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Clinical experience on $tcPco_2$ during labor

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1 Introduction

While the number of fetuses endangered by hypoxia has been reduced to a large extend after the introduction of fetal blood sampling and cardiotocography both techniques have shortcomings [1, 2, 6, 8]. The cardiotocography is a reliable screening technique as the occurence of fetal hypoxia is in most cases indicated by the heart rate pattern. On the other hand the large amount of false positive indications of fetal distress in the CTG leads to unnecessary operative deliveries, when the technique is used as the only method of surveillance [3, 5, 11]. The additional use of the fetal blood analysis (FBA) provides a reliable diagnosis of fetal distress but has the disadvantage of being a random test and that it gives informations only intermittently. Furthermore, a traumatization of the fetal skin is a precondition for FBA as an incision in necessary to get the blood sample [8]. In order to evaluate the potential clinical benefit of fetal $tcPco_2$ measurement, which provides continuous information about the biochemical status of the fetus in a nontraumatic way a clinical trial was performed in our unit using a biochemical $tcPco_2$ sensor [4, 10]. Within this trial we tried to answer the following questions:

Is it possible to define the normal range of $tcPco_2$ levels?
What is the relationship of $tcPco_2$ and the acidity of fetal blood?
Has the $tcPco_2$ level a prognostic value for the clinical status of the newborn infant?

2 Material and methods

$tcPco_2$ measurements were performed on 224 high risk fetuses during labor in addition to combined supervision by means of continuous CTG and intermittent fetal blood sampling. All cases has suspicious, prepathologic or pathologic heart rate patterns, either at the admission or in the delivery room. Fetal blood analysis was performed according to the indications defined by SALING [8]. 154 patients were para I, 31 were para II, 39 were para III or more. Operative delivery for fetal distress was performed in 30 patients (13%). The indication for operative delivery was in 21 cases a critical value of the pH (pH < 7.25 with decreasing tendency) and in 9 cases a pathologic heart rate pattern occuring after the fetal head had reached the pelvic floor. In another 72 cases an operative delivery had to be performed because of the arrest of labor. 122 infants were born spontaneously, 54 by vacuum extraction, 15 with the help of Saling spoons and 33 by cesarean section. All infants had vertex presentation. 102 patients received epiduralanesthesia. The status of the newborn was investigated by both biochemical and clinical parameters. The biochemical status was evaluated by a pH measurement of a blood sample from the umbilical artery collected directly after birth of the babies. In one case pH level in the umbilical artery was 7.09, in 12 cases it was $7.10-7.19$, in the remaining cases the pH was ≥ 7.20. The clinical status of the newborn was evaluated using a modified score according to SALING [7]. All infants were born in vigorous state (score: ≥ 7).

A modified Severinghaus electrode was used for all the measurements [10]. By modification of a commercially available $tcPco_2$ electrode (Radiometer E 5230) we have succeeded in improving the application to the fetal head and additionally integrated an ECG electrode into the measuring chamber of the transcutaneous system, so that the penetration of the fetal scalp has become superflu-

ous. Details of this design are reported elsewhere [9]. In the study an electrode temperature of 39 °C (n = 105) respectively 44 °C (n = 119) was chosen. Due to the CO_2 production of the skin and the effect of the raised temperature the $tcPco_2$ values exceeded the values of the fetal blood. This methodological deviation, which is more pronounced at a measuring temperature of 44 °C as compared with 39 °C can be corrected by a formular proposed by SEVERINGHAUS [10]. During the study no correction was used for the influence of the heating temperature of the electrode.

For the statistical evaluation of the data the $tcPco_2$ measurements, the biochemical values and the clinical data of the patients were evaluated with the Statistical Package for Social Science (SPSS) of Northwestern University. The normal range of the $tcPco_2$ values was defined calculating the mean value and two standard deviations of $tcPco_2$ at either 39 °C or 44 °C in cases, in which no hypoxic complication occurred. For the comparison between the $tcPco_2$ and the pH level the linear correlation coefficient, the slope, and the intercept were calculated. The result was drawn up graphically on a printing machine. The ability of $tcPco_2$ registration for identifying or excluding a risk to the fetus was calculated. In order to evaluate the relation between fetal acidity, fetal heart rate pattern and $tcPco_2$; normal, prepathologic and pathologic results of either method were compared and the contigency coefficient according to Pearson was calculated. For this evaluation a retrograde cardiotocogram of the 30 preceeding minutes was analyzed by means of the HAMMACHER score [1]. Furthermore, the mean value of the $tcPco_2$ during normal, prepathologic and pathologic heart rate patterns was calculated.

In order to evaluate the prognostic value of $tcPco_2$ measurements in the fetus during labor with regard to the prediction of neonatal outcome, the level of $tcPco_2$ was sampled with a frequency of 10 minutes during the second stage of labor and compared with the result on the assessment of the neonatal outcome.

3 Results

As a result of our investigation on the normal range of fetal $tcPco_2$ during labor we found, that these values are dependent on the selected temperature. Using a measuring temperature of 44 °C we found a value of 55.91 mmHg ± 4.39 (SD) for the early first stage of labor while during the second stage of labor the value was 67.28 mmHg ± 10.63 (SD) (figure 1) as can be expected at a measuring temperature of 39 °C the values are significantly lower ($p < 0.05$). Here we found a value of 50.87 mmHg ± 9.81 (SD) respectively 58.67 mmHg ± 10.51 (SD). In order to evaluate the relationship between $tcPco_2$ and pH values in the fetal blood, the actual pH value was compared with the synchronously recorded $tcPco_2$ value. At both measuring temperatures we found a statistically significant correlation ($p < 0.001$). The correlation coefficient for 44 °C was −0.53, the intercept 788.83 and there was a negative slope of −0.99 (figure 2). While there was a considerable scattering of $tcPco_2$ values in the pH range of above 7.25 no preacidosis occurred during $tcPco_2$ values of ≤ 70 mmHg and no pH values of < 7.20 were observed with $tcPco_2$ values of ≤ 80 mmHg. At a measuring temperature of 39 °C we found a correlation coefficient of −0.57, an intercept of 812.09 and a slope of −1.03 (n = 135). No preacidotic values were observed with $tcPco_2$ values ≤ 55 mmHg, while acidotic

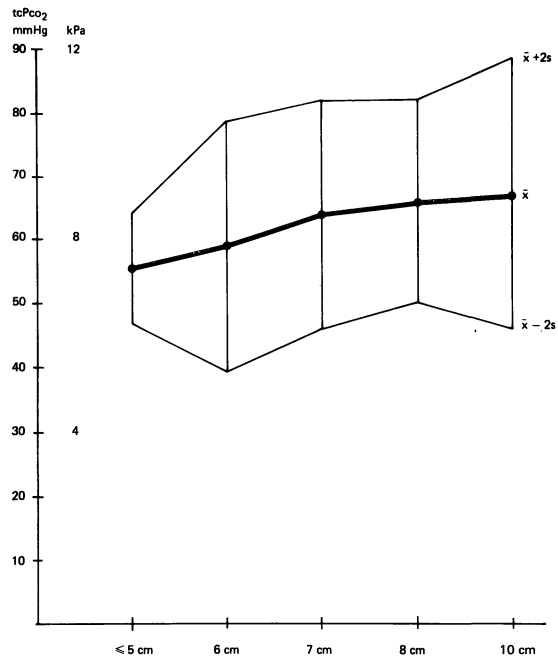

Figure 1. The normal range of $tcPco_2$ in the fetus during labor. A considerable rise occurs with the dilatation of the cervix from 5 to 10 cm. The $tcPco_2$ was measured at 44 °C. Values were not corrected for the temperature effect and the Pco_2 production of the tissue.

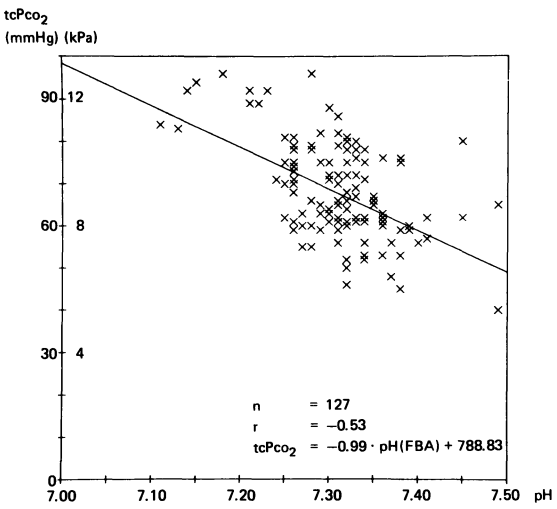

Figure 2. Comparison of $tcPco_2$ with the pH values in the fetal blood (FBA). The $tcPco_2$ was measured at 44 °C. Values were not corrected for the temperature effect and the Pco_2 production of the tissue. 80 mmHg was chosen as a clinical action line as all acidotic values (pH < 7.20) and most preacidotic values (pH < 7.25) corresponded with $tcPco_2$ values above this level. Below 70 mmHg preacidotic values were not found.

values did not occur with $tcPco_2$ values ≤ 63 mmHg at this temperature. During the measurement of $tcPco_2$ at a measuring temperature of 44 °C and using an arbitrary action line of 55 mmHg, when adjusted to the blood gas level, a preacidosis could be correctly identified in 9 cases. In one case preacidosis was not recognized. In 8 cases preacidosis could not be excluded. During the measurement of $tcPco_2$ at a measuring temperature of 39 °C a preacidosis could be correctly excluded in 96 cases. In 8 cases preacidosis was correctly identified. In 5 cases preacidosis was not recognized. In 26 cases preacidosis could not be excluded. The $tcPco_2$ level here exceeded the value of the action line, whilst the pH level was > 7.24. According to these results we calculated a sensitivity of 0.61 for 39 °C and 0.90 for 44 °C, while the specificity was 0.79 for 39 °C and 0.93 for 44 °C.

As a result of the comparison of normal, prepathologic and pathologic pH values with $tcPco_2$ values of ≤ 70, 71−80 and 80 mmHg we found a significant relationship. We calculated a contingency coefficient of 0.58 according to Pearson (71.19%). Additionally, the data shown in table I demonstrate the potential clinical benefit of $tcPco_2$

Table I. Comparison of $tcPco_2$ values with pH values during the first stage of labor (44 °C).

pH value	$tcPco_2$ values (mmHg)		
	⩾70 normal	71−80 prepathologic	>80 pathologic
≥ 7.25 normal	66	29	4
7.20−7.24 prepathologic		1	2
< 7.20 pathologic			4

Table II. Comparison of fetal heart rate pattern according to the Hammacher score with pH values during the first stage of labor (44 °C).

pH value	Fetal heart rate pattern		
	0−2 normal	3−7 prepathologic	⩾ pathologic
≥ 7.25 normal	4	79	16
7.20−7.25 prepathologic		1	2
< 7.20 pathologic	1	1	2

monitoring, as the large majority (96 out of 106) of fetal blood samplings necessary to exclude fetal distress during the first stage of labor would be superfluous using an action line of 80 mmHg (see above). Comparing the pH values with the result of the fetal heart rate pattern we calculated a contingency coefficient of 0.31 (39%, see table II). Using the Hammacher score instead of the Saling indication for fetal blood sampling the clinical benefit would have been only of minor degree as only in five cases (score 2−0) the result was normal. Comparing the mean values of $tcPco_2$ found in cases with different Hammacher scores we found that the $tcPco_2$ is not significantly different between cases with normal (score 0−2) or suspect (score 3−4) CTG (figure 3). On the other hand the mean $tcPco_2$ value of prepathologic and pathologic heart rate patterns (score ≥ 5) is significantly elevated (74.58 ± 13.08 [SD]).

Comparing the $tcPco_2$ level during the second stage of labor with the status of the newborn we

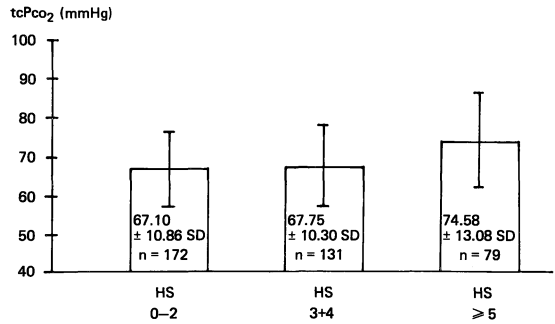

Figure 3. Mean values of $tcPco_2$ (44 °C) in cases with 0–2, 3 + 4 and > 5 points in the Hammacher scoring (HS) system. While there is no significant difference of the $tcPco_2$ values between normal and suspect heart rate patterns, the $tcPco_2$ is significantly higher, when prepathologic or pathologic heart rate patterns occur.

found an obvious relationship. The mean value of the $tcPco_2$ during the second stage of labor in cases with a pH of ≥ 7.30 in the umbilical artery was 63.37 ± 10.56 (SD), in cases with a pH of 7.20–7.29 the mean value was significantly higher (70.03 ± 10.73). In cases with acidosis the mean value was 73.38 ± 9.76. The good prognostic value of the $tcPco_2$ level during the second stage of labor is also indicated by the close relationship to the clinical status of the neonate (figure 4). While all babies were born in a vigorous state [8], the Saling score differentiates between babies that are born without depression. Those born with optimal status showed the lowest $tcPco_2$.

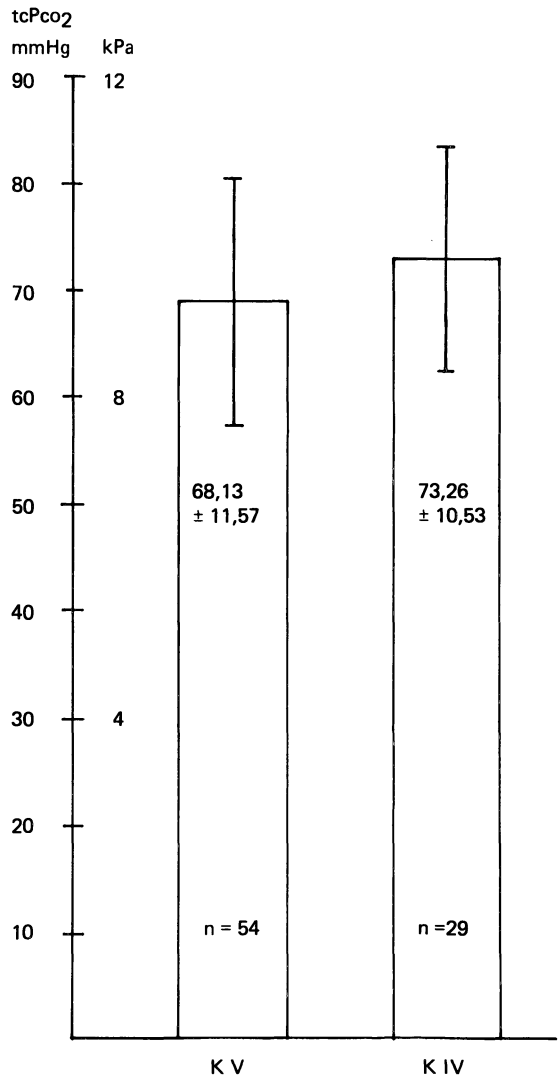

Figure 4. Mean value of $tcPco_2$ according to the result of the neonatal assessment. The level of the $tcPco_2$ during the second stage of labor is significantly lower in cases, where the baby is born with the optimum result in the scoring system. KV: □ KIV: □.

4 Discussion

The newly available biochemical $tcPco_2$ sensor potentially is a usefull additional tool for the clinical management of high risk deliveries. A precondition of its adequate use is a definition of the normal range of values in the fetus during labor. Due to the peculiarities of transcutaneous CO_2 measurement with heated sensors the measuring technique itself influences the actual $tcPco_2$ values by elevating the Pco_2 due to the temperature effect. In order to adjust the $tcPco_2$ values to the blood gas level the Pco_2 production of the tissue has to be taken into account. The normal range of the $tcPco_2$ as defined by our clinical trial after correction of the above mentioned factors corresponds well with the normal range of the Pco_2 evaluated by means of fetal blood sampling. For the clinical use of the $tcPco_2$ monitoring as a continuous biochemical parameter the question how accurate changes of acidity are indicated is most critical. Its additional use during high risk deliveries should lead to an early detection of changes in the gas transfer, providing a basis for prophylactic obstetrical action, aiming at the avoidance of severe metabolic acidosis and clinical depression of the baby at the moment of delivery. Such early detection will give time for intrauterine resuscita-

tion and will thus rather reduce than increase number of operative deliveries. The percentage of operative deliveries for fetal distress during our clinical trial (13%) supports this assumption. A more conservative obstetrical view will rather stress the necessity to detect severe complications leading to metabolic acidosis. A $tcPco_2$ rise during intrauterine complications can be expected, when the Pco_2 rises due to impairment of carbon dioxide transfer from the fetus to the mother and also when a certain amount of carbon dioxide will be displaced when the concentration of lactic acid in the fetal blood increases. Further, fetal shock syndrome can be detected by an increase of the difference between transcutaneous Pco_2 values and Pco_2 values in the fetal blood during centralization of the fetal circulation. In this way the transcutaneous measurement could indicate fetal distress even at normal blood Pco_2 levels in the cause of a progressing disturbance. During our clinical trial the occurrence of an acute complication was in all cases indicated by the rise of the $tcPco_2$ value from its original level to a value of the $tcPco_2$ above 80 mmHg respectively 63 mmHg at a measuring temperature of 44 °C respectively 39 °C.

As pH values of the fetus during labor in the cause of an intrauterine complication might change rapidly, it is essential to compare synchronously selected data. A time lag between the end of the transcutaneous tracing and the blood sampling for pH analysis will thus lead to results that are misleading.

One main clinical benefit of the additional use of the $tcPco_2$ is the possibility to reduce the number of fetal blood samplings in cases with abnormal heart rate patterns (see tables I and II). In this context it is an interesting finding, that $tcPco_2$ values above the normal range (80 mmHg) usually indicate critically raised fetal acidity (pH < 7.25), when a measuring temperature of 44 °C is used (figures 1 and 2). Such benefit cannot be expected to the same extent, when the electrode temperature is reduced (39 °C). While it has been shown by previous investigations that the risk of a critical raise in acidity is neglectable during normal heart rate patterns false positive results indicating fetal distress that does not really exist cannot be avoided, even using cumbersome scoring systems such as the Hammacher score. From our data we can expect to reduce fetal blood sampling to a large extent by using the $tcPco_2$ (table I).

Of special clinical interest is the good prognostic value of the $tcPco_2$ to predict the biochemical and clinical status of the newborn. Hopefully it will help to improve the selection of cases, in which operative delivery for fetal distress is actually necessary [3].

Summary

$tcPco_2$ measurements in the fetus during labor were evaluated by analysing the clinical experience in 224 cases. This additional mode of supervision was performed in combination with continuous cardiotocography (CTG) and intermittend fetal blood sampling (FBA) in cases with suspect, prepathologic or pathologic heart rate patterns. The prechosen measuring temperature was 39 °C in 105 and 44 °C in 119 cases. The normal range of the $tcPco_2$ was defined by calculating the mean value and two standard deviations in cases without hypoxic complications. The absolute values of the normal range were different according to the measuring temperature, when no correction factor was used. After adjusting the transcutaneous values to the blood gas level by means of the Severinghaus formular no significant differences in the $tcPco_2$ values were notified for the two applied temperatures (39 °C and 44 °C). There is an obvious rise of $tcPco_2$ with the progress of labor. Comparing the $tcPco_2$ values with the pH values in the fetal blood we found a statistically significant correlation at either temperatures ($p < 0.001$). Aiming at an early detection of raising acidity in the fetal blood, an action line of 55 mmHg after correction (80 mmHg at 44 °C, 63 mmHg at 39 °C) is an adequate basis for clinical intervention as all acidotic (pH < 7.20) and the majority of preacidotic value (pH 7.20 – 7.24) can be excluded. One clinical benefit that can be expected by the additional use of $tcPco_2$ is the reduction in the necessity of fetal blood sampling in a number of cases with abnormal heart rate patterns. At a measuring temperature of 44 °C FBA becomes superfluous in 90%. While operative delivery for fetal distress was performed in only 13% of cases with abnormal CTG, all babies were born in viguorous state (modified Apgar score ≥ 7).
The $tcPco_2$ measurement seems to be a useful additional tool especially in cases with abnormal heart rate patterns and in fetuses with high risk of hypoxia.

Keywords: Fetal acidosis, fetal blood analysis, fetal monitoring, $tcPco_2$.

Zusammenfassung

Klinische Erfahrungen mit $tcPco_2$-Messungen während der Geburt

Der klinische Nutzen von $tcPco_2$-Messungen beim Feten während der Geburt wurden durch eine Analyse der Daten von 224 Fällen evaluiert. Diese zusätzliche Art der Überwachung wurde kombiniert mit der kontinuierlichen Kardiotokographie (CTG) und der intermittierenden Fetalblutanalyse (FBA) in Fällen mit suspekten, präpathologischen oder pathologischen Herzfrequenzmustern. Die vorgewählte Meßtemperatur war 39 °C in 105 und 44 °C in 119 Fällen. Der Normbereich der $tcPco_2$-Werte wurde durch Auswertung des Mittelwerts und zwei Standardabweichungen in Fällen ohne hypoxische Komplikationen definiert. Die Absolutwerte des Normbereichs waren in Abhängigkeit von der Meßtemperatur verschieden, wenn kein Korrekturfaktor verwendet wurde. Nachdem die transkutanen Werte dem Blutgasniveau angeglichen wurden (Severinghaus-Formel) wurden keine signifikanten Unterschiede in den $tcPco_2$-Werten für die beiden verwendeten Temperaturen notiert (39 °C und 44 °C). Es besteht ein deutlicher Anstieg des $tcPco_2$ mit fortschreitender Geburt. Beim Vergleichen der $tcPco_2$-Werte mit den pH-Werten im fetalen Blut fanden wir eine statistisch signifikante Korrelation bei beiden Temperaturen ($p < 0.001$). Mit dem Ziel, einen Anstieg der Azidität im fetalen Blut früh erkennen zu können, ist eine „action-line" von 55 mmHg nach Korrektur (80 mmHg bei 44 °C, 63 mmHg bei 39 °C) als ausreichende Grundlage für eine klinische Intervention geeignet. Alle azidotischen Werte (pH < 7.20) und der größte Teil der präazidotischen Werte (pH 7.20–7.24) können ausgeschlossen werden. Ein zu erwartender klinischer Vorteil durch die zusätzliche Anwendung der $tcPco_2$-Werte ist die Reduzierung der Fetalblutanalysen in einer Reihe von Fällen mit anormalen Herzfrequenzmustern. Bei einer Meßtemperatur von 44 °C wird die Fetalblutanalyse in 90% der Fälle überflüssig. Obwohl eine operative Entbindung in nur 13% der Fälle mit auffälligem CTG durchgeführt wurde, sind alle Kinder lebensfrisch geboren worden (modifizierter Apgar-Score ≥ 7).

Die $tcPco_2$-Messung scheint ein nützliches zusätzliches Verfahren zu sein, besonders in Fällen mit auffälligen Herzfrequenzmustern und bei Feten mit hohem Hypoxie-Risiko.

Schlüsselwörter: Fetalblutanalyse, fetale Azidose, fetale Überwachung, $tcPco_2$.

Résumé

Experience clinique de la $tcPco_2$ au cours du travail

L'utilisation clinique de la mesure de la $tcPco_2$ transcutanée du fœtus au cours du travail a été évaluée sur une série de 224 cas. Cette méthode complémentaire de surveillance a été associée à l'enregistrement continu de la fréquence cardiaque fœtale (FCF) et à des prélèvements discontinus de sang fœtal dans les cas de tracés de FCF suspects, pré-pathologiques ou pathologiques. La température pré-déterminée de mesure était 39 °C dans 105 cas et 44 °C dans 119 cas. L'intervalle de variation normal de $tcPco_2$ a été défini en calculant la moyenne et 2 écarts-types dans les cas sans complication hypoxique. Les valeurs absolues de cet intervalle de variation sont différentes selon la température de mesure si l'on n'utilise pas de facteur de correction. Après ajustement des valeurs transcutanées aux niveaux de gaz sanguins par la formule de Severinghaus, on n'observe plus de différence entre les valeurs de $tcPco_2$ obtenues aux deux températures utilisées (39 °C et 44 °C). La progression du travail entraîne une augmentation évidente de la $tcPco_2$. En comparant les valeurs de $tcPco_2$ et celles du pH sur le sang fœtal on a obtenu une corrélation statistiquement significative quelle que soit la température utilisée ($p < 0{,}001$). Afin de permettre une détection précoce d'une augmentation de l'acidité du sang, le seuil de 55 mmHg après correction (80 mmHg à 44 °C, 63 mmHg à 39 °C) paraît une limite convenable pour une intervention, puisqu'elle permet d'exclure tous les cas d'acidose (pH < 7,20) et la majorité des cas de préacidose (pH = 7,20–7,24). Un effet clinique bénéfique peut être attendu de l'utilisation complémentaire de l'électrode à $tcPco_2$, c'est la réduction de la nécessité du prélèvement de sang sur le scalp dans de nombreux cas d'anomalie de FCF. A une température de mesure de 44 °C la détermination de l'équilibre acido-basique sanguin devient inutile dans 90% des cas. Alors qu'une intervention pour souffrance fœtale n'a pas été pratiquée que dans 13% des cas avec anomalies de la FCF, tous les enfants sont nés en bon état (Score d'Apgar modifié < 7).

Les mesures de $tcPco_2$ paraissent constituer un complément utile, particulièrement en cas d'anomalies de la FCF et chez les fœtus à risque élevé d'hypoxie.

Mots-clés: Acidose fœtale, monitorage fœtal, prélèvements de sang fœtal, $tcPco_2$.

References

[1] HAMMACHER K, RB DEL RE, R GAUDENZ: Kardiotokographischer Nachweis einer fetalen Gefährdung mit einem CTG-Score. Gynäkol Rundsch 45 (1974) 61

[2] HAVERKAMP AD, M ORLEANS, S LANGENDORFER: A controlled trial of the differential effects of intrapartum fetal monitoring. Am J Obstet Gynecol 134 (1979) 399

[3] JONGSMA HW, TKAB ESKES: Validity of fetal monitoring during labor, results of a multicenter study – discussed during a meeting, Nijmegen, June 28, 1985, within the frame of the EC-project Perinatal Monitoring. 4th progress report of the Project Perinatal Monitoring. Commission of the European Communities, Amsterdam 1985

[4] LÜBBERS DW: Theoretical basis of the transcutaneous blood gas measurement. Crit Care Med 9 (1981) 721

[5] PARER J: Benefits and detriments of fetal heart rate monitoring. Semin Perinatol 2 (1978) 113

[6] QUILLIGAN EJ, RH PAUL: Fetal monitoring: Is it worth it? Obstet Gynecol 45 (1975) 96

[7] SALING E, KH WULF: Zustandsdiagnostik beim Neugeborenen. Gruppeneinteilung. Fortschr Med 89 (1971) 12

[8] SALING E: Fetal scalp blood analysis. J Perinat Med 9 (1981) 165

[9] SCHMIDT S, K LANGNER, J ROTHE: A new combined noninvasive electrode for $tcPco_2$ measurement and fetal heart rate recording. J Perinat Med 10 (1982) 297

[10] SEVERINGHAUS JW, M STAFFORD, AF BRADLEY: $tcPco_2$ electrode design, calibration and temperature gradient problems. Acta Anaesthiol Scand 68 (1978) 118

[11] SYKES GS, TM MOLLOY, P JOHNSON: Fetal distress and the condition of newborn infants. Br Med J 287 (1983) 943

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