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Prediction of Fetal Acidemia Base on Accurately Identify the Deceleration Zone

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Abstract

The study of fetal heart rate is very important for the growth of food in the uterus and the health status after birth. General doctors check the fetal heart rate curve with the naked eye and experience. This paper studies the quantitative analysis of the difference and area recognition of the deceleration area, so that the fetal heart rate The analysis of the rate signal is more accurate, and the research on fetal acidemia is further advanced. To meet the precise identification of the deceleration zone, it must be accurately positioned first, and then further identified, so the calculation of the baseline appears to be basic and important. It can be seen from the research results in this paper that the recognition accuracy of the deceleration zone has been improved and the calculation of its area is more accurate, which has greater value for the fetus and subsequent evaluation.

Keywords

Fetal heart rate baseline calculation; Deceleration feature; Fetal condition.

1. Introduction

Intrauterine acidemia is an important cause of perinatal neonatal death. The second stage of labor has a higher incidence[1, 2]. Acidemia is manifested in the decrease (or deceleration) of fetal heart rate in fetal heart contractions[3, 4]. Therefore, the extraction and recognition of fetal heart rate deceleration features have important clinical value for judging fetal acidemia[4, 5]. The indexes to evaluate the deceleration of fetal heart rate include deceleration times, valley value, duration, recovery time, lag time, etc. Thus, Alison predicted the severity of fetal acidemia by using the deceleration depth, duration, frequency and other indicators of fetal heart contractivity[6]. However, these indicators cannot comprehensively reflect the fetal heart rate deceleration. Strachan Used the deceleration area to describe the above characteristics and successfully used in the detection of fetal acidemia[7]. The analysis of acidemia and normal fetal heart rate signals also shows that deceleration area is significantly different, indicating that deceleration area can be used as a clinical reference indicator for the diagnosis of neonatal acidemia[8]. In recent years, there have been studies on the interpretation of fetal heart monitoring patterns through various methods[9], and there have also been studies on the extraction of mathematical features of the patterns through mathematical analysis to assist in the diagnosis of fetal hypoxia[10, 11]. However, it is still in the exploration stage. In conclusion, it is significant and effective to support the clinical prediction of neonatal acidemia through the identification and area calculation of fetal heart rate deceleration zone.

The identification of the deceleration zone and the area calculation method determine the accuracy of predicting acidemia based on deceleration area characteristics. For the recognition of fetal heart rate deceleration zone, the traditional methods are as follows: Firstly, the valley value in the fetal heart rate curve is scanned and identified. The valley value is 15 bpm (beats per min) lower than the

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baseline value as the suspected deceleration area. Then, the boundary of the deceleration area is determined through a fixed threshold, and the location of fetal heart rate deceleration is determined accordingly[12]. However, it can't locate the start point and the end point of deceleration zone accurately. For the calculation of the area of the deceleration zone, people usually approximate the deceleration zone to a triangle, and obtain deceleration area through the valley value and duration[13]. However, this method has a higher requirement on the wave pattern of the deceleration area. But there is a large calculation error. The next steps are the research steps of this article.

2. Experiments and methods

The experimental data comes from Physio Bank and was jointly provided by the Czech University of Technology and Prague University Hospital（https://www.physionet.org/physiobank/database/ctu-uhb-ctgdb/）. There were 552 cases of fetal heart and contractions, the sampling frequency was 4Hz, the duration of monitoring ranged from 50 to 90min, and the duration of the second stage of labor was no more than 30min. The data include the basic information of the parturient: age, gestational age, pH value, etc. Among them, a total of 113 cases were excluded, including poor data quality, short monitoring time, and cesarean section, and a total of 439 cases were included in this study. The process of deceleration feature extraction included preprocessing, baseline estimation, deceleration boundary recognition and deceleration area calculation.

2.1 Fetal heart rate signal preconditioning

Because of the interference signals such as bad value, broken line and burr in the original data of fetal heart contractions, preprocessing was needed for further calculation and analysis. Therefore, according to the Laeda criterion, a 20-second moving window was used to calculate the corresponding value of the fetal heart rate and further denoise. The specific process was as follows: First, the mean value and standard deviation of the fetal heart rate signal calculated in the moving window, a bad value is defined as a signal value greater than three standard deviations above the mean, and the broken lines in the fetal heart rate curve were interpolated by Lagrange spline interpolation. Then, the bad value points in the signals of fetal heart contractions were identified and removed by using the Laeda criterion; Finally, according to the five-point cubic smoothing algorithm proposed in our laboratory, the signal of fetal heart contractile was filtered[14]. Remove the burr in the original data and the introduced high-frequency signal component to improve the smoothness of the curve. The specific calculation method is as follows:

$$\begin{cases} Y_1 = \frac{1}{70}[69Y_1 + 4(Y_2 + Y_4) - 6Y_3 - Y_5] \\ Y_2 = \frac{1}{35}[2(Y_1 + Y_5) + 27Y_2 + 12Y_3 - 8Y_4] \\ Y_I = \frac{1}{35}[-3(Y_{I-2} + Y_{I+2}) + 12(Y_{I-1} + Y_{I+1}) + 17Y_I] \\ Y_{M-1} = \frac{1}{35}[2(Y_{M-4} + Y_M) - 8Y_{M-3} + 12Y_{M-2} + 27Y_{M-1}] \\ Y_M = \frac{1}{70}[-Y_{M-4} + 4(Y_{M-3} + Y_{M-1}) - 6Y_{M-2} + 69Y_M] \end{cases} \quad (1)$$

Among them, Y_1 and Y_2 are the signal value processing methods of the initial two-point fetal heart contractions, Y_{M-1} and Y_{M-2} are the end two signal value processing methods, and Y_i is the other signal value processing methods (I = 3, 4,...) , m-2), which involves five points around (Y_{I-2}, Y_{I-1}, Y_I, Y_{I+1} and Y_{I+2}).

2.2 Baseline estimation of fetal heart rate

Based on pre-processed fetal heart contraction signal, according to the clinical definition of baseline of fetal heart rate (mean fetal heart rate over 10min)[15]， the baseline was extracted by forward and backward filtering in the confidence interval. The specific process was as follows: 1) Determined a temporary baseline value to identify non-baseline sections. The method to determine the temporary reference value as follow: set a moving window length as 5s, in the sliding window, the point where

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the difference between the maximum and minimum is ≤10bpm is the stable point of the fetal heart rate. The set of stable points is the stable part of the curve of fetal heart rate, 3 of fetal heart rate values with the most frequent occurrence in the stable part were selected, and heart rate curve intersection heart rate value of the maximum number of basic value as a temporary; 2) According to the clinical definition of non-baseline (data segment with instantaneous change amplitude of fetal heart rate ≥ temporary reference value 15bpm and duration ≥ 15s)[16], identified and removed non-baseline paragraphs, and used Lagrange interpolation to transform the fetal heart rate curve into a relatively stable curve; 3) Based on the concept of confidence interval in statistics, forward and backward filtering of the modified fetal heart rate curve, to get the baseline. The realization process of forward and backward filtering method was as follows: calculated the mean value fhr_mean and standard deviation fhr_std of the reconstructed fetal heart rate curve, calculated the frequency of fetal heart rate values within the confidence interval [fhr_mean-fhr_std, fhr_mean+fhr_std], selected the term with the highest frequency and set it as the base value P. Then, used the transformed fetal heart rate curve to iteratively process the initial value B0 of the forward and backward filtering, and the number of iterations was the data length N, i∈[1,N] within the confidence interval. The initial value B0 was obtained. Finally, the curve was smoothed five times by forward and backward filtering to obtain baseline. The specific formula is as follows:

$$B_0 = k_2 \times B_0 + k_1 \times P, \quad (2)$$

$$B_i = k_2 \times B_{i-1} + k_1 \times B_i, \quad (3)$$

$$B_i = k_2 \times B_{i+1} + k_1 \times B_i, \quad (4)$$

Formula (2) is the initial value of forward and backward filtering; Formula (3) is forward filtering; Formula (4) is the backward filtering. Where, k_1=0.15, k_2=0.85, B_i is the current fetal heart rate value, and b_{i-1} and B_{i+1} are the fetal heart rate values of the two points before and after B_i.

2.3 Recognition of fetal heart rate deceleration zone

Combining the obtained baseline, we used the iterative threshold method to determine the starting point (j_sta) and ending point (j_end) of the deceleration zone. Here, fhr was the fetal heart rate data, fhr_i was the fetal heart rate value of time i seconds, and a and b were the thresholds of the start point and end point of the deceleration zone, respectively. The iterative threshold process was as follows: 1) found the data value fhr_i and the occurrence time i less than baseline-15bpm in fhr; 2) Searched for trough fhr_j and occurrence time j within 30s after i; 3) Searched for fetal heart rate sampling points larger than baseline-a within 60s before j, where the iteration range of a value was (0-15); 4) Within 60s after j, the sample point of fetal heart rate was searched which was larger than the baseline-b, and the iterative range of b value was (0-15); 5) Recorded the first j_sta and j_end of the first ⩾ baseline-a in the first 60s of j time and the first j_end of the first ⩾ baseline-b in the last 60s; 6) Recorded j_sta and deceleration duration j_end-j_sta that meet the conditions (j_end-j_sta⩾30s).

In addition, we also used the traditional fixed threshold method to obtain j_sta and j_end-j_sta to illustrate the effectiveness of this method, whose threshold is the baseline.

2.4 Recognition of fetal heart rate deceleration zone

Based on the obtained j_sta, j_end-j_sta and baseline, the deceleration area was calculated using the effective integral method, and the calculation formula is as follows:

$$AREA = \sum_{i=j\_sta}^{j\_end} k \times \frac{(baseline - fhr_i)}{f_s} \quad (5)$$

Where, fhr_i is the instantaneous value of fetal heart rate identified as the deceleration zone, i∈[j_sta,j_sta+1,j_sta+2…j_end], f_s is the sampling rate of the sampled signal, k=1/(600×f_s) is a correction factor that reflects the clinical paper feed speed, sampling frequency, and unit length corresponding to the fetal heart rate value.

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In addition, we also use the traditional approximate triangle method to calculate the deceleration area[17]. It is used to illustrate the effectiveness of the method. The definition is $AREA_{classic}$. The calculation formula is as follows:

$$AREA_{classic} = k \times \frac{(baseline - \min\{fhr_i\}) \times (j\_end - j\_sta)}{2 \times f_s} \quad (6)$$

Among them, $\min\{fhr_i\}$represents the minimum value of fetal heart rate in $[j\_sta, j\_end]$, $i \in [j_{sta}, j_{sta}+1, j_{sta}+2 \cdots j_{end}]$.

3. Results and analysis

The research results in this paper included three parts: fetal heart rate deceleration area characteristics, deceleration area and fetal umbilical artery blood analysis results based on the deceleration area characteristics.

3.1 Feature extraction results in the deceleration zone

In this paper, the feature extraction results of deceleration zone are divided into pretreatment, baseline estimation and deceleration zone identification. As shown in Fig. 1, there are interference signals (Figure 1A) such as bad value, broken line, burr, etc. in the original data of fetal heart contractions. After denoising, interpolation and filtering, we removed bad values, connected broken wires, removed glitches in the original data and the introduced high-frequency signal components, and obtained relatively smooth pre-processed signals (Figure 1B). Furthermore, a relatively stable baseline was obtained by forward and backward filtering within the confidence interval (Figure 1C). Finally, the starting and ending positions of the deceleration zone were determined by the iterative threshold method (Figure 1D).

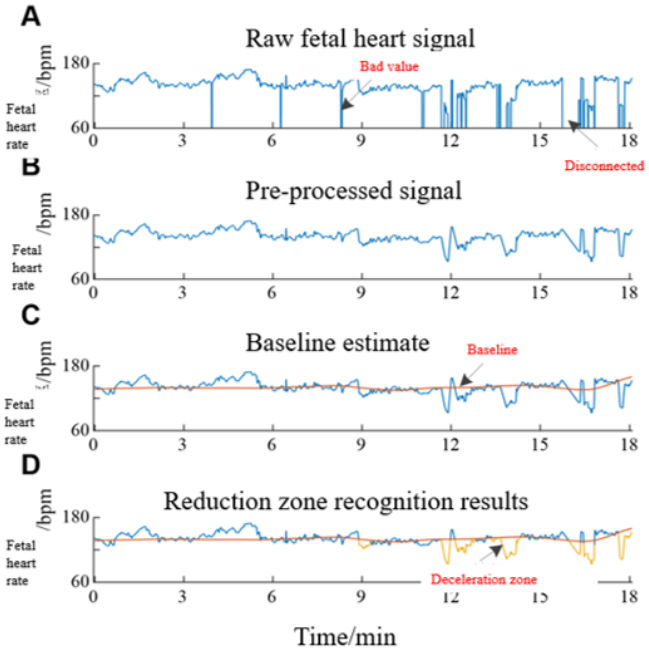

Figure 1. Sample of fetal heart rate deceleration feature extraction. Original signal (A), preprocessing (B), baseline estimation (C) and deceleration location (D)

3.2 Reduction zone identification and area calculation

Based on the pre-processed signal, the method in this paper and the traditional method were used to estimate the area of deceleration zone. As shown in Fig. 2, the start and end points identified by this method are 67s and 121s, respectively (Figure 2A), while the start and end points recognized by traditional methods are 59s and 149s, respectively (Figure 2B). The range of deceleration region identified by this method is smaller than that of traditional method, which can effectively remove the

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non-deceleration region between 121s and 149s, and accurately locate the boundary of deceleration region. This is mainly because the traditional fixed threshold method is used to identify the boundary of the deceleration zone through continuous scanning until the sampling point that meets the condition of fixed threshold stops. This method will miss the detection of the deceleration zone. On the contrary, the iterative threshold method not only sets the upper limit of recognition time (60 s) before and after the minimum fetal heart rate, but also iterates the threshold for many times. This method first find the value and the position which is smaller than the baseline value minus 15 bpm, the valley value point is found within 30 seconds after this position. Then search for a satisfying condition in front of the valley value point: the first point that larger than the fetal heart rate minus a (a is the iteration threshold, the value range is 0-15); Search backward from the valley value point to the point that meets the condition: the first point larger than the fetal heart rate minus b (the value range of b is 0-15). So as to complete the identification of an iterative deceleration zone.

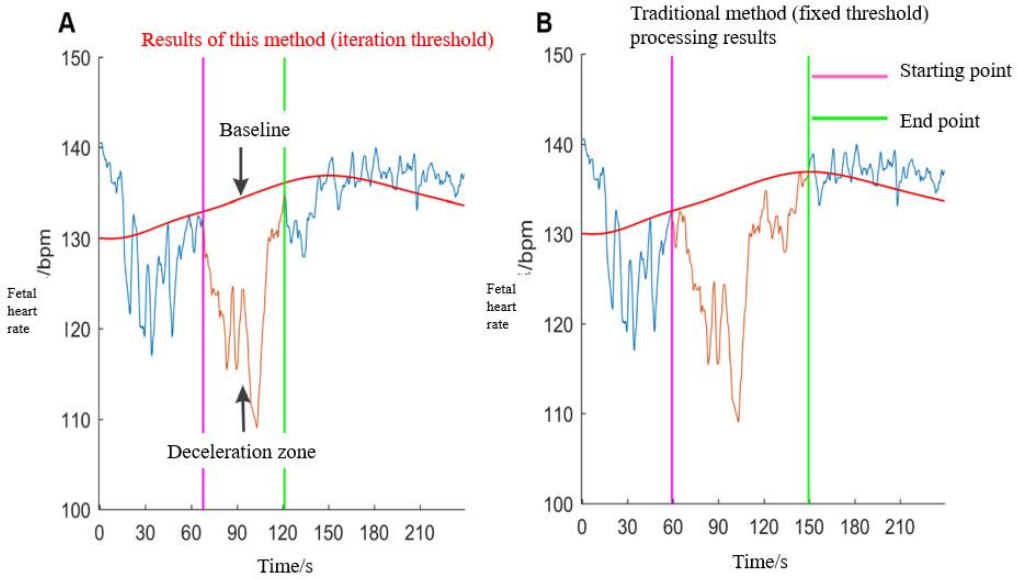

Figure 2. Example of identifying the deceleration zone by this method (A) and traditional method (B)

Furthermore, the accuracy of the method was verified by the data of 10 cases with clinical annotation. The traditional deceleration recognition method (fixed threshold method) and the threshold iterative fetal heart rate deceleration recognition algorithm designed in this paper were used to identify the fetal heart rate deceleration zone. The deceleration zone of fetal heart rate marked by clinical experts was taken as the reference standard, and the deceleration times and time within 15min were counted. At last, the relative error between the traditional method and the reference standard was compared. The average deceleration times were 3 times. The deceleration time (128 s) calculated by this method was closer to the reference value (124 s) than the traditional method (131 s). Therefore, the average relative error of this method is reduced by 3.5% compared with the traditional method (table 1).

Table 1. Deceleration zone extraction results of 10 cases of fetal heart rate signals

	Mean deceleration times ± standard deviation	Mean deceleration time ± standard deviation (s)	Mean relative error ± standard deviation (%)
Guideline	3.3±1.3	124.8±53.7	-
This method	3.4±1.2	128.6±57.6	6.4±5.4
Traditional method	3.2±1.0	131.1±56.0	8.9±6.2

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3.3 Analysis results of fetal umbilical arterial blood based on the characteristics of deceleration area

According to the reference standard of clinical acidosis diagnosis (pH < 7.2), the data were classified into acidosis group (160 cases) and control group (279 cases). Maternal age, gestational age, pH value and deceleration area were calculated in the two groups. The deceleration area included the average deceleration area calculated by the traditional method and the method in this paper. K-W one-way non-parametric anova was used to analyze the difference. The experimental results are shown in table 2. Unlike the non-significant difference of the old method (P> 0.05), the difference of this method is statistically significant (P <0.05).

Table 2 Difference analysis based on the area of fetal heart rate deceleration

Item	Acidosis group (n=160)	Control group (n=279)	P
Average age (years)	30(21-42)	30(18-42)	0.5502
Mean gestational week (week)	40(38-42)	40(37-42)	0.3563
pH value	7.14(6.89-7.19)	7.28(7.20-7.48)	0.0000
Area of this method (cm^2)	9.46(4.92-12.38)	5.00(2.42-10.58)	**0.001**
Area of traditional method (cm^2)	11.64(5.9-19.68)	8.28(3.22-16.8)	**0.088**

In order to further verify the effectiveness of this algorithm in clinical application, the sensitivity and specificity of deceleration area statistics calculated by the traditional method and this method were used to predict fetal acidemia. First, used a dichotomy method to set the value of pH≥ 7.2 as the state variable 0, that is, the diagnosis of fetal acidemia was negative; the value of pH <7.2 was set as the state variable 1, that is, the diagnosis of fetal acidemia was positive. Then, SPSS 17.0 data analysis software was used to draw Receiver operating characteristic curve (ROC). The Receiver operating characteristic curve (ROC) of the average deceleration area for 15 minutes and the pH of neonatal umbilical cord blood was shown in Figure 3. The area under curve (AUC) of traditional ROC method was 0.67, and the AUC area of this method was 0.70. In comparison, this method has higher reliability. Finally, when the deceleration area reached 8.5cm^2, the sensitivity and specificity of the method for diagnosing acidosis were 52.3% and 74.8% respectively.

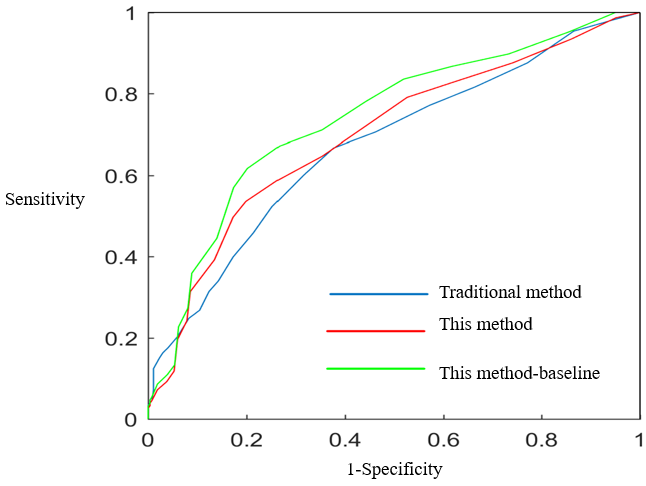

Figure 3. Receiver operating characteristic curve of traditional method, this method and this method baseline

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The four indicators of difference, AUC, sensitivity and specificity indicate that: first, there is a significant difference in the calculation results of deceleration area for the positive or negative diagnosis of fetal acidemia, that is, the occurrence of intrauterine hypoxia in fetuses. Therefore, the use of deceleration area as a quantitative indicator for the prediction of fetal acidemia has certain clinical value. Then, through comparative experiments, this method has significant differences and also has high predictive sensitivity and specificity. However, the calculation result of sensitivity because of: In the prediction of fetal acidemia, fetal heart rate deceleration is one of the characteristic parameters. When the heart rate loses the regulation of the central nervous system, it is naturally unable to reflect the hypoxia of the fetus through the decelerating change of fetal heart rate.

4. Conclusion

In this paper, a set of fetal heart rate deceleration zone identification and its area calculation method were designed based on fetal heart contractile graph, which was applied to the prediction of fetal condition. First, in terms of the accuracy of identifying the fetal heart rate baseline. Compared with the old method, it avoid false recognition of non-deceleration segments; Secondly, through the control experiment, the average relative error of the interval method recognition algorithm proposed in this paper was 6.4%, and 3.5% lower than the average relative error of the old method. Finally, in order to verify the influence of deceleration area combined with fetal heart rate baseline on the prediction sensitivity, ROC curve analysis was carried out on fetal heart rate baseline data, the sensitivity was 52.3%, and the specificity was 74.8%, indicating that the comprehensive judgment combined with deceleration area and fetal heart rate baseline could further improve the clinical reliability of fetal acidemia prediction.

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