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Assessment of the baseline pattern of fetal heart rate using software algorithms

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Abstract

Background: Currently, fetal heart monitoring is the most widely used primary method for assessing fetal health.
Objectives: The current study intended to investigate the baseline patterns of fetal heart rate using software technology.
Methods: This is a software design study. Medical records of maternal deliveries of Mousavi Hospital in Zanjan were examined using the convenience sampling method and required information were collected and the fetal heart monitoring strips were scanned. The tests were interpreted by three faculty members with a clinical background and related experience in teaching from the Zanjan and Tehran Universite of Medical Sciences. The strips were also interpreted using software designed by computer engineers without knowing the results of the research medical team. The accuracy of the diagnoses made by the software was compared against the diagnosis made by the skilled faculty members.
***Results*:** The mean (standard deviation) of the baseline feat heart rate calculated by the software was 142.06 (10.61) and the mean of the rate calculated by the skilled faculty members was 142.08 (10.77). There was a 95.9% correlation between the baseline calculated by the software and by experts ($p<0.001$). Besides, 92.1% of the baseline variance calculated by the software was determined by the baseline calculated by the experts ($p<0.001$). Software's reports on fetal tachycardia had 100% sensitivity and 98.7% specificity and, for fetal bradycardia, reports had 100% sensitivity and 99.7% specificity, compared to the expert's report.
Conclusion: According to the results, the software can be useful for health staff to accurately diagnose the baseline pattern of fetal heart rate and its related disorders.

Keywords: fetal heart rate, software algorithm, electrical monitoring

Introduction

Fetal monitoring intends to diagnose fetal hypoxia to provide information for timely action and to prevent asphyxia, fetal death during childbirth, neurological damage, and neonatal mortality. In such cases, the long-term prognosis depends on the nature and severity of the underlying problem, but using timely diagnosis and appropriate interventions such adverse outcomes can effectively be prevented [1,2]. Three decades ago the Electrical recording of Fetal Heart Rate (FHR) was established as an appropriate diagnostic method in response to this issue [3]. FHR monitoring intends to provide information to detect asphyxia in its early stages and to allow the obstetrician to intervene to prevent neurological complications and fetal death [4]. Electrical FHR monitoring due to its ease of use and lack of contraindication is the standard method of prenatal assessment in many midwifery centers all around the world [5]. Globally, one of the most important health indicators is the mortality of pregnant mothers and infants. Health policymakers are trying to reduce these indicators as much as possible. Unfortunately, infant mortality and stillbirth rates are very high in Iran, yet [6]. Countries such as Iceland, Finland, Sweden, and Japan could successfully reduce the under 5 child mortality rate to 3 to 5 deaths per thousand live births [7,8]. In Iran, the infant mortality rate is one percent, and 45% of infant deaths occur on the first day and 78% in the first week. After the premature birth, the most common causes are neonatal abnormalities, neonatal disorders, and asphyxia encephalopathy [9]. The main reason for introducing electronic monitoring of FHR was to use it as a screening test for asphyxia and to prevent severe asphyxia that causes neurological damages, including cerebral palsy. By diagnosing asphyxia in the early stages and in-time provision of interventions, brain damage caused by this process can be prevented [3,10].

Nowadays, all monitoring devices collect information concerning several fetal (i.e. heart rhythm, oxygen saturation, obvious fetal body movements) and maternal (i.e. heart rhythm, electrocardiogram, oxygen saturation, and blood pressure) variables. The Electronic Fetal Monitoring (EFM) device has two main parts, one of which detects and processes the FHR and the other one detects uterine contractions. Currently, EFM is the most widely used method of fetal health screening and is a simple, non-invasive, and cost-effective procedure. In many cases where there is a possibility of fetal distress, EFM is performed and decisions on the continuation or termination of the pregnancy are made based on the results [11].

The pattern of the FHR which has been present for a long time without periodic accelerations or decelerations is named the baseline pattern. It is reported that differences in diagnosis made for various individuals and diagnosis made for one individual at different situations are due to diagnosis errors of this low-cost and available method; Therefore, the current study aimed to investigate the baseline patterns of fetal heart rate using software algorithms.

Methods

This is a software design research. The research project was implemented after approval of the proposal, obtaining a legal license from the Zanjan University of Medical Sciences, obtaining an official letter of introduction from the treatment department of the university and coordinating with Mousavi Hospital. To collect information medical records of the hospital were reviewed. So that medical records of maternal deliveries from July to December 2018 were assessed regardless of the outcome. Records were selected using the convenience sampling technique and required information as well as the fetal heart rate strips were obtained. All fetal heart rate patterns were defined in the software based on the latest classification provided by the American College of Obstetrics and Gynecology. The tests were interpreted by three faculty members with a clinical background and related experience in teaching from the Zanjan and Tehran Universite of Medical Sciences. Then, computer software engineers interpreted the strips without knowing the results reported by experts**.** The checklist contained the mother’s age, gestational age, number of pregnancies, number of live births, number of abortions, and high-risk pregnancies. The validity of the software was examined in a step-by-step manner by comparing the diagnoses made by the software and the medical team. The sensitivity and specificity of software diagnoses were also investigated**.**

Inclusion Criteria: Included strips that could be interpreted medically to determine the health of the fetus, a gestational age over 28 weeks (due to the value of the strips of this gestational age), having single fetus, and the absence of Central Nervous System (CNS), and heart abnormalities**.**

Exclusion Criteria: Strips that did not have a continuous signal recording for at least 5 minutes, strips that did not have a baseline, as well as strips that did not have an acceptable image quality for image processing, and files that did not contain the required information for accurate diagnosis**.**

Data were edited using the Photoshop software and the extra sections were cropped (e.g. seals and the signatures of doctors and midwives). Curves induced by the crooked papers or improper paper angle on the scanner were removed. Finally, the edited scans were delivered to software engineers**.**

Methods for software designing: This section was divided into two separate phases of data extraction and data analysis; each of which had separate sub-sections (Figure 1).

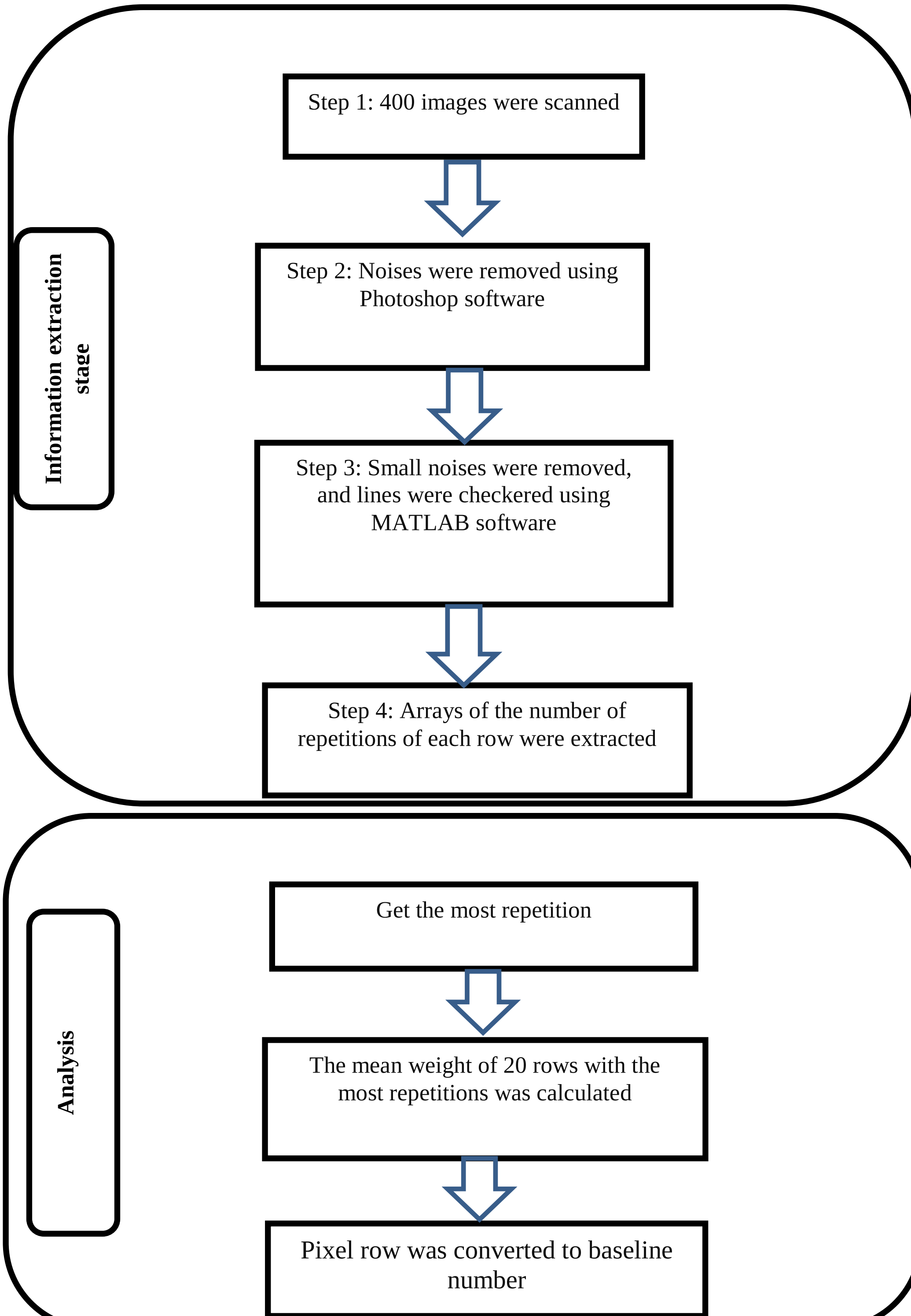

Figure 1: How to extract the baseline

Matlab R2014a software was used to extract the data from scanned images. There were checkered lines and other noises on the scanned images. So, the recorded pixels of the FHR line separated from checkered lines and other pixels. First, the contrast (brightness intensity) of all images was edited through the approved imadjust method and using the stretchlim command in the second argument, which increased the contrast distance of the signal pixels from the rest of the image. Then, pixel to pixel investigation of all images was conducted using the software. In the following, scanned images were converted into black and white images containing the signal. Then, the position of the black pixels was stored vertically and horizontally in a file. The number of repetitions in each row of pixels was estimated through black dots of each histogram. In this way, an array of numbers was obtained and the number of repetitions in each row was used to determine the baseline.

Initially, according to the following formula, the maximum number of arrays was checked by the method of maximum repetition and the results were analyzed. Then, the weighted average of 20 rows with the most frequent numbers was calculated.

$$WeightedAverage = \frac{\sum_{n=1}^{20} NST(n) * Rep(n)}{\sum_{n=1}^{20} Rep(n)}$$

```
 myra = sortrows(myra,2);
 myra = flipud(myra);
rep = 0;
mult = 0;
for cn = 1:20
    mult = mult + (myra(cn,1)*myra(cn,2));
    rep = rep + myra(cn,2);
end
myBL = mult/rep;
```

To calculate the baseline weights, the first column of the recorded repetition array (pixel row) was multiplied by the second column (number of repetitions). Then, twenty rows of the data file were added together and the obtained value was divided by the number of repetitions. Based on the first and last pixels of the image and using the following formula, the exact number of the baseline weights was obtained.

BL= round((100-(Baselineposition* 100/m))* ((nst_ max- nst_ min) / 100) + nst_ min))

Data analysis: After entering the data into the SPSS, descriptive statistic was used to identify the normal and abnormal patterns, using the software and skilled individuals. So, the mean, standard deviation, absolute values, percentage of demographic, and fertility variables were calculated. Then, sensitivity, specificity, positive predictive value, and negative predictive value of the designed software reports of tachycardia and bradycardia were compared to the reports made by experts using the analytical statistics. Pearson's correlation test was used to assess the correlation between the detection of the baseline reported by the software and experts. Moreover, the linear regression test was used to estimate the amount of variance explained in the software baseline from the diagnosis of experts.

According to Cochran's formula, about 400 samples were needed to achieve the maximum required sample size (50% ratio) with a 5% error.

The arrhythmia pattern was not available in the strips and the number of bradycardia patterns was very small, so the researchers tried to use the strips available on the Internet to check this issue, which, unfortunately, because they were not standard and due to high-levels of the uncertainty of the baseline patterns in the Internet strips as well as the lack of clarity of images, it was abandoned after much effort.

Results

The mean (standard deviation) age of mothers was 28.08 (5.76) years. On average, every woman had two to three pregnancies and there was no history of abortion. The mean gestational age was 38.21 (1.32) weeks. Most of the mothers were living in rural areas (51.2%). Most of them had a normal vaginal delivery (60%) and most of the babies were healthy (95%). The average weight of neonates was 3161 (400.91) grams and most of them were girl (53%). The mean Apgar score was 8.89 (0.60) (Table 1).

Table1: Demographic, quantitative, and qualitative characteristics of mothers and infants born in Mousavi Hospital

	variable		Average	Standard deviation	Number	percent
Demographic characteristics and quantitative fertility variables of the mothers	Age		28.08	5.76		
	Gravida		2.30	1.09		
	Para		0.99	0.94		
	Abortion		0.29	0.53		
	Gestational age		38.21	1.32		
Demographic characteristics and qualitative fertility variables of the mothers	Residency	City			195	48.8
		Village			205	51.2
	Responsible for childbirth	Gynecology resident			306	76.5
		Midwife			94	23.5
	Type of delivery	NVD			240	60
		Cesarean section			160	40
	Neonatal Outcome	Healthy			380	95
		Hospitalized in the neonatal ward			9	2.8
		Hospitalized in NICU			11	2.8
Characteristics of newborns	Weight		3161	400.91		
	Apgar		8.89	0.60		
Gender	Male		188	47		
	Fmale		212	53		

The mean minimum heart rate of neonates was 98.39 (18.19). The mean baseline rate reported by the software (calculates using the weighted mean method) [142.06 (10.61)] was very close to experts' reports [142.08 (10.77)] (Table 2).

Table2: Fetal heart rate profile

Fetal Heart Rate		**Weighted Mean**	
		Mean	**Standard deviation**
Reported by software	Min	98.33	18.19
	Max	182.16	10.20
	Baseline	142.06	10.61
	Baseline Range	113	187
Reported by experts'	Baseline	142.08	10.77
	Baseline Range	110	185

There was a high correlation between the baseline reported by the software report and the experts' reports. The Pearson correlation coefficient between the baseline calculated by the software and by the experts was 0.959 ($r=0.959$, $P<0.001$). Also, the linear regression test showed that 92.1% of the variable changes in the baseline calculated by the software were determined by the baseline calculated by the experts ($P<0.001$) (Figure 2).

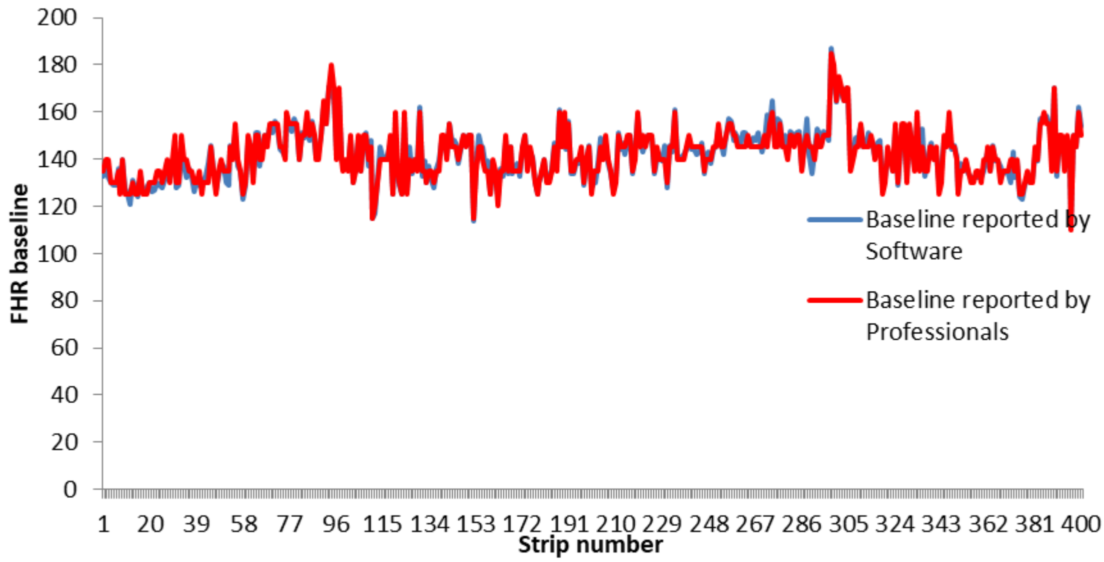

Figure 2: Correlation of the baseline heart rate reported by the software with the experts' reports

The software report of fetal tachycardia based on the weighted mean had 100% sensitivity, 98.7% specificity, 73.68% positive predictive value, and 100% negative predictive value compared to the experts' reports. Also, the software report of fetal bradycardia had 100% sensitivity, 99.7% specificity, 75% positive predictive value, and 100% negative predictive value compared to the experts' reports (Table 3).

Table 3: Accuracy of software reports about fetal tachycardia and bradycardia based on experts' report

Method	Experts report / software report	Normal		AbNormal		Total		Sensitivity	Specificity	Positive Predictive Value	Negative Predictive Value
		Number	percent	Number	percent	Number	percent				
Tachycardia	**Tachycardia**	14	100	5	1.3	19	4.75	100	98.7	73.68	100
	Lack of Tachycardia	0	0	381	98.7	381	95.25				
	Total	14	100	386	100	400	100				
Bradycardia	**Bradycardia**	3	100	1	0.3	4	1	100	99.7	75	100
	Lack of bradycardia	0	0	396	99.7	396	99				
	Total	3	100	397	100	400	100				

Discussion

According to the results, the mean baseline rate reported by the software and the experts was 142.06 (10.61) and 142.08 (10.77), respectively. Also, the software reports had 100% sensitivity and 98.7% specificity about fetal tachycardia, and 100% sensitivity and 99.7% specificity about the fetal bradycardia compared to the experts' reports. The average baseline read by software and experts was in the normal range. The strips were given from a normal and non-pathological population. Therefore, in normal range being of the FHR made sense. In clinical practice, to reduce human vision error when calculating the FHR, the approximate average rate in a 10-minute strip was "rounded" to 5 beats per minute. Such an approach in software development would reduce the accuracy of the software. Therefore, it was

abandoned. It seems that using software to diagnose clinical cases will reduce vision errorsand improve the definitions of FHR patterns.
The baseline calculated by the software was highly correlated with baseline reported by the experts and explained a large share of variations. Hence, it seems that this method of reporting the baseline through software is currently close to the opinion of experts in this field and explains a good pattern of FHR reporting in clinical practice. This method has also been recommended by Noguchi et al. According to the basic pattern, other patterns such as accelerations and decelerations were also defined [12].
The software reports had 100% sensitivity and 98.7% specificity to fetal tachycardia and 100% sensitivity and 99.7% specificity to fetal bradycardia compared to experts' reports. A program called SisPorto® is provided by Ayres-de-Campos et al. which works according to FIGO criteria and can automatically analyze cardiotocographic signals. In line with the results of the current study, the SisPorto program showed a 100% sensitivity and 99% sensitivity [13] Although the number of fetal tachycardia and bradycardia was very small, 100% sensitivity means that the software identifies all clinical cases identified by experts, which indicates the high specificity of the software (i.e. most of the healthy reported cases of the software would be healthy based on the experts' reports) .
The positive predictive value of the software reports was about 70 to 75% in detecting fetal tachycardia and bradycardia. That is, for software reports, in 70 to 75% of cases the fetus is expected to have tachycardia or bradycardia. The software's negative predictive value for both aforementioned outcomes was 100%, indicating that if the software reports that the fetus is healthy, it is almost 100% expected that the experts' report will also confirm that the fetus is healthy. There were very few bradycardia patterns in the samples, and no arrhythmic pattern of FHR was observed on the strips. Therefore, the researchers re-examined the hospital archives, but, unfortunately, failed to find these patterns.

Conclusion

The results of the present study showed that the developed software recognizes the baseline FHR very close to the opinions of experts and identifies abnormalities with high sensitivity and specificity. It is recommended that other patterns, such as acceleration, deceleration, and so on, be assessed based on the baseline pattern provided by the software in future studies.

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Conflict of interest

The author declares no conflicts of interest.

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