

Original Article

The significance of amplitude and duration of fetal heart rate acceleration in non-stress test analysis[☆]

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Abstract

Objective: This study was conducted to assess the relative significance of the amplitude versus the duration of accelerations in non-stress test (NST) analysis.

Materials and Methods: A total of 3055 normal fetal heart rate (FHR) tracings at 30–42 weeks' gestation were analyzed by automated FHR analyzing software. Accelerations were classified as one of four combinations of amplitude and duration: 15 bpm–15 seconds (Acc15–15), 15 bpm–10 seconds (Acc15–10), 10 bpm–15 seconds (Acc10–15) and 10 bpm–10 seconds (Acc10–10). We estimated the correlation among the FHR acceleration combinations using correlation analysis based on linear regression models.

Results: Linear regression models demonstrated statistically significant linear associations between Acc15–15 and Acc15–10 ($r^2 = 0.998$, $p < 0.0001$) and between Acc10–10 and Acc10–15 ($r^2 = 0.989$, $p < 0.0001$). There was significant association based on amplitude and relatively low correlation based on duration (Pearson correlation coefficient = 0.99 between Acc10–10 and Acc10–15, and 0.99 between Acc15–15 and Acc15–10). In the relationships of the FHR-work values, amplitude was a more important component of FHR acceleration than duration [Acc10–10 (1.67 beat) < Acc10–15 (2.50 beats) = Acc15–10 (2.50 beats) < Acc15–15 (3.75 beats)].

Conclusion: Amplitude was a more significant component of FHR acceleration than duration in the computerized analysis of NST.

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Keywords: acceleration; amplitude and duration; computerized analysis; fetal heart rate; non-stress test

Introduction

The non-stress test (NST) is one of most valuable electronic fetal heart rate (FHR) monitoring tests, and it has been widely and routinely performed in both high risk and normal pregnancies. Many parameters of FHR tracings need to be interpreted for the prediction of fetal well-being and either a reassuring or non-reassuring fetal status during the NST.

The main feature of normality in the interpretation of NSTs is the presence of FHR accelerations, i.e., reactive tracing. Accelerations, which resemble a spike-like or transitory increase above baseline as a result of sympathetic nervous system stimulation, have been shown to be reassuring both antepartum and intrapartum [1,2], and indicate a non-acidotic fetus [3,4]. The suggested optimum number of accelerations varies in the literature from one to five over a period of 20 or 30 minutes [5]. In contrast, the absence of accelerations (non-reactive tracing) is considered suspicious, and the management of a non-reactive NST first requires the extension of the recording time to 40–50 minutes. Clinical evaluations performed on shorter time intervals may be misleading.

This study was conducted to assess which component of FHR acceleration, with the use of National Institute of Child Health and Human Development (NICHD) criteria, was more

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significant in the analysis of NST using a computerized automated analysis system, thus providing new understanding of FHR acceleration.

Materials and methods

Patients and control subjects

For 10 years, between January 1996 and December 2005, a total of 4635 pregnant women received a NST at Hanyang University Hospital, Seoul, South Korea, before delivery. Of these, 3055 pregnant women without labor or any complications at 30–42 weeks' gestation were included in this study. Indications for these women were single normal pregnancies who delivered normal infants without perinatal morbidity.

All were in a semirecumbent position for a minimum of 10 minutes before data collection, all of which occurred from 2:00 to 6:00 PM. After excluding above 10% signal loss, only one FHR tracing was used per patient by computer-based random selection, and only the first 20 minutes of NST data were analyzed.

All had a single fetus with newborns without any malformations, chromosomal anomalies, or any other perinatal problems. The birth weight was >2500 g, and in each case 1-minute and 5-minute Apgar scores were >5 and >7, respectively. Each FHR tracing was analyzed by our own automated FHR analyzing software, the Hanyang Fetal Monitoring (HYFM-II) system [6]. This study did not require Institutional Review Board approval, due to its retrospective approach in evaluating NST results.

Computerized analysis of FHR parameters

A Corometrics 115 model (Medical Systems, Wallingford, CT, USA) was used to develop the HYFM-I system in 1988, with the assistance of Professor Dawes from Oxford University, England. The basic concepts of this program and data retrieval methods for various FHR parameters have been described previously [6, 7]. Briefly, FHR data were collected beat-to-beat, 140 times per minute (i.e., 2.3 times per second). Fetal movements (FMs) were recorded simultaneously. All data were sent to a given unit, and intervals were calculated at an average of 100 milliseconds as previously described by Dawes et al [8]. FHR parameters including baseline FHR, number of FMs, amplitude (AMP), mean minute range (MMR) and number of FHR accelerations and decelerations were analyzed.

Amplitude and mean minute range were used as the index of variability. Amplitude was calculated by the difference between maximum and minimum measurements in each minute. The average of the amplitude for the duration of recording (20 minutes) was expressed in bpm. In each minute, the computer acquired 16 measurements of fetal pulse intervals; each measurement was the average interval in milliseconds over a period of 3.75 seconds. The difference between the minimum and the maximum of the measurements was calculated as the minute range. The average of the minute

ranges over the duration of recording, i.e., the mean minute range in milliseconds, was calculated as an index of long-term FHR variability.

Each FHR acceleration was classified as one of four combinations of amplitude and duration: 15 bpm–15seconds (Acc15–15), 15 bpm–10seconds (Acc15–10), 10 bpm–15 seconds (Acc10–15) and 10 bpm–10 seconds (Acc10–10). We calculated a value termed FHR-work to compare each combination of amplitude and duration, and estimated the correlation among the four definitions of FHR acceleration.

In order to confirm the usefulness of FHR-work, we compared the same FHR-work of the FHR tracings with Acc10–15 and Acc15–10 in normal and abnormal fetuses.

Statistical analysis

Statistical analysis was performed using Statistical Analysis System software (SAS, version 9.1, USA). To determine differences between the groups, we used SAS general linear models. We estimated correlation among the four definitions of FHR acceleration by correlation analysis on the basis of linear regression models. All the analyses were performed using an alpha level of 0.05 as the criterion for statistical significance.

Results

Table 1 shows FHR parameters according to gestational weeks. Mean FHR (bpm) and FM (number/20 minutes) decreased gradually as gestational weeks increased ($p < 0.0001$) and variability (AMP, MMR) was highest at 36 to 37 weeks of gestation ($p < 0.01$).

The distribution of each combination of FHR acceleration, amplitude and duration according to number of FHR accelerations of 15 bpm and 15 seconds (Acc15–15) is given in Table 2.

The number of all combinations (Acc15–10, Acc 10–15, Acc10–10) rose as the number of Acc15–15 accelerations increased. Interestingly, there was a significant difference between the number of Acc15–10 and Acc10–15 accelerations, although the numbers of Acc10–15 and Acc10–10 accelerations appeared to be similar.

Linear regression models among the four combinations of FHR accelerations in Table 2 were as follows: Acc15–15 = $0.013 + 0.983 \times \text{Acc15–10}$ ($r^2 = 0.998$, $p < 0.0001$), Acc10–10 = $0.106 + 0.991 \times \text{Acc10–15}$ ($r^2 = 0.989$, $p < 0.0001$).

The models demonstrated statistically significant linear associations between Acc15–15 and Acc15–10 and between Acc10–10 and Acc10–15, respectively.

The Pearson correlation coefficient was 0.99 between Acc10–10 and Acc10–15 and 0.99 between Acc15–15 and Acc15–10, indicating a perfect linear relationship based on the amplitude component of FHR accelerations. In contrast, the coefficient was 0.79 between Acc10–10 and Acc15–10 and 0.80 between Acc15–15 and Acc10–15, suggesting a relatively low correlation based on duration. Comparisons

Table 1
FHR parameters according to gestational ages.

| | GA (wk) ^a | Mean FHR (bpm) ^a | FM(no./20 min) ^a | AMP (bpm) ^b | MMR (ms) ^b |
|--------------------|----------------------|-----------------------------|-----------------------------|------------------------|-----------------------|
| 30–31 wk (n = 244) | 30.50 ± 0.03 | 146.33 ± 0.40 | 4.11 ± 0.26 | 17.25 ± 0.30 | 50.88 ± 0.86 |
| 32–33 wk (n = 348) | 32.53 ± 0.03 | 145.18 ± 0.39 | 3.93 ± 0.22 | 17.82 ± 0.29 | 53.33 ± 0.86 |
| 34–35 wk (n = 471) | 34.55 ± 0.02 | 144.31 ± 0.35 | 3.64 ± 0.20 | 18.66 ± 0.25 | 56.46 ± 0.77 |
| 36–37 wk (n = 622) | 36.54 ± 0.02 | 144.30 ± 0.35 | 3.27 ± 0.16 | 18.70 ± 0.27 | 56.83 ± 0.86 |
| 38–39 wk (n = 793) | 38.53 ± 0.02 | 142.97 ± 0.31 | 3.15 ± 0.13 | 17.81 ± 0.23 | 54.44 ± 0.71 |
| 40–42 wk (n = 577) | 40.60 ± 0.03 | 142.89 ± 0.37 | 3.00 ± 0.15 | 17.83 ± 0.27 | 54.69 ± 0.84 |
| Total (n = 3055) | 36.58 ± 0.06 | 143.96 ± 0.15 | 3.39 ± 0.07 | 18.08 ± 0.11 | 54.85 ± 0.34 |

Data are represented as mean ± standard error. AMP = amplitude (bpm); FM = number of fetal movements (number/20 minutes); GA = gestational ages (weeks); mean FHR = mean baseline FHR (bpm); MMR = mean minute range (milliseconds).

^a alpha level = 0.0001 by general linear model.

^b alpha level = 0.01 by general linear model.

based on unmatched amplitude and duration also yielded weaker correlations (Table 3).

Fig. 1 illustrates the four definitions of FHR accelerations (i.e., Acc10–10, Acc10–15, Acc15–10 and Acc15–15). We termed bpm × seconds, as ‘FHR-work’. In the range of Acc10–10, FHR-work was calculated as 1.67 beats (10 beat/60 seconds × 10 seconds). In the same manner, the FHR-work values of Acc10–15, Acc15–10 and Acc15–15 were 2.5 beats (10 beat/60 seconds × 15 seconds), 2.5 beats (15 beat/60 seconds × 10 seconds) and 3.75 beats (15 beat/60 seconds × 15 seconds), respectively. If the power of amplitude (bpm) and duration (seconds) are assumed to be equal, the relationships of the FHR-work values are: Acc10–10 < Acc10–15 = Acc15–10 < Acc15–15.

We found, however, that amplitude and duration did not have an equal effect, and therefore propose the following instead:

$$\text{Acc10–10} \approx \text{Acc10–15} < \text{Acc15–10} \approx \text{Acc15–15}.$$

In this model, amplitude is a more important component of FHR acceleration than duration.

Fig. 2 shows the significance of difference for abnormal and normal fetuses by using by the FHR acceleration

Acc10–15 and Acc15–10 in the same FHR-work [7, 9]. The F-value of Acc15–10 was higher than that of Acc10–15 and this result suggests that Acc15–10 was a more useful parameter of NST in differentiating abnormal fetuses from normal fetuses. With regards to the *p* value, Acc15–10 (0.1874) at a significant level alpha 0.20 could be used to distinguish abnormal fetuses from normal fetuses, while Acc10–15 (*p* = 0.7251) could not used for that purpose.

This comparison of the same FHR-work of the FHR tracings using our prior data shows that amplitude is a more significant component of FHR acceleration than duration for abnormal fetuses as well as normal fetuses in a computerized analysis of NST.

Discussion

FHR monitoring continues to be the predominant method for fetal surveillance, despite questions about its efficacy in predicting fetal outcomes [1,10].

In 1997 the NICHD provided research guidelines for the interpretation of NST which are widely used [4]. These initial guidelines were affirmed and/or updated in 2008 [11]. Prediction of fetal well-being during FHR monitoring requires the interpretation of multiple parameters of FHR tracings. In FHR tracings, accelerations are defined by the basic components of amplitude and duration. The presence of acceleration

Table 2
Distribution of each combination of amplitude and duration of FHR acceleration according to number of FHR acceleration of 15 bpm and 15 seconds.

| Number of Acc15–15 | Acc15–10 ^a | Acc10–15 | Acc10–10 ^b |
|--------------------|-----------------------|--------------|-----------------------|
| 0 (n = 1191) | 0.01 ± 0.00 | 1.89 ± 0.08 | 1.91 ± 0.08 |
| 1 (n = 446) | 1.02 ± 0.01 | 3.66 ± 0.14 | 3.71 ± 0.14 |
| 2 (n = 325) | 2.03 ± 0.01 | 5.07 ± 0.20 | 5.17 ± 0.21 |
| 3 (n = 241) | 3.01 ± 0.01 | 6.29 ± 0.22 | 6.35 ± 0.22 |
| 4 (n = 172) | 4.09 ± 0.07 | 6.98 ± 0.26 | 7.17 ± 0.29 |
| 5 (n = 166) | 5.15 ± 0.07 | 8.01 ± 0.22 | 8.22 ± 0.23 |
| 6 (n = 104) | 6.11 ± 0.06 | 9.57 ± 0.33 | 9.71 ± 0.33 |
| 7 (n = 111) | 7.03 ± 0.02 | 10.56 ± 0.33 | 10.64 ± 0.34 |
| 8 (n = 80) | 8.00 ± 0.00 | 11.38 ± 0.32 | 11.38 ± 0.32 |
| 9 (n = 61) | 9.13 ± 0.13 | 13.20 ± 0.58 | 13.34 ± 0.59 |
| ≥10 (n = 158) | 13.07 ± 0.29 | 16.61 ± 0.42 | 16.65 ± 0.42 |
| Total (n = 3055) | 2.65 ± 0.06 | 5.27 ± 0.09 | 5.33 ± 0.09 |

Data are represented as mean ± standard error. Acc15–15, Acc15–10, Acc10–15, and Acc10–10; FHR accelerations for 15 bpm–15 seconds, 15 bpm–10 seconds, 10 bpm–15 seconds and 10 bpm–10 seconds, respectively.

^a alpha level = 0.0001 by general linear model.

^b alpha level = 0.01 by general linear model.

Table 3
Correlation between FHR acceleration combination of amplitude and duration.

| | Pearson correlation coefficient* |
|-------------------------------------------|----------------------------------|
| Based on the same amplitude (bpm) | |
| Acc10–10 and Acc10–15 | 0.99 |
| Acc15–15 and Acc15–10 | 0.99 |
| Based on the same duration (sec) | |
| Acc10–10 and Acc15–10 | 0.79 |
| Acc15–15 and Acc10–15 | 0.80 |
| Based on unmatched amplitude and duration | |
| Acc10–10 and Acc15–15 | 0.79 |
| Acc10–15 and Acc15–10 | 0.79 |

**p* < 0.0001.

Acc15–15, Acc15–10, Acc10–15, and Acc10–10; FHR accelerations for 15 bpm–15 seconds, 15 bpm–10 seconds, 10 bpm–15 seconds and 10 bpm–10 seconds, respectively.

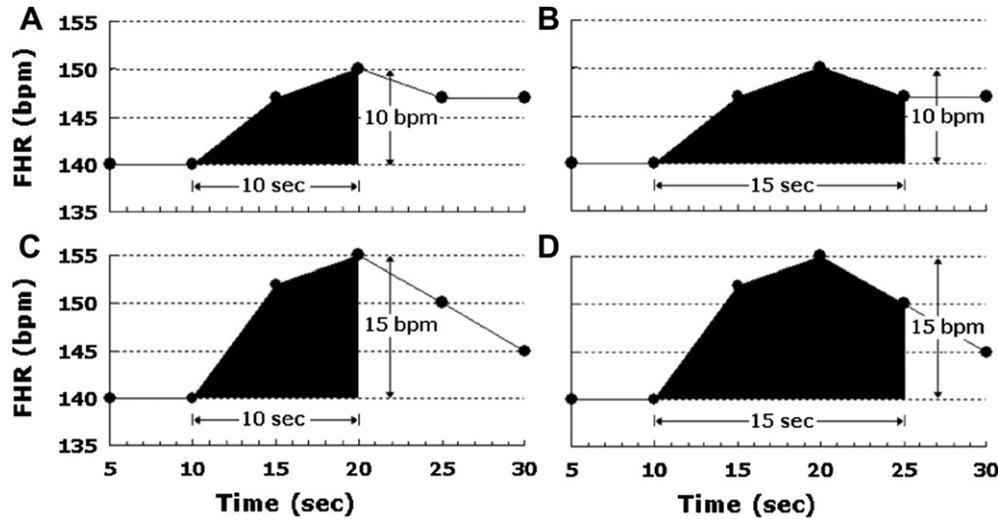


Fig. 1. Diagram of the FHR-work value (beat) of each FHR acceleration combination. (A) Acc10–10; (B) Acc10–15; (C) Acc15–10; and (D) Acc15–15. The FHR-work value (beat) of (A) Acc10–10 = (10 beat/60 seconds) × (10 seconds) = 1.67 beats; (B) Acc10–15 = (10 beat/60 seconds) × (15 seconds) = 2.5 beats; (C) Acc15–10 = (15 beat/60 seconds) × (10 seconds) = 2.5 beats; (D) Acc15–15 = (15 beat/60 seconds) × (15 seconds) = 3.75 beats.

is a reassuring indicator in both antepartum and intrapartum fetal evaluation of fetal well-being, and also indicates a non-acidotic fetus.

In the present study, we analyzed the impact of both amplitude and duration on the definition of FHR acceleration with the use of NICHD criteria. We determined the statistical relationship between four combinations of components of FHR acceleration on the basis of correlation analysis. We calculated the number of beats (FHR-work) from Acc10–10, Acc10–15, Acc15–10 and Acc15–15, and compared them with the practical results, revealing the following relationships: Acc10–10 ≈ Acc10–15 < Acc15–10 ≈ Acc15–15.

This model suggests that FHR accelerations with the same amplitude (i.e., 10 or 15 bpm) may have the same or a similar number of accelerations despite different durations (i.e., 10 or 15 seconds). Based on our findings, the definition of FHR acceleration depends on amplitude (bpm) more than duration (seconds). The notion that FHR acceleration represents the beat-to-beat push–pull effect of the fetal parasympathetic

system and sympathetic system [12] supports our supposition that the numerical value of FHR acceleration represents the work of the heart rate, and that our deduced ‘FHR-work’ relationships are potentially meaningful. If a certain FHR tracing has a push–pull effect of 10 seconds or 15 seconds, respectively, that last more than 10 bpm above the baseline, the amount of energy of each event would not differ much. The same reasoning could be applied to the condition of 15 bpm. In contrast, the FHR-work of a given FHR tracing >10 bpm over the baseline could not be the same as one >15 bpm.

In order to confirm the usefulness of FHR-work, we compared the same FHR-work of the FHR tracings with Acc10–15 and Acc15–10 in normal and abnormal fetuses [7, 9]. This comparison demonstrated that amplitude (bpm) was a more significant component of FHR acceleration than duration (seconds) in computerized analysis of NST.

The analysis of the variability of structural characteristics of FHR acceleration, like our study, may help explain the beat-to-beat push–pull effect of the fetal parasympathetic system and sympathetic system [12]. It is not clear that abnormal signs in FHR monitoring directly represent serious morbidity. Recent reports suggest that even FHR variability itself, a long-standing predictor of fetal health, does not necessarily predict whether fetal outcome is good or not [9, 13]. Nevertheless, in fetal reactivity, which is closely related to fetal well-being, the presence of FHR acceleration has been recognized as valuable. Furthermore, the absence of FHR acceleration (non-reactive tracing), is regarded as suspicious and generally results in an expansion of recording time to 50 minutes along with additional investigations such as vibroacoustic stimulation or contraction stress tests [14].

Based on our computerized analysis of NST, amplitude of FHR acceleration was a more significantly important component than duration in the relative importance of amplitude

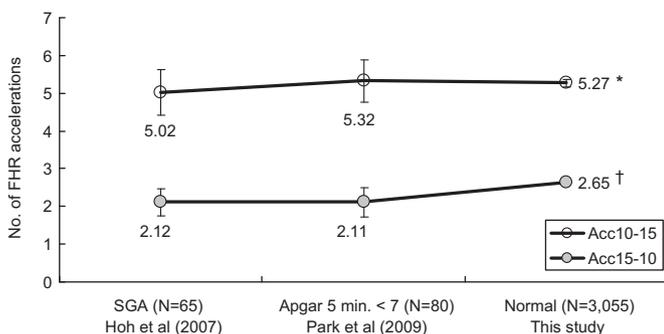


Fig. 2. Significance of difference for abnormal and normal fetus using by the FHR acceleration Acc10–15 and Acc15–10 in the same FHR-work. No. of FHR accelerations. Plots are represented as mean ± standard error. Acc10–15 and Acc15–10 = FHR accelerations for 10 bpm–15 seconds and 15 bpm–10 seconds, respectively. ^aAcc10–15 [^bAcc15–10] (significance using by the general linear model): F-value = 0.32 [1.68], *p* = 0.7251 [0.1874].

versus duration. This finding may help clinical visual analysis of NST.

In conclusion, among the four combinations of amplitude and duration of fetal heart rate acceleration (15 bpm–15 seconds, 15 bpm–10 seconds, 10 bpm–15 seconds and 10 bpm–10 seconds) in non-stress test analysis, there was a significant association based on amplitude. In contrast, there was a relatively low correlation based on duration.

To the best of our knowledge, this is the first report investigating the relationships between the amplitude and duration of FHR accelerations. We also demonstrated the value of using a computerized system for analysis. Our findings may help to define more precise criteria for the interpretation of acceleration of the FHR in NSTs using NICHD criteria for visual interpretation in the future.

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