Systematic Documentation of Fetal Heart Rate (FHR) Patterns and the Correlation with pH Computed in the Umbilical Artery

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Abstract: *Introduction:* A new computer program was written to analyze FHR-tracings of 601 fetuses from the Frauenklinik Detmold in Germany. This program is demonstrated in this paper using data of one fetus only.

Material and methods: During a time period of eleven years 601 FHR-tracings were recorded electronically and further analyzed. To demonstrate the program only one fetal case was further analyzed: 1.) In this case we measured the fetal heart frequency (FHF) and one broad deceleration, 2.) the micro-fluctuation (micro) of this fetus and the micro during the large deceleration, 3.) the oscillation amplitude (OZA) during the whole CTG and the OZA during this broad deceleration. In addition the weighted WAS-score (reference 14) was determined and the actual pH-value was computed (not measured) for umbilical blood. All these parameters are available in each case of these 601 fetuses.

Results: Besides the electronic CTG-analysis it is new to determine the actual pH-values in umbilical blood using only the FHF: Both variables are not identical but belong closely together. The FHR helps to determine fetal well being and it helps to compute the pH-values in umbilical fetal blood. Therefore, micro-blood sampling (MBU) according to E. Saling seems to be no more necessary. These results are preliminary because our number of MBU's is still small. The new program is able to analyze FHR-tracings thoroughly and to determine the pH-values in umbilical blood continuously.However, FHR-monitoring with a small computer seems to be necessary.

Conclusions: The fetus in utero can be monitored seriously using his FHR together with other parameters. In hypoxic danger, the foetus can be monitored sufficiently without intermittent control of his actual pH-values in peripheral blood. Fetal pH-values can be determined approximately and continuously using only the FHR.

Keywords: Computer analysis of the FHF, FHF, Micro-fluctuation, Oscillation amplitude, WAS – score, Computed fetal pH-values.

INTRODUCTION

Since the introduction of fetal heart-rate (FHR) monitoring by E.H. Hon [1], R. Caldeyro-Barcia [2] and K. Hammacher [3] some 60 years ago the obstetrical attention was focused on avoidance of fetal hypoxia and acidosis. The clinical success however was doubtful [4] and criticism was flourishing [5]: In 1995 our American colleagues stated: '… with the exception of the reduction of the rate of neonatal seizures, the use of routine electronic fetal monitoring (EFM) has no measurable impact on morbidity and mortality'. Indeed, during many years there was no general consensus in defining a 'pathological' or non-reassuring FHR-tracing. Years later it was J.T. Parer and Ikeda [6] in America among others who developed in 2007 a framework for a standardized management of intra-partum FHR patterns using the baseline FHR, the baseline variability and the types of decelerations. The two authors colour-coded the tracings and made it possible to construct a standardized approach to Intra partum FHR management which was evidence-based and received also consensus in the literature [7].

Thereafter many other authors [8-11, 15] tried to ameliorate the efficacy of fetal monitoring using always still other methods in combination with FHR-monitoring. Success seemed to be present.

Years ago E. Saling [12, 13] in Berlin was the first who introduced fetal blood sampling (FBS) to monitor the fetus sub partu. Many years later we tried to overcome FBS because the FHR-parameters seemed to be sufficient for monitoring the fetus. We used a score [14], the WAS-score, for monitoring the fetus and the actual pH-value measured always in the umbilical artery (pH, UA) to assess fetal well being after birth. Therefore, no micro-blood samplings (MBS) were analyzed in this paper. In the past our number of MBS was very small (< 2%).

To compute this score mentioned above three variables derived from the FHR were computed electronically for each CTG-minute:

1.) The number of local maxima and minima (ozf) during each minute of the FHR. We called this parameter "micro-flucuation" (see Figure **1**). The value in fetuses with normal pH-values amounts to about 60 turns / min. Micro-fluctuation differs from true beat-to-beat variability but - according to our data - offers the

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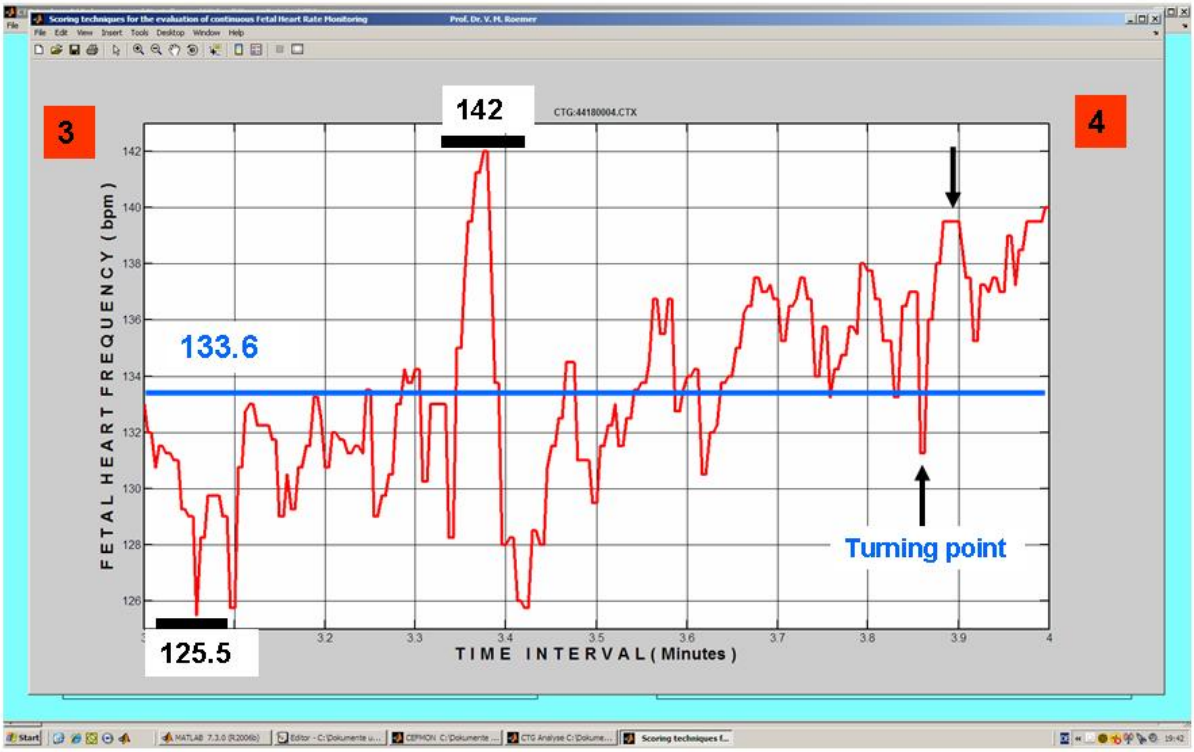

Figure 1: shows the 4th minute of a CTG measured electronically. Three parameters are explained (at the top). They are used for further management.

best correlation with the parameters of the fetal acid-base balance [19].

2.) The oscillation amplitude of each minute (*oza)*, covering all decelerations and accelerations (unit: beats per Minute (bpm)). The dips were not classified because in our series the uterine activity was never recorded electronically and

3.) The mean fetal heart rate (FHR) - frequency of each CTG-minute (fhm, unit: bpm).

In this study we want to show our electronic management using nearly all our FHR-data and demonstrate the efficacy of FHR-monitoring without any FBS.

MATERIAL AND METHODS

The FHF signals (*i.e*. the R-R intervals of the F-ECG) of 646 fetuses were recorded also with a computer. The sampling rate was 4 frequencies per second using a normal CTG: 8040A (Hewlett-Packard). During a period of eleven years (2000 - 2010) all recordings were realized in the Frauenklinik of the Klinikum Lippe Detmold GmbH, Germany, (Former head: Prof. Dr. V. M. Roemer).

To enter the study all fetuses must have been delivered by the vaginal route and each tracing could last some minutes up to many hours. During forceps- and/or vacuum-deliveries recordings were always continued; However in the beginning the FHR-signals were not always perfect.

Therefore, short-lasting (< 20 Sec.) electronic signal losses were overcome by electronic signal repair algorithms developed in our institution [8]. Cases with long lasting signal losses were excluded. Therefore, in this study no caesarean sections were included because fetal monitoring was not possible during the preparation for the operation. If necessary, a new scalp-electrode was inserted immediately during bad monitoring. Recordings of fetuses with chorio-amnionitis and tracings of severely malformed neonates were also excluded after birth. During the eleven years, the 648 fetuses were not randomly

selected in our hospital, because it was not really possible: We performed no computerized monitoring at night.

No major doses of maternal drugs were given during the time of fetal recording. Thus 601 recordings of overall 648 fetuses were left and analyzed in this study.

All data in this paper were analyzed electronically by the authors using MATLAB, the language of technical computing (USA).

This program was written by Prof. Dr. R. Walden former senior system engineer and physicist at the university of Bielefeld. It was translated in English by VMR. The program summarizes our actual experience on this field. Each of the 601 cases can be addressed and analyzed separately. This program is not suitable for FHR-management and general documentation [16].

In this paper pictures of only one case (CTG-Number: 36280920ctx) are given in order to explain and comment the procedure.

Early during our investigation we suggested that typically different FHR-patterns occur in fetuses being awake (german: wach), being acidotic (Azidose) and/or being in sleep (in german: Schlafzustand). Therefore we called this simple triplet WAS-score: Wachen-Azidose-Schlafen – score. We used these three fetal parameters to quantify fetal well-being in utero sub partu by weighting these variables empirically. After some years it turned out that this score was good correlated with the pH_{UA}-values measured soon (minutes) after delivery [14].

Therefore, electronic optimizing-procedures lead to the following index:

$$WAS_{Index}(t) = \frac{fhm(t) \cdot g_{fhm}(fhm(t)) \cdot ozf(t) \cdot g_{ozf}(ozf(t))}{oza(t) \cdot g_{oza}(oza(t))}$$

where g_{fhm}, g_{ozf} and g_{oza} denote three mathematical weighting functions comparable approximately to boundaries in discontinuous scoring-procedures *e.g.* in the APGAR-score. It turned out that this index was good correlated with the actual pH-values measured in the umbilical artery [14].

RESULTS

For a better understanding, Figure **1** shows three variables which were always analyzed during each individual CTG-minute. The variable micro-fluctuation

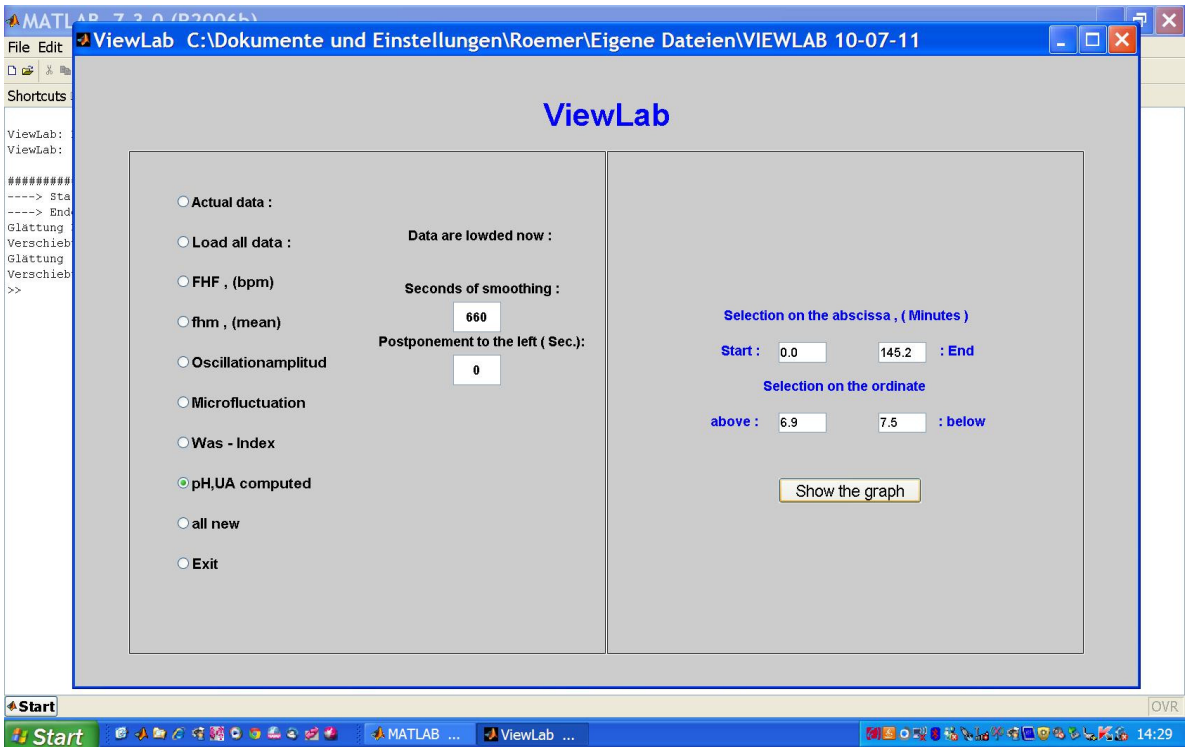

Figure 2: shows the variables which can be determined electronically. The boundaries for the six parameters are given on the right hand side.

refers to the number of turning points during always one CTG-minute.

The oscillation amplitude (16.5 bpm in this minute) was not used numerically in the WAS – score.

Figure **2** shows one of the starting-pictures of the computer program itself available to analyze the data of each case of the 601 fetuses.

We decided to evaluate only one case, the fetus 36280920ctx (Year: 2003, month: June, starting-time of the CTGt: 09:20; alpha-numeric figures are also used). This baby was born spontaneously at the 40th week of pregnancy, weighting 3610 g and measuring 53 cm.

The acid-base values measured in the umbilical artery (all parameters in the umbilical vein were determined also) was 7.160, the pCO_2 amounted to 83.0 mm Hg and the pO_2 was 13.5 mm Hg. BE_B and BE_{ECF} were not determined and further analyzed [18] in this paper. The APGAR-scores were 6 / 9 / 10 after 1, 5 and 10 Min.

Figure **3** shows the whole monitor of the last 145.2 min before delivery.

During the 22th and 42th min. occurs a broad deceleration due probably to a cord complication which however was not fount at delivery.

All useful possibilities of documentation are possible using a computer. After considering the whole tracing lasting 145.2 min. we looked to the FHR pattern between the 22th and 42th min. and we omitted frequencies below 50 bpm because the obstetrician is usually not used to frequencies below 50 bpm. This is demonstrated in Figure **4**.

Figure **4** shows this unusually large deceleration lasting ca. 9 min.

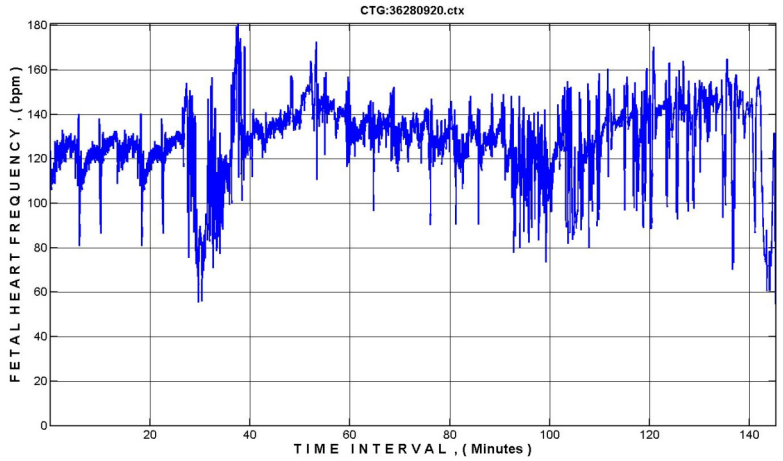

Figure 3: shows the FHR-monitor Number 36280920, which lasted 145.2 min. until delivery. The compression of the monitor is unusual for an untrained obstetrician.

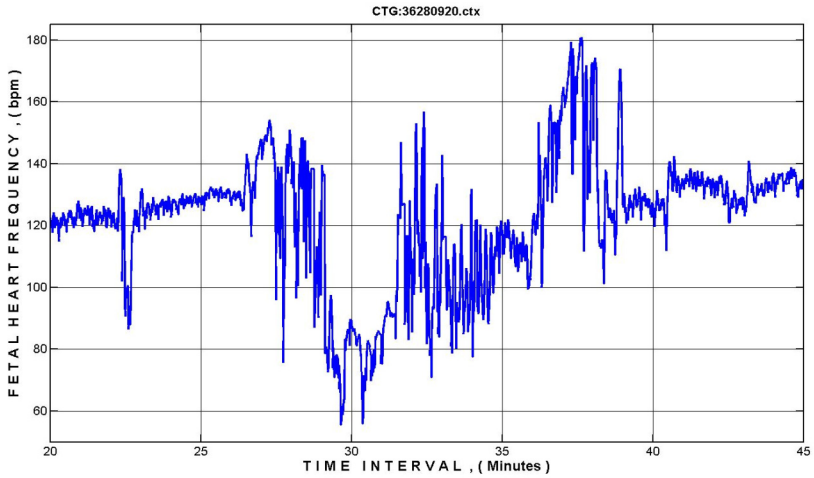

Figure 4: concentrates to a large deceleration of unknown origin (cord compression ?) which was further analyzed. Note the duration of this deceleration (ca. 9 Min.). However it might be three dips each about ca. 3 min. duration.

The reason might have been a cord-compression due to fetal movements during this recording. We do not know the uterine activity during this time interval but we can realize the deceleration pattern. These decelerations are shown in Figure **5** and Figure **6**: Note that all the decelerations are turned exactly about 180 degrees measuring only the amplitude of each dip. As mentioned before the dips are not further classified. Only the amplitude (ordinate) of the dips are given in bpm.

Figure **5** shows the fetal deceleration - pattern again during the whole tracing (145, 2 min.).

Below (Figure **6**) only all decelerations during the 25 min of fetal compromise are shown: There are many variable decelerations. This however was not entirely clear : The program is not able to discern late dips from variable dips because the uterine activity is not included in our study: The reason for this deficit was that it turned out after many attempts that this would be too difficult electronically because the uterine signals are not constant enough.

These 25 min. are given in Figure **6**. covering the 9 min. of the deceleration.

Let us now consider micro-fluctuation, the most sensible parameter.

Micro-fluctuation is not identical with beat-to-beat variability (see Figure **1**). In healthy and mature fetuses this parameter amounts to about 60 units pro min. In our studies [19] we found that it is the most sensible

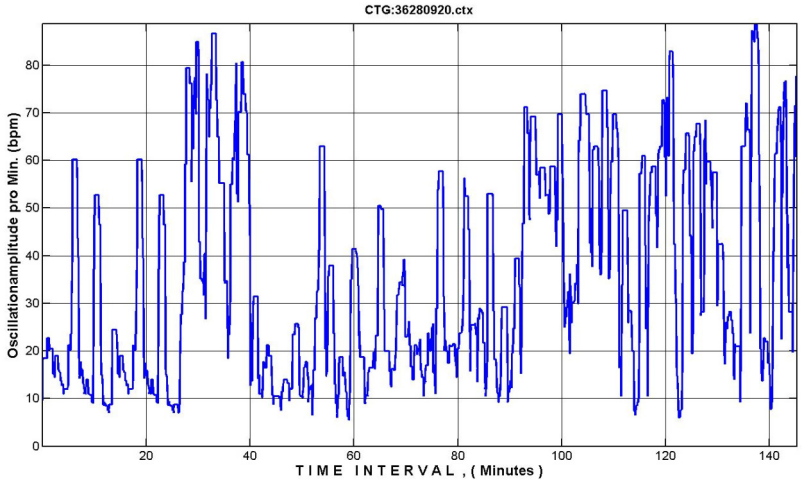

Figure 5: shows the amplitude of the oscillation pattern during this unusual deceleration. The type of deceleration is not analyzed (‘late’ or variable) because the uterine activity is never recorded in our system. The width of the baseline is recorded also at the bottom.

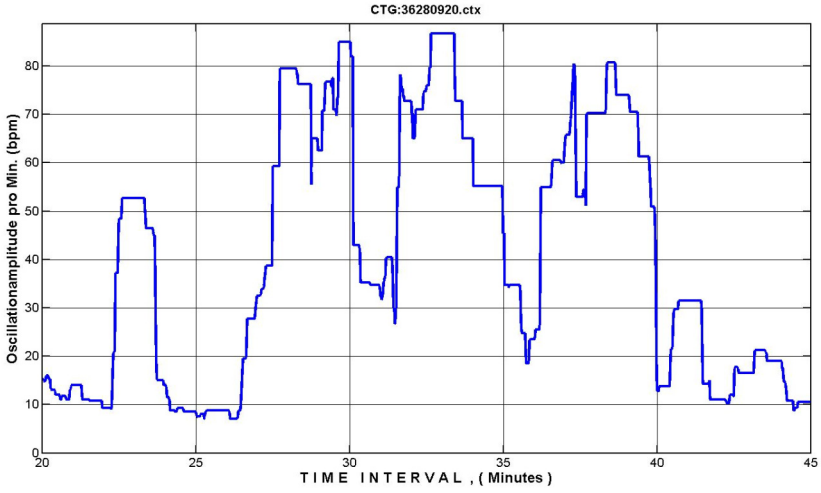

Figure 6: shows three large decelerations which were most probably the reason for the FHR alteration(s). The basal tonus was not constant.

parameter of the FHR when compared with all other variables. Micro-fluctuation can not be measured precisely with the naked eye. It can only be measured electronically. It is thµerefore a strong argument to perform FHR-monitoring with a small computer in the near future.

Figure **8** shows micro-fluctuation again during 25 min. covering the large deceleration of ca 9 min. (see Figure **4**) and indicating that micro-fluctuation comes down from ca. 60 (N/min.) to less than 20 during this event; this indicates fetal hypoxia and acidosis during this time interval.

Micro-fluctuation is strongly associated with the FHF-level in non-acidotic fetuses: r = 0.641, P<<0.001, [19]. However, this reaction-pattern is still complex [14] and not further discussed in this context.

Afterwards (see Figure **7**) micro-fluctuation was again steadily decreased down to ca. 25 turns / min. with a final pH,UA of 7.160.This baby was slightly depressed (APGAR 6 after 1 min.) . Probably this could have been avoided. These few pictures show the sensibility of this parameter.

Figure **9** shows the actual pH-values now determined exclusively by the FHR and displayed continuously the first time. These pH-values represent the actual pH measured in blood of the umbilical artery not in peripheral blood (head or buttocks). These values were always computed using the FHR only without any pH-measurements. It is not astonishing

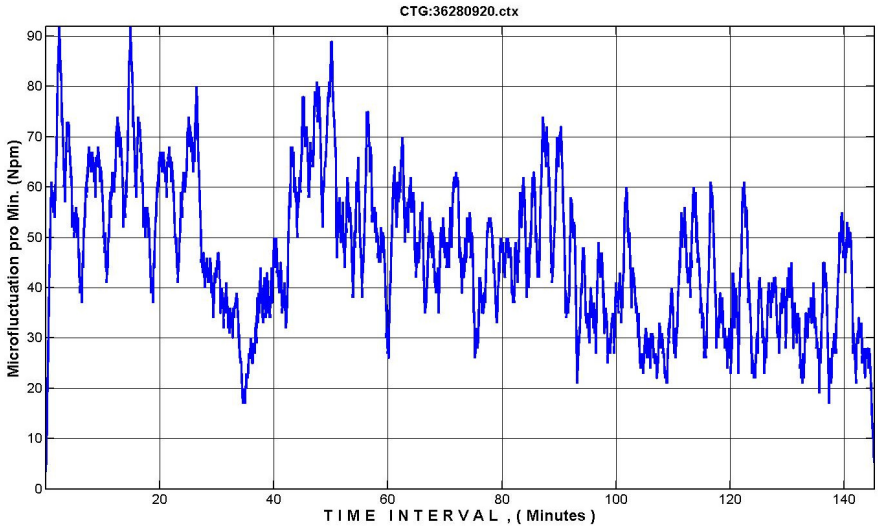

Figure 7: gives the micro-fluctuation measured during the whole record showing a continues decrease indicating fetal hypoxia and acidosis probably due to cord entanglements in utero.

Figure 8: demonstrates micro-fluctuation during 25 min covering the large FHR deceleration(s). The frequency comes down from ca. 60 to below 20 turning points pro min. indicating true hypoxia.

that the curve resembles the curve of micro-fluctuation. The FHF seems to be not sensitive enough.

There is still a small difference between the computed actual pH-values and the measured pH,UA-values determined in umbilical blood. This difference however is small, [14]. Therefore we believe that fetal blood-sampling might be no more necessary in the near future.

Figure **10** shows that electronic smoothing alters the pH,UA-values numerically: They come down at the end to nearly a straight line. If we avoid any smoothing the curve starts at zero min. (abscissa, not at 60 min.) but gives less information. Each smoothing-interval can be chosen electronically. This interval should be determined by the obstetrician: There is a mixture of blood in the foetus; this mixing - process needs some time which we have to note and to accept.

Therefore, the computed pH-value in the umbilical artery is not identical with the measured value but it seems to be close to it. In this newborn the computed pH-value was also 7.160. Note: the dynamics shown in Figure **9** is absent in Figure **10**.

DISCUSSION AND CONCLUSIONS

This is the first attempt to combine FHR-monitoring with fetal acidemia without any measurements of fetal blood pH. It seems to be useful however, it is still not perfect. We need a proof. Our own number of FBS in peripheral blood is still too small. Therefore we must attack the pH-values in umbilical blood. These values however are present only when the baby has been born. Therefore, we should use the CTG to measure (guess) fetal pH also. This however seems to be possible only with a small computer.

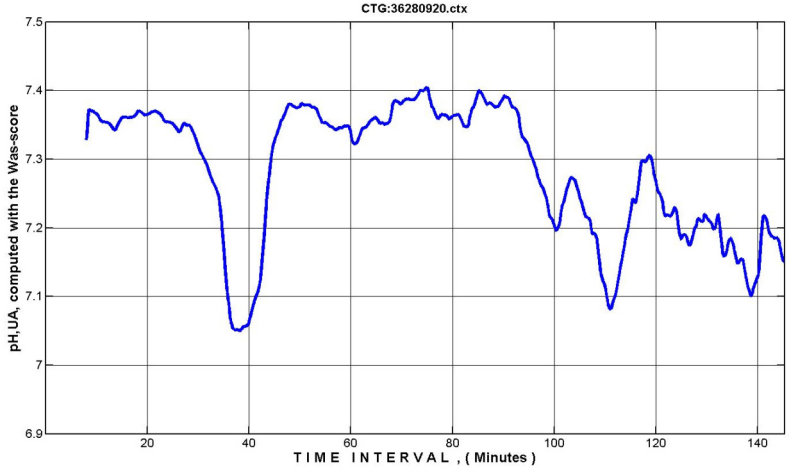

Figure 9: shows the actual pH-value computed continuously during the whole recording of 145.2 min. The large dip is mirrored in the tracing: The actual pH comes down to about 7.05 and after recovery is decreased further on to 7.160.This pH-value was measured in the umbilical artery at delivery. Measured and computed pH-values are not identical but close together. Therefore the hypoxic fetal stress might also be monitored continuously.

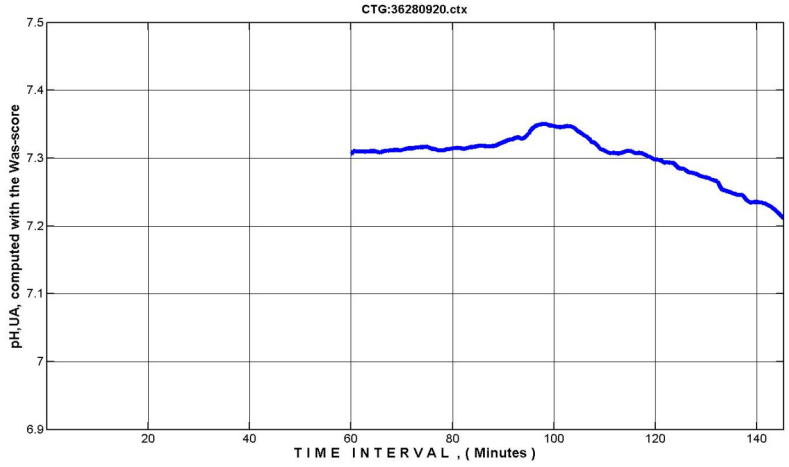

Figure 10: shows clearly that heavy smoothing of the computed pH-values (3600 sec = 60 min.) disturbs the sensibility and alters the computed pH-values. The chosen values in this context are extreme.

We should remember: During increasing asphyxia (APGAR score, 1 Min.: 0 – 3) the pH in the fetal centrum (heart and umbilical arteries) is more reliable then the pH in the peripheral skin (skin of the head, buttocks and sometimes also extremities) measured by normal FBS according to E. Saling. Fetal age and fetal weight play also a certain role. These parameters could be determined before or during delivery using ultrasound measurements. These variables however are numerically not included in our analysis until now. This should be the next step.

There must be a correlation between the FHR (*i.e*. CTG) and the fetal acid-base balance which we don't know until now and which we should use in the near future.

The WAS-score is difficult enough but it shows in our hands already a clear correlation ($r = 0.654$, $P << 0.001$) with pH, UA in 483 newborns examined during the last 30 min. of delivery [14].

We should remember therefore: FBS is not easy to perform; it is time- and money-consuming and the pH-values are never achieved continuesly.

Nevertheless we should trust in FHR-monitoring - assisted by a small computer - because these CTG-parameters are reliable, sensitive and easy to manage.

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