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Diagnostic Value of Non-stress Test Interpreted by Smart Interpretive Software

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ABSTRACT

Background and aim: Using appropriate methods for the assessment of fetal health including non-stress test during high-risk pregnancies due to possible placental insufficiency is of paramount importance. Due to complexity in medical decisions, using information systems is being increased to support complex medical decisions. We conducted this study to measure the diagnostic value of non-stress test interpreted by smart interpretive software.

Materials and Methods: This study was carried out on 400 non-stress tests obtained from patients' records regardless of the results of tests in Bent-Ul-Hoda Hospital, Bojnord, Iran. Then, to increase the accuracy of tests, they were interpreted by two specialists with Master's degree in Midwifery. Finally, the tests were interpreted by the given software. The diagnostic test accuracy was measured using sensitivity and specificity of the software.

Results: Out of 400 selected tests, experts interpreted 126 tests with reaction and 274 cases without reaction. The diagnostic accuracy, sensitivity, and specificity of the software were 92.45%, 94.07, and 88.40, respectively .

Conclusion: According to the results, the use of this software for interpreting non-stress test results, reduce false- positive and false-negative diagnoses.

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Introduction

Placental insufficiency leads to perinatal mortality in addition to preterm labor, which is considered as the only way to rescue fetus exposed to the risk, in the case of favorable status of fetus (1, 2). Therefore, using appropriate techniques for the evaluation of fetal health during high-risk pregnancies due to possible placental insufficiency is of paramount importance.

Non-Stress test (NST) is the most commonly used technique for the assessment of fetal health (3). This method is simple, non-invasive, and cost-effective (4). The decision to continue or terminate a pregnancy is taken according to the results of NST and other factors (5).

The NST is based on the increase in fetal heart rate (FHR) in response to fetal movements and or without any movement. This rise in FHR is related to autonomic nervous system, and it may not exist normally before the gestational age of 24 to 35 weeks (6).

Artificial intelligence (AI) denotes systems that may simulate human behaviors including the perception of complex conditions, thinking processes, reasoning methods, learning, and potential for knowledge acquisition by means of

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deduction for solving problems (7).

Artificial neural networks were utilized for the diagnosis of strabismus in another study that was a web-based information system (www.strabnet.com). Therefore, physician could easily enter data after medical examination.

The assessment of this system showed that the rate of accuracy in this system was 100% for real data. Convolutional neural network was used to distinguish automatically between normal electrocardiogram and that with myocardial infarction (8, 9).

The diagnosis of hyperkalemia could be made by electrocardiography and computer-assisted image processing technique (10). We did not review any study on the use of AI for interpreting fetal electrocardiogram in scientific websites. In addition, we wanted to minimize the human error. Accordingly, this study was conducted to evaluate the diagnostic value of non-stress test interpreted by smart software.

Materials and Methods

This study was carried out on 400 non-stress tests obtained from patients' medical records regardless of their results in Archive Unit of Bent-Ul-Hoda Hospital, Bojnord, Iran. The cases were selected through available sampling technique. Thereafter, to increase accuracy, the tests were interpreted by two midwives with Master's degree in Midwifery. The NSTs, the extracted form of fetal electrocardiogram, were scanned by a scanner (Kodak Scanmate I1120 Scanner, Eastman Kodak Company, USA) with the resolution of 300dpi and introduced to the given software. This program was implemented by MATLAB software (R22009a) and processed by a computer with 3 gigabytes main memory and dual core processor (2.7GHz).

This paper is a part of proposal approved by North Khorasan University of Medical Sciences, Bojnord, Iran, under the code NO. 93/P/739.

A summary of trend for the design of software:
Extraction of non-stress test signal from the scanned image: In this section, the method of extraction or retrieval of NST signal from the scanned image of was described.

Scanning of printed fetal electrocardiogram: The process of printing from digital-based images may be executed with different resolutions. Higher resolution scans record more details of image, and they are more flexible for the extraction of signal from the image. However, high resolution scanning requires further memory and time to scan documents and fetal electrocardiogram with the resolution of 300 dpi. In this study, the process of scanning was executed in normal size and the format of "jpg" by the scanner (Figure 1).

Conversion of image to greyscale: The images were scanned with colored format because colored image may assist for the separation of signal from total image. The signal of NST includes black color, and vertical and horizontal axes are green. In addition, the color image processing requires more memory and longer time. Therefore, these images were converted to greyscale at the first step. Several parts of background table might be deleted due to less luminosity in this conversion. Nevertheless, the signal completely remained with respect to high black luminosity (Figure 2).

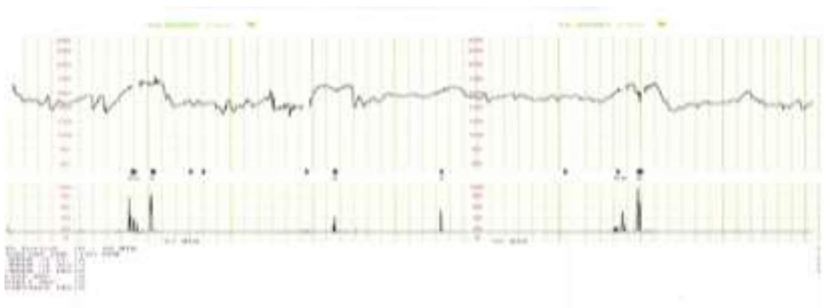


Figure 1. Scanned image of fetal electrocardiogram

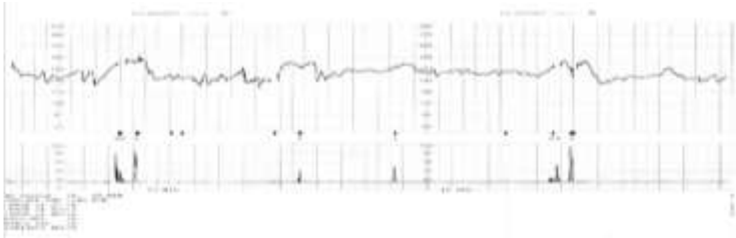


Figure 2. Greyscale image from fetal heart rate tape

Separation of signal from diagram: The two-dimensional greyscale image may be processed by appropriate threshold limit to separate the signal from the whole image; thereby, the background table was deleted and signal was separated from the image.

This separation process led to the creation of noises due to the deletion of vertical and horizontal axes. We described how to delete noise in subsequent phases (Figure 3).

Deletion of image noises: Given the fact that the diagnosis and calculation of properties are done on NST signal, the lack of noise in extracted signal can be important in increasing the accuracy of computation and final diagnosis.

Therefore, we initially deleted noises at this step. There are two classes of noise in this type of images (Figure 4).

Salt and pepper noises removing: We used kFill algorithm, which is designed for deleting salt and pepper noise. This algorithm operates by moving a window with the size of k×k from image points on the given image. The window size selection was proportional to the size of image noises.

The noises were removed by filling central core in proportion to $(k-2)^2$ values in other points of image inside the window. Deciding whether or not to fill this window requires that all of the kernel's image points are identical, and that the three variables of n, c, and r are calculated based on the neighboring points that comprise the kernel of the window. The n, c, and r variables represent the number of black dots in the window, number of dots attached in the window, and number of black dots in the kernel of window. The core is filled with black content if the condition of Eq. (1) is established.

Eq. (1)

$$(c=1) \text{ AND}\{(3k-4<n) \text{ AND } [(3k-4=n) \text{ OR } (r=2)]\}$$

Status in *n* and *r* point is a function of window size. Constraint (c=1) guarantees that filling does not lead to change in a continuous part. For instance, it does not link two objects in image and/or it does not cut two connected parts (Figure 5).

Figure 3. Extracted signal from the image of fetal electrocardiogram

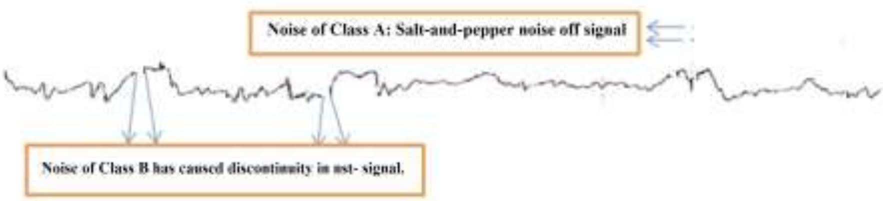
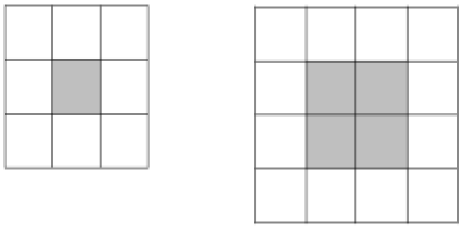


Figure 4. Extracted signal from image with noise



(b) (a)

Figure 5. Two windows with dimensions (k×k) and core region and neighborhood points in k=3 in image (b) and k=4 in image (a)

The noises that led to the discontinuity of signal to separate signal from image: To fill signal discontinuity, which was created due to the deletion of background table and extraction of signal from total image, we use Eq. (2) provided that discretion value is limited.

Eq. (2) $$P(n) = d1 - [k \times \frac{height}{distance}]$$

K_1 is discontinuity origin point and *K_2* point is the end of discontinuity in a signal.

Distance is interval between K_1 and K_2 (Figure 6).

Eq. (3) $$distance = [k1 - k2]$$

To acquire discrete parts of signal, columnar survey (vertical profile) was done, in which any point in signal was equivalent to row number.

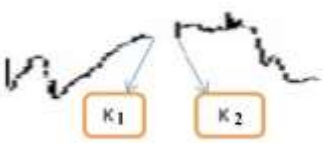


Figure 6. Noise leads to discontinuity in signal, in which the black point is placed.

Therefore, the value of profile is typically derived from the points of k_1 and k_2. We indicated the profile values at the points of k_1 and k_2 with $P(k_1)$ and $P(k_2)$, respectively. Therefore, we obtained height value from Eq. (4).

Eq. (4) $$height = P(k1) - P(k2)$$

The P(n) is the value of vertical profile that is calculated for all points located among the points of k_1 and k_2 using Eq. (2) (Figure 7).

Figure 7. Extracted signal from fetal electrocardiogram after noise removing

Non-stress test signal analysis: At this step, the final signal was analyzed to extract the properties.

Extraction of property in basic rate: To extract basic rate, the mean of the maximum and minimum FHRs should be calculated. We calculated them by the aid of horizontal survey of image (horizontal profile) of signal, and the basic rate was computed according to Formula (1).

(1) $$FHR_{base} = \frac{FHR_{max} + FHR_{min}}{2}$$

Calculation of acceleration: Acceleration is defined as 15 pulses of FHR higher than basic rate that continue at least more than 15 seconds. If there are at least two accelerations along the NST tape, fetal health is considered as normal.

Vertical profile design was employed to count the accelerations. Therefore, all studied columns and those columns, in which FHR was higher than basic rate were stored in an array. If there were 15 common cells in this array, we considered them as an acceleration.

Results

The experts interpreted 126 tests as reactive and 274 cases as non-reactive among totally 400 NSTs. The software interpretation is demonstrated in Table 1.

Table 1. Results of tests

Software	Diagnosis by expert		Number of NST* tapes
102 normal NSTs 24 abnormal NSTs	126	Normal NST	400
237 abnormal NSTs 37 Normal NSTs	274	Abnormal NST	

* Non-stress test

Table 2. Results of tests after revision

Software	Diagnosis by expert		Number of NSTs*
123 Normal 7 Abnormal	130		400
254 Normal 16 Normal	270	Abnormal	

* Non-stress test

After the revision of samples, which had been diagnosed as reactive and produced system as non-reactive, it was identified that in some cases system and in other cases midwifery specialists incorrectly diagnosed due to visual error.

However, the system operated more accurately due to precision. The obtained results are demonstrated in Table 2.

The diagnostic precision of software was 94.25% and its sensitivity and specificity are showed in Table 3.

Table 3. Sensitivity and specificity of software

	254	Real positive
Sensitivity = 94.07	7	False positive
Specificity = 88.40	123	Real negative
	16	False negative

Discussion

The NST was introduced by Sadovsky in 1973 for the first time, and subsequent studies confirmed its reliability as a method for screening fetal health (1). Nowadays, this test is the most commonly used technique for the assessment of fetal health (3).

This method is simple, non-invasive, time-consuming, and cost-effective (4). There are several definitions for normal results of NST and the subject of interpretation of results is problematic (5). In this study, we examined the diagnostic value of the smart software for test interpretation and compared it with interpretation by experts.

Despite of non-invasive nature and wide usage of this test for fetal health assessment, this test might be conducted with higher reliability as well. According to the results of the present study, out of 400 NST tapes, 130 and 270 tapes were interpreted as normal and abnormal by the experts, respectively.

In addition, software interpretation showed that 139 tapes were normal and 261 tapes belonged to unhealthy cases. The diagnostic precision, sensitivity, and specificity of the software were 94.25%, 94.07%, and 88.40%, respectively.

The application of information systems has been increased to support medical decisions due to their complexity (7). According to several definitions of normal results of NST, the subject of potential for the generalization of interpretation of results is problematic (8, 11).

One of the limitations of this study was overlooking fetal movements on tape because of lack of recording movements on all tapes and ignoring beat-to-beat changes.

Conclusion

Regarding the results of current study and high sensitivity and specificity of the designed software, cost-effectiveness, and capability for use in all medical centers, it is recommended to use this software for the interpretation of NST results to reduce false positive and negative results.

In this analysis, NST on printed fetal electrocardiogram was dependent on the rate of accuracy in extracted signal from total image with respect to employed techniques for noise removing (kFill algorithm and new method for filling discontinuous points in signal). This technique is very efficient in the increase of precision in this system. Nevertheless, in several cases, medical experts diagnose more accurately.

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Conflicts of interest

Authors declared no conflicts of interest.

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