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Monitoring the intravascular P_{O_2} in newborn infants

Albert Huch, Renate Huch, Gösta Rooth

Department of Obstetrics and Gynecology, Marburg/Germany,
Max-Planck-Institut für Arbeitsphysiologie, Dortmund/Germany,
Research Department 1, E-Blocket, University Hospital, Lund/Schweden

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It is often necessary to perform repeated P_{O_2} analyses on a patient. Particularly in the case of newborn infants it is technically difficult to obtain arterial blood samples and the sampling cannot be performed as often as desired. Furthermore — as we will show below — there are great **short-time variations in the arterial oxygen tension** (Pa_{O_2}), wich cannot be revealed by a single analysis.

In order to perform **continuous** P_{O_2} measurements we (A. H. and R. H.) have developed **three different types of electrodes** based on the CLARK principle [6]:

1. a **catheter electrode** for intravascular monitoring,
2. a **cannula electrode,** mainly for intraarterial monitoring in adults,
3. a **skin surface electrode** for transcutaneous monitoring of blood P_{O_2} on "arterialized" skin.

The present paper describes the catheter electrode and a clinical study of its efficiency in newborn infants. A preliminary report has already been published [13].

1. The P_{O_2} electrode

The following should be required of an electrode for intravascular P_{O_2} measurements: The electrode should be **small** and should at the same time have a **high mechanical stability** in order **to ensure flow independency** and **sufficient stability of calibration.** It should have a **minimal stirring effect,** but a sufficiently **quick response time;** these two requirements compete against each other. Finally there must be a guarantee against loss of any part of the electrode within the blood vessels; coagulation risk must be held low by using only teflon and polyethylene at exposed surfaces and the whole assembled electrode must be sterilizable.

Curriculum vitae

ALBERT HUCH: *Study of medicine in Göttingen. After State Examination and registration, from 1965 to March 1967 at Max-Planck-Institut für experimentelle Medizin, Abteilung Physiologie, Göttingen. Since April 1967 at Universitäts-Frauenklinik, Marburg. Since 1968 in laboratory research together with* R. HUCH *(Max-Planck-Institut für Arbeitsphysiologie, Dortmund) in the Universitäts-Frauenklinik, Marburg. Main fields of interest: Development and clinical trial of measuring systems and devices for intravascular and transcutaneous monitoring of blood-gases.*

1.1 Technical dates

Using the experience gained in LÜBBERS' institute [12, 22], a miniature P_{O_2}-CLARK-electrode was fitted into the tip of a standard feeding tube No. 5 [15]. The **outer diameter is 1.5 mm** and the **length of the electrode is 4.0—5.0 mm** (fig. 1). The details of the construction are shown in the diagram of fig. 2. A 15 μ platinum wire was welded to a 100 μ wire using an air-gas flame. The 100 μ platinum wire facilitates handling the 15 μ wire and provides mechanical support. A glass capillary was electrically moulded around the platinum cathode and then the glass-encased wire was glued with Araldite® into a 4.5—5.0 mm long silver tube — the anode. This silver cylinder has at one end the point of attachment for the feeding tube and at the other end a thread for the screwing on of a **teflon cap,** which has the same diameter as the feeding tube. A 12 μ teflon membrane was welded on to the cap, a

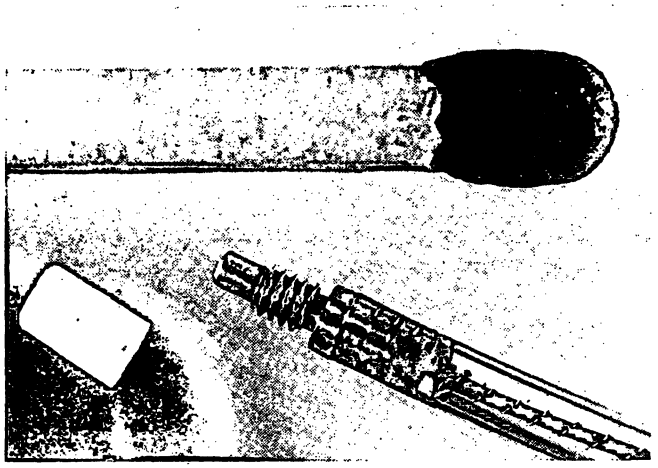

Fig. 1. P_{O_2} catheter electrode with detached screw-on teflon cap as compared to the head of a match.

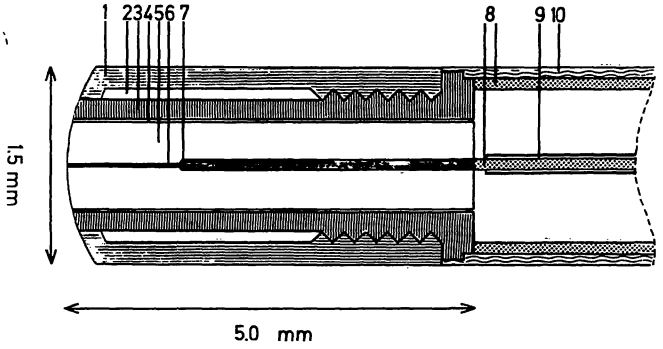

Fig. 2. Diagram of the P_{O_2} catheter electrode; 1 teflon membrane and cap, 2 electrolyte chamber, 3 Ag/AgCl anode, 4 Araldite®, 5 glass, 6 Pt 15 μ, 7 Pt 100 μ, 8 Cu-shielding, 9 insulation, 10 feeding tube.

procedure which requires great technical skill. The screwing on the cap guarantees its fixation and the obtained tension of the membrane provides constant calibration.

The electrode is prepared by applying a moist **cuprophane membrane** [10] between the cap and the electrode and by filling the cap with electrolyte. Experience has proved that preference should be given to a **0.2—0.5 M gel-like KCl electrolyte.** Air bubbles must be avoided. This is a decisive point for the perfect functioning of the electrode. In order to facilitate the electrode assembling a simple mounting device was built.

1.2 Calibration

The 95% response time of our electrode is 3—4 sec. The calibration curve is **linear** as shown in fig. 3. Consequently, calibration with **two gases of known P_{O_2}** is sufficient. The calibration was performed in water at 37° C equilibrated with nitrogen and with air respectively. The current

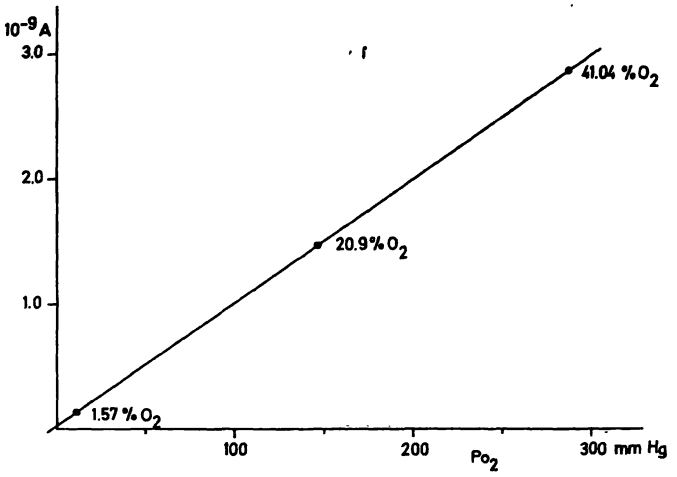

Fig. 3. Calibration curve.

at 0 mm Hg was smaller than 0.05 $\times$ 10^{-9} A and at the P_{O_2} of air (approx. 150 mm Hg) between 1.2 and 1.8 $\times$ 10^{-9} A. The applied voltage was about 700 mV. As amplifiers we used nano-ampèremeters of KNICK, Berlin. Continuous registration of the output from the electrode was made with a RIKADENKI Multi-Pen recorder (HELLIGE, Freiburg) with a chart speed of 120 mm/min and a paper width of 250 mm.

24 hours before use, the electrode was assembled, tested and **sterilized with ethylene oxide at high vapor pressure,** the latter in order to avoid drying of the electrode. Shortly before use the electrode was calibrated in sterile distilled water.

2. Material

Nine newborn infants were studied. The deliveries were uncomplicated and there were no signs of fetal distress. Immediately after delivery the cord was clamped and the infant brought to the resuscitation room where the monitoring equipment was held in readiness. The mothers' consent was obtained after we had explained to them that we were testing new equipment for monitoring asphyxiated infants and needed experience with healthy ones.

The catheter was inserted 7 to 10 cm beyond the umbilicus through one of the umbilical arteries and lodged in the descending aorta. The respiration rate was registered from changes in the intraoesophageal pressure.

3. Results

In seven infants the catheter was in place within five minutes after birth and in one of these within the second minute. There was a rise in oxygen tension in all these cases as shown in fig. 4. **The individual variations were such that mean values are of little use.** During the first minutes after birth most of the infants had a Pa_{O_2} of 25—35 mm Hg which increased to 55—75 mm Hg after eight to ten minutes. As also shown in fig. 4, in the five cases studied beyond twelve minutes there was a small decrease in Pa_{O_2} at about ten minutes after birth.

There were consistently considerable variations in Pa_{O_2} in one and the same infant as shown in fig. 5. This was a quiet infant, whose Pa_{O_2} varied as much as 28 mm Hg in 25 sec. These changes were parallel to variations in the respiratory rate.

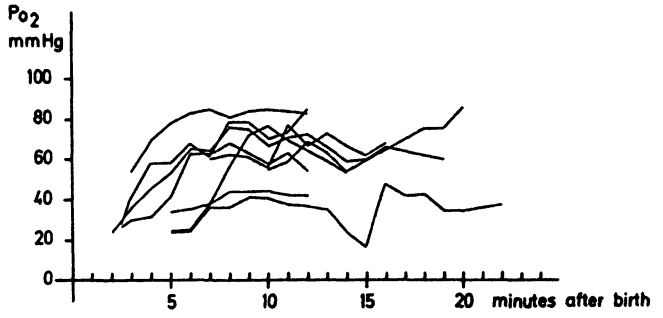

Fig. 4. Po_2 increase after birth in 9 healthy newborn infants. The curves represent the Pa_{O_2} values taken from the 9 individual continuous recordings at one-minute intervals.

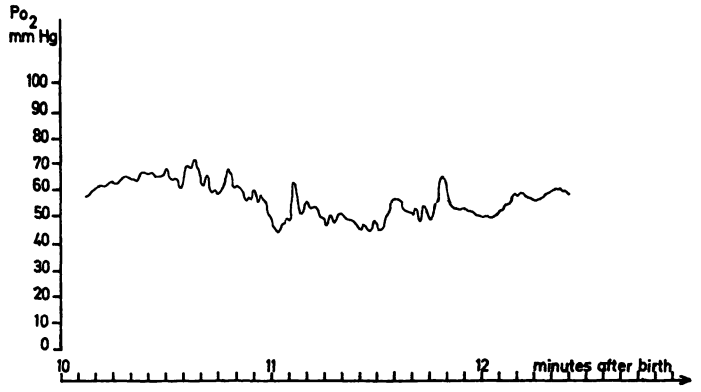

Fig. 5. Part of a continuous recording illustrating the Pao_2 variations of a newborn infant during air-breathing.

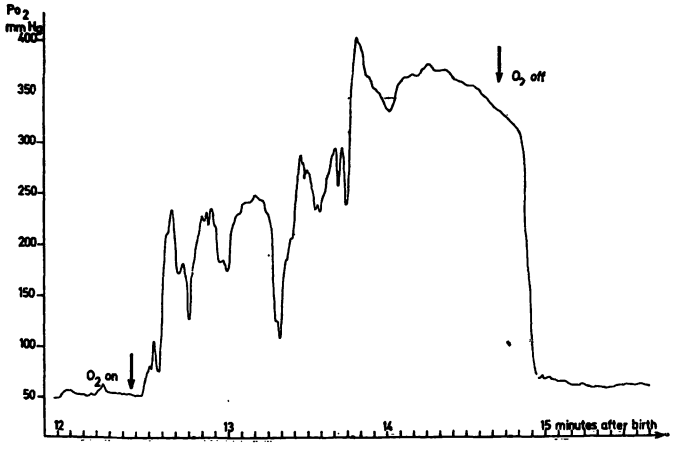

Fig. 6. Part of a continuous recording illustrating the Pa_{O_2} increase of a newborn infant during supplementary oxygen administration (75% O_2/25% N_2).

Once a relatively stable level of Pa_{O_2} was obtained, **additional oxygen** was given to five infants. A mixture of 75% oxygen and 25% nitrogen was administered by face mask. As shown in figs. 6 and 7, **Pa_{O_2} increased to more than 100 mm Hg within 5 sec. and reached a maximum value of about 400 mm Hg.** Occasionally Pa_{O_2} showed variations of up to 100 mm Hg from one breath to another.

In one case the supplementary oxygen was given twice and in another case three times for a period of 30 sec. each. Inbetween, the initial Pa_{O_2} levels were observed and the same peak levels were reached.

By contrast, in another two infants the Pa_{O_2} increase was relatively small during oxygen inhalation and the peak values remained below 100 mm Hg. We noticed that these infants — unlike the others — **cried strongly.**

Catheterization never lasted more than 17 minutes. After the measurement the electrode was recali-

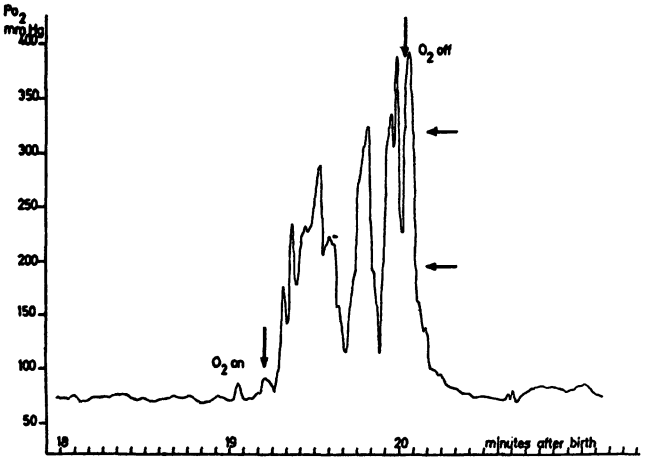

Fig. 7. Part of a continuous recording illustrating the Pao_2 variations of a newborn infant during supplementary oxygen administration (75% O_2/25% N_2). The horizontal arrows mark a single breath.

brated. Should a drift in the calibration have occured this could easily corrected as the drift is linear with time. No complications were observed.

4. Discussion

Repeated information concerning arterial P_{O_2} is of primary interest in respiratory distress and other serious conditions of the infant as recently reported in the work of VESNY, CLARK, JUNG and JENKINS [31], who developed a system for automated intermittent blood sampling similar to FABEL's [8]. Such a type of intermittent blood sampling has certain limitations, not only because of the small blood volume of infants, but also because of the loss of information due to a damping effect which results because blood sampling cannot be performed at the same speed as that at which variations in the blood stream occur. By comparison, intravascular monitoring of P_{O_2} has several advantages. **Continuous and fast information** unaffected by the mentioned damping effect is obtained. **No blood needs to be drawn.** Heretofore the technical difficulties have been great: None of the published studies on intravascular measurements in adults resulted in commercially available electrodes nor were any of the various catheter electrodes described in literature tested in human patients [1, 3, 5, 16, 17, 18, 19, 20, 23, 24, 26, 27, 28, 30].

The present modification of the CLARK electrode has proven to be reliable. It fullfils the requirements mentioned at the beginning of this paper provided the person using the electrode has experience in handling and assembling this micro-electrode under the microscope. This should not be difficult for anyone who already has experience with P_{O_2} measurements. In order to be sure that after the 24 hours sterilization at least one of the electrodes is still an optimally working instrument, it is advisable to prepare two or three micro-electrodes and to sterilize them simultaneously.

Drying during sterilization or defects of the membrane are **the main causes of incorrect functioning.**

The accuracy of a **continuous** measurement cannot be described by conventional criteria used for **single** measurements. In the present paper the accuracy of the analysis depended mainly on the calibration and not so much on the error of the measuring unit and of the recorder. If calibration is constant the P_{O_2} values during continuous measurements are as accurate, if not better, than those obtained with any of the methods for in vitro blood P_{O_2} measurements [10, 25, 29].

4.1 Practical conclusions

The present study was undertaken in order to gather practical experience with the electrode before its clinical use in sick infants. **We have seen that continuous intravascular measurements allow us to observe physiological variations** which cannot be revealed by other monitoring systems, **The arterial P_{O_2} already varies greatly in healthy newborn infants because of variations in respiration, pulmonary circulation and oxygen tension in the surrounding air; all the more should it be continuously controlled in sick infants — particularly during O_2-inhalation.** We have since observed similar changes in adult patients whose arterial P_{O_2} was monitored with a cannula electrode [14].

This study has confirmed the earlier results as to the level and increase in Pa_{O_2} during the first minutes of life [2, 7, 9, 21]. The experience gained during the supplementary oxygen inhalation **contradicts** earlier textbook information stating that, because of shunting, Pa_{O_2} cannot exceed 100 mm Hg during the first hour of life and agrees with the results of GAUCH, BEUTNAGEL and FABEL [9]. **We found that in normal infants toxic levels of oxygen tension may be already attained within the first minutes of life.** Although it is doubtful and unlikely that such levels will be seen in sick infants, the results indicate that routine oxygen administration should never be given to newborn infants.

Additional studies are necessary to verify and quantify the observation that **resting infants have less shunting during oxygen inhalation than crying infants.** In the labile stage of relative pressures in the systemic and pulmonary circulation it would not be surprising if shunting increased during crying.

4.2 Complications

The use of intraarterial catheters carries a certain risk, as shown in recent studies [4, 11] and the longer the catheters are in situ, the greater the risk. In clinical practice, however, this is justified by the information obtained and intraarterial monitoring with catheter electrodes should be less harmful than repeated arterial sampling. In the present short time study, **no complications were noted.**

Summary

In newborn infants with respiratory distress syndrome it is often necessary to measure the arterial P_{O_2} repeatedly. However, it is usually difficult to obtain the desired number of blood specimens. We therefore developed a **catheter P_{O_2} electrode** to be inserted through one of the umbilical arteries into the aorta. This allows **continuous registrations of arterial P_{O_2}.**

A very small P_{O_2} electrode was built according to the CLARK principle and fitted on to the tip of an ordinary feeding tube No. 5 (figs. 1 and 2). An important feature of the construction of the electrode is a **detachable teflon cap** with an oxygen-permeable teflon membrane. Because this cap can be screwed on and off, the electrode may be easily assembled and reproducible calibration values are obtained. The coagulation risk was diminished by the use of teflon and polyethylene on the exposed surfaces. The whole assembly may be **sterilized in ethylene oxide.**

The electrode is fast, with a **95% response time of only 3—4 sec.,** the calibration is easy to perform (fig. 3), the stability is high, and the flow dependency is low.

This new catheter electrode was tested in nine healthy newborn infants. The consent of the mothers was always obtained. The catheter was inserted as soon as possible after birth, in the earliest case within 2 minutes. The arterial P_{O_2} changes were continuously monitored for up to 17 minutes.

Our continuous measurements confirmed earlier results, based on intermittent blood sampling, regarding the postnatal Pa_{O_2} increase (fig. 4) and the postnatal level of Pa_{O_2}.

A new observation was that Pa_{O_2} varies as much as 20—30 mm Hg within a few seconds even during air-breathing in healthy newborn infants (fig. 5). Consequently it is hardly possible any longer to speak of one single Pa_{O_2} value as has been done. We also found that during inhalation of supplementary oxygen the arterial P_{O_2} could vary as much as 200 mm Hg after a few breaths (fig. 7). **Consequently toxic Pa_{O_2} levels may be already attained within the first 10 minutes of life in healthy newborn infants who have been given oxygen** (figs. 6 and 7). This new oxygen electrode proved itself reliable for continuous monitoring of the arterial P_{O_2} both qualitatively and quantitatively. No complications were observed.

Keywords: Newborn, Infant, Monitoring system, Blood gas analysis, Oxygen, Respiration, Catheterization

Zusammenfassung

Überwachung des intravaskulären P_{O_2} beim Neugeborenen

Es ist oft notwendig, bei Neugeborenen mit Atemstörungen den arteriellen P_{O_2} wiederholt zu kontrollieren. Da ständige Blutabnahmen beim Säugling technisch schwierig und nicht in beliebiger Anzahl durchzuführen sind, wurde von uns eine **P_{O_2}-Katheter-Elektrode** entwickelt, die nach Einführung über eine der Arteriae umbilicales **in der Aorta P_{O_2}-Veränderungen kontinuierlich** registrieren kann.

Eine Miniatur-P_{O_2}-Elektrode nach dem CLARK-Prinzip wurde in die Spitze einer handelsüblichen Ernährungssonde Nr. 5 eingepaßt (Abb. 1, 2). Das wesentliche Konstruktionsmerkmal der Elektrode ist eine **aufschraubbare Teflonkappe,** auf die ihrerseits die sauerstoffdurchlässige Membran fest aufgeschweißt ist. Mit Hilfe dieser Kappe kann die Elektrode relativ einfach hergerichtet werden. Das Koagulationsrisiko wurde durch Verwendung von ausschließlich Teflon und Polyäthylen an den exponierten Teilen reduziert. Die hergerichtete Elektrode kann **mit Äthylenoxyd sterilisiert** werden.

Die Elektrode ist schnell; die **95% Einstellzeit** beträgt nur **3—4 sec.** Die Eichung ist einfach durchzuführen (Abb. 3). Flow independency und Eichstabilität sind ausreichend groß.

Die neue Katheter-Elektrode wurde bei 9 gesunden Neugeborenen erprobt, von deren Müttern die Einwilligung zur Untersuchung vorlag. So schnell es möglich war, wurde der Katheter nach Geburt eingeführt. Im frühesten Fall lag der Katheter in der 2. Lebensminute in situ. Die arteriellen P_{O_2}-Veränderungen wurden längstens 17 Minuten lang kontinuierlich registriert.

Unsere kontinuierlichen Messungen konnten frühere, durch intermittierende Blutabnahmen gewonnene Ergebnisse wie einen initialen P_{O_2}-Anstieg (Abb. 4) und die Größenordnung der arteriellen P_{O_2}-Werte unmittelbar nach Geburt bestätigen.

Darüber hinaus aber konnte gezeigt werden, daß es auch **bei gesunden Neugeborenen unter Luftatmung nicht einen arteriellen P_{O_2} gibt, sondern daß innerhalb weniger Sekunden Pa_{O_2}-Schwankungen zwischen 25 und 30 mm Hg physiologisch in dieser Lebensphase sind (Abb. 5).**

Die kontinuierlichen Messungen demonstrieren auch, daß bei gesunden Neugeborenen bei O_2-Atmung der Pa_{O_2} innerhalb weniger Atemzüge um rund 200 mm Hg variieren kann (Abb. 7) und daß bereits **in den ersten Lebensminuten toxische Pa_{O_2}-Werte erreicht werden können, wenn Beatmung mit Sauerstoff** erfolgt (Abb. 6, 7).

Die neue Katheter-Elektrode hat sich in der vorliegenden Studie als sehr geeignet erwiesen, den arteriellen P_{O_2} qualitativ und quantitativ kontinuierlich zu registrieren. Komplikationen wurden nicht beobachtet.

Schlüsselwörter: Neugeborenes, Überwachung, Blutgasanalyse, Sauerstoff, Atmung, Katheterismus, Elektrode, Messung-kontinuierliche.

Résumé

Surveillance continue de la P_{O_2} intra-vasculaire chez le nouveau-né

Chez le nouveau-né présentant un syndrome de détresse respiratoire, il est souvent nécessaire de mesurer la P_{O_2} artérielle de manière répétitive. Cependant, il est habituellement difficile d'obtenir le nombre désiré d'échantillons sanguins. Nous avons été ainsi amenés à mettre au point **une électrode à P_{O_2} montée sur un cathéter** susceptible d'être introduit dans l'aorte par les artères ombilicales.

Une très petite électrode à P_{O_2} construite selon le principe de CLARK a été fixée à l'extrémité d'une sonde d'alimentation ordinaire n°. 5 (fig. 1 et 2). Une importante particularité du montage est l'existence d'un **embout de teflon détachable,** porteur de la membrane perméable à l'oxygène. Cet embout pouvant être facilement dévissé, le montage de l'électrode et sa calibration sont aisés. Le risque de coagulation est diminué du fait de l'utilisation de teflon et de polyéthylène sur les surfaces exposées. L'ensemble peut être **stérilisé par l'oxyde d'éthylène.**

L'électrode est rapide: elle atteint 95% de la réponse en 3 à 4 secondes. La calibration est facile à faire (fig. 3), la stabilité est élevée et le débit ne la modifie guère.

Cette nouvelle électrode a été testée chez neuf nouveau-nés en bonne santé. L'accord des mères avait toujours été obtenu. Le cathéter était introduit dès que possible après la naissance, le délai le plus court ayant été de 2 minutes pour un cas. Les changements de la P_{O_2} artérielle ont été suivis en continu jusqu'à 17 minutes après l'introduction du cathéter.

Nos mesures continues ont confirmé les résultats antérieurs obtenus à partir d'échantillons isolés, tant pour l'élévation post-natale (fig. 4) que pour le niveau post-natal de la Pa_{O_2}.

Mais de plus, nous avons pu montrer qu'au début de la respiration chez le nouveau-né sain la Pa_{O_2} peut varier en quelques secondes de 25 à 30 mm Hg (fig. 5). En conséquence, il est dorénavant difficile d'attacher une valeur à une mesure unique de la Pa_{O_2} au cours de cette période de la vie.

Nous avons pu montrer également que durant l'inhalation d'oxygène supplémentaire la P_{O_2} artérielle pouvait varier de 200 mm Hg après quelques inspirations (fig. 7). **Ainsi des taux toxiques de Pa_{O_2} peuvent être atteints dès les dix premières minutes de la vie chez des nouveau-nés sains auxquels on donne de l'oxygène (fig. 6 et 7).**

Cette nouvelle électrode à oxygène s'est avérée satisfaisante pour la surveillance continue de la P_{O_2} artérielle, tant qualitativement que quantitativement. Aucune complication n'a pu être observée.

Mots-clès: Nouveau-né, oxygène, oxygène (mesure d'), analyses des gaz du sang, électrode.

Acknowledgment

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Priv.-Doz. Dr. Albert Huch
Univ.-Frauenklinik
D-3550 Marburg
Pilgrimstein 3
Germany