Pathophysiology, clinical relevance of continuous measurement of pH and/or CO_2 in the fetus

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Hypoxia is - now as before - a serious danger to the fetus that can occur within a relatively short period of time. Concerning fetal supervision, particularly during labor, we must be quite clear about the special conditions that exist here. Direct insight into the blood gas exchange and the acid-base balance of the fetus have up to now only been possible during labor, that is after the membranes are ruptured. Access exists only to the presenting part, which in over 90% of the cases is the area of the fetal scalp.
Of particular interest is the measurement of the acid-base balance. In the foreground here are fetal blood analyses, which have been used now for 22 years. During the past few years continuous tissue pH measurement has been tested in an experimental way, but without success for routine use.
Using fetal blood analysis we should be aware that we are examining the situation in the peripheral circulation. The blood composition does not differ too much from arterial blood, because the arterio-venous difference in the peripheral circulation is estimated as being relatively small on account of the low metabolism in the skin. There is no difference in the composition of the blood between arteries to the brain and those supplying the scalp, as they both receive blood from the same main branch of the aorta. Of course, it would be more informative to analyse venous blood from those organs of special interest, for instance from the brain. However, this is scarcely possible in routine clinical work. However, for diagnostic purposes it is important to know that particularly in subacute and chronic hypoxia the fetus undergoes the so-called O_2 conserving adaptation of its circulation (9), and as a result of this pathophysiological mechanism the supply to the brain and heart is affected much later. Other organs, such as the skin, muscles and intestines are subjected to a reduced O_2 supply much earlier.
The basic concept of the O_2 conserving adaptation is the following: faced with a gradual reduction in oxygen supply due to placental insufficiency or to some other subacute or slowly progressive complications, the fetus reacts by means of a compensatory adaptation of its circulation. The blood flow and hence the oxygen supply to a number of the less important parts of the body - such as the extremities, abdominal viscera and lungs - are reduced by vasoconstriction. The oxygen saved in this way now becomes available for use by the two particularly vital organs, the brain and the heart. These continue to be supplied with the required amount due to the fact that the total O_2 consumption of the fetus has been reduced and the O_2 content of its circulating arterial blood maintained at normal or near-normal levels. To a lesser extent this achievement may be helped by an increase in umbilical-placental blood flow; for hypoxemia is known to lead to an increase in fetal systemic blood pressure due to peripheral vasoconstriction on the one hand (2,3) and to dilatation of the umbilical

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vessels on the other (8,11).
Local hypoxaemia in the tissues leads to anaerobic glycolysis. As a result there is an increase in the formation of lactic acid. Because a reduced blood flow to the tissues is still present, lactic acid reaches the central circulation. As long as the amount remains limited, it probably serves as a source of energy for the organs still receiving an adequate oxygen supply. However, when formation of lactic acid is excessive, its level in the blood rises and we are confronted with the strange picture of lactic acid overload in the presence of only little reduced blood O_2 values - the condition we have called the primary metabolic acidosis of the fetus.
Let us return to the circulatory supply to the brain.
It is known from the pathophysiology of the cerebral circulation, that even in cases of significant changes of blood pressure in the body circulation, a stable supply of blood to the brain is maintained, through the highly adjustable autoregulation of the brain circulation (5). Accordingly, we can assume that generally before the brain circulation is affected there will have been disturbances in the periphery, for instance in the muscles, leading to anaerobic glycolysis and to the overproduction of lactic acid. Thus, through fetal blood analysis or tissue measurement the falling pH values are in any case early warning signs, and one can draw the necessary conclusions.
Animal experiments recently performed by Kastendieck and co-workers (4) confirm the reliability of fetal blood analysis for judging cerebral impairment due to hypoxia. They wrote:
"Concentration of lactate in brain and heart were closely correlated with lactate concentration and pH and base excess in the fetal blood, suggesting that intracellular accumulated lactic acid is rapidly transferred into the extracellular volume.
Since the intracellular production of lactic acid in the fetal brain is well reflected by lactate and by pH and bases excess in the blood, micro blood analysis gives us reliable information about the oxygen debt in the brain tissue."
There are certain doubts, however, whether - as Mann and co-workers (6) found - an isolated severe cerebral ischemia can occur with substantial head compression accompanied by bradycardia with subsequent permanent psycho-motor impairment of the infant. Follow-up examinations of children with increased intracranial pressure showed higher incidence of abnormalities only after more than 20 hours of protracted labor (7). From these results it can be concluded that relatively short lasting head compressions, as they sometimes occur during labor if at all, do not seem to be seriously dangerous.
Progress in intrauterine diagnostics is advancing further, and so possibilities of being able to answer these questions non-invasively are getting nearer. Recently we achieved success in cooperation with T. Blum, a neurophysiologist, and his co-worker, R. Bauer in tracing a prenatal magnetoencephalogram for the first time in a fetus at 35 weeks of gestation in an undisturbed pregnancy (1). So the way is probably open here for direct observation of brain reaction to suspected hypoxia and may be for comparative studies between biochemical blood parameters found by fetal blood analysis and the brain reaction.
It is quite clear from all these considerations that records of continuous parameters from the fetal acid-base balance during labor would be of

great clinical importance.
Without doubt fetal blood analysis does have certain disadvantages. It allows only random insight into the acid-base balance; the incisions, although minimal, are nevertheless traumatising and the technique involves repeated manipulations in the intravaginal region. The main advantage of fetal blood analysis is - now as before - that high reliability is achieved through direct measurement in the blood and also the blood sampling technique is relatively simple.
Up to now the main disadvantages of continuous tissue pH measurement are the too critical invasiveness of the electrode and the insufficient precision.
Also the transcutaneous Po_2 and Pco_2 measuring methods are still too complicated to be used in clinical routine on a wide scale. However, in the near future considerable progress is perhaps to be expected through automation of calibration and adjustment procedures.
What clinical information do we expect to gain from continuous transcutaneous measurements of the two gases?
As already mentioned, Po_2 as an exclusive parameter would scarcely be a reliable method of clinical supervision of a fetus at high risk (suspect or pathologic cardiotocogram). So it could be possible that Po_2 levels do not decrease to a comparable amount in spite of progressive acidosis.
The situation appears to be better as regards Pco_2. When more acute complications occur one can in any event reckon with an increase in Co_2. There might be an increase of carbon dioxide partial pressure during subacute or chronic complications for two reasons: firstly, the carbon dioxide transfer from the fetus to the mother may be impaired. Additionally a certain amount of carbon dioxide might get displaced from the buffer substances when concentration of lactic acid in the fetal blood increases. This can also lead to a rise in the Pco_2 level in the fetal blood.
It is still not clear whether and how often a clinical situation occurs in which - in spite of steadily increasing metabolic acidity (lactate increase) with an O_2 conserving adaptation of the fetal circulation - the elimination of the well diffusing Co_2 is faster than the increase in the blood. In such cases one must reckon that the continuous Co_2 measurement can be misleading, because the total acidity keeps on increasing, the pH values fall, but the Pco_2 does not increase adequately. Up to now we have not yet observed such a situation during the course of our recordings during labor. In spite of a relatively large number of cases of fetuses supervised during labor by $tcPco_2$ measurement in our department (10), - in the meantime n = 224 - the collective of cases where manifest intrauterine complications also occurred (n=13), is still too small to draw any such conclusions.
In spite of doubts already mentioned, it is clear that the further development of continuous transcutaneous O_2 and Co_2 measurements is of great clinical importance. By using these methods it can be expected

a) to considerably reduce the number of fetal blood analyses, namely when cardiotocogram is suspicious, but both blood gases are within the normal range,
b) to reduce unnecessary operative interventions for terminating labor due to fetal indications. Always when the cardiotocogram is suspicious or pathologic and the blood gases are normal. This is of particular importance for obstetrical departments in which fetal blood analysis is not performed.

Finally it should be noted that continuous blood gas monitoring can also be of scientific benefit. In all situations in which fetal blood analyses have deficiencies or other disadvantages due to their randomized character complementary information can be gained from such continuous recordings.

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