte über die Anwendbarkeit der Methodik beim Feten unter der Geburt sind nur vereinzelt vorhanden und beschränken sich auf Fallmitteilungen. Bei der vorliegenden Arbeit wird über eine systematische Untersuchung der intrapartalen, fetalen und mütterlichen tcPO_2 -Bestimmungen berichtet. Das Untersuchungsgut umfaßt 19 Kreißende, in der Mehrzahl Nulliparae. Alle Feten lagen in Schädellage. Die tcPO_2 -Bestimmungen dauerten im Mittel 1 Stunde (Tab. I). Die fetale Herzfrequenz wurde gleichzeitig mitbestimmt. In 12

Fällen war die Elektrode mit einem Gewebekleber und in 7 Fällen mit einer Saugvorrichtung am vorangehenden Teil fixiert. Die Elektrode wurde angelegt, wenn die Muttermundweite 4–6 cm betrug. Der mittlere tcPO_2 betrug 20 mm Hg zu Beginn der Registrierung und zeigte einen schwachen Abfall des Spiegels während der Geburt bis auf 14 mm Hg am Ende der Registrierdauer (Fig. 5). Diese Werte sind in guter Übereinstimmung mit jenen, die von anderen Autoren in früheren Untersuchungen gefunden wurden. In einigen der vorliegenden Fälle konnten sehr tiefe tcPO_2 -Werte gemessen werden. Die klinische Bedeutung dieser tiefen tcPO_2 -Werte bleibt unklar; es ist unmöglich festzulegen, in welchem Umfange diese Meßergebnisse eine wirkliche physiologische Bedeutung haben; sie könnten auch auf technische Faktoren zurückzuführen sein.

Schlüsselwörter: Fetale Erkrankung, Fet, Skalp, Transkutaner Sauerstoff, Wehentätigkeit.

Résumé

Monitoring du PO_2 transcutané chez le fœtus et la mère en cours de travail normal

La mesure du PO_2 transcutané (tcPO_2) est une méthode non-invasive qui fournit une information continue sur le PO_2 central. La méthode avait déjà été testée sur des nouveaux-nés et des adultes et les rapports relatifs à son application sur les fœtus en cours de travail sont encore insuffisants et limités à des observations.

Le présent article traite d'une étude systématique du monitoring de tcPO_2 fœtal et maternel intrapartum. Le matériel porte sur 19 parturientes dont la plupart étaient nullipares. Tous les fœtus se sont présentés par le vertex. Les enregistrements de tcPO_2 ont duré une heure en moyenne (Tab. I). Le FHR (fréquence cardiaque) a été enregistré simultanément. Dans 12 cas, l'électrode a été fixée avec de la colle et dans 7 cas par aspiration, mais,

chaque fois, pas avant que le cervix ne soit dilaté de 4 à 6 cm. Le tcPO_2 moyen a été de 20 mmHg au début de la courbe d'enregistrement pour baisser ensuite légèrement au cours du travail et atteindre 11 mmHg en fin d'enregistrement (Fig. 5). Ces valeurs concordent avec celles trouvées par d'autres auteurs dans des recherches

antérieures. On a pu observer dans quelques-uns de nos cas des valeurs très basses de tcPO_2 dont la cause nous échappe encore et il est impossible de déterminer dans quelle mesure ces relevés témoignent d'un processus physiologique authentique ou dépendent de facteurs techniques.

Mots-clés: Epicrâne, foetal, mal foetal, oxygène transcutané, travail.

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Received February 14, 1977. Accepted June 16, 1977.

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