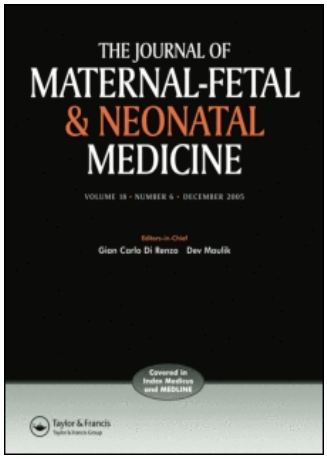

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A comparison of subjective and mathematical estimations of fetal heart rate variability

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Abstract

Objectives. To develop a computerized algorithm to quantify fetal heart rate (FHR) variability and compare it to perinatologists' interpretation of FHR variability.

Methods. FHR variability was calculated using data from 30 women who had a fetal scalp electrode placed for a clinical indication, and compared to the assessment of FHR variability from four perinatologists who interpreted paper tracings of the same data. Inter-rater reliability was calculated and receiver–operator curve analysis was done.

Results. Correlation between the computer algorithm's assessment of variability and the perinatologists' assessment (0.27–0.68) was similar to the inter-rater reliability between perinatologists (0.33–0.72).

Conclusions. A computer-based algorithm can assess FHR variability as well as expert clinicians.

Keywords: *Fetal monitoring, variability, fetal heart rate*

Introduction

The normal regulation of the fetal heart rate (FHR) is closely controlled by the central nervous system. Heart rate and rhythm are governed by the sinoatrial node and modulated by autonomic influence. At rest, vagal tone is the dominant source of variation in heart rate, however this variation is affected by the interaction between vagal and sympathetic activity, as well as central respiratory and motor centers, and peripheral oscillations in blood pressure and respirations [1–5].

When continuous FHR monitoring was introduced in the 1970s, there was enormous optimism that the widespread use of this technology would dramatically reduce intrapartum fetal injury and death. Unfortunately, FHR monitoring has not lived up to its initial promise: one meta-analysis of nine randomized, controlled trials comparing FHR monitoring to intermittent auscultation of the fetal heart rate showed that FHR monitoring increases use of cesarean, forceps, and vacuum delivery, but does not reduce perinatal morbidity or mortality [6]. Another similar meta-analysis did find that the use of continuous FHR monitoring decreased the incidence of neonatal seizures, but did not influence the rate of perinatal mortality [7]. This study also showed an association between continuous FHR monitoring and an increased rate of operative delivery. In the intervening 30 years, there have been no clinically significant advances in intrapartum fetal monitoring.

Considerable disagreement persists about what constitutes a non-reassuring fetal heart tracing. This inconsistency is both a reflection of our incomplete understanding of this signal, as well as an impediment to evaluation of FHR as a clinical tool across different studies. However, there is loose consensus that in the presence of FHR accelerations and/or the presence of moderate or marked variability, fetal acidosis is unlikely [8,9].

In spite of a standard definition for components of the FHR tracing [10], another problem with this technique is the poor inter-observer reliability among

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clinicians interpreting FHR tracings [11,12]. Consequently, interpretation of whether an FHR tracing is reassuring, non-reassuring, or ominous remains inconsistent [10].

A number of investigators have described algorithms to quantify components of the FHR tracing [13], and have quantified FHR variability, usually in terms of the mean difference in FHR during a period of time [14–16]. Although a number of these algorithms were able to quantify FHR variability, none have provided a system for directly comparing visually-measured FHR variability using the National Institute of Child Health and Human Development (NICHD) criteria with variability measured using signal processing mechanisms.

There has been recent interest in an automated mechanism for the interpretation of FHR tracing components [17,18], but it is unknown what criteria these systems use to define the components that they are interpreting. This is a difficult proposition because the definitions of the FHR tracing components were described using a system that depends on subjective interpretation by the clinician [10].

Our objective with this study was to correlate the NICHD definition of variability, which is 'quantified' visually as the difference between peak FHR and trough FHR in beats per minute, with a mathematical definition that can be used to standardize the reporting of variability in clinical applications.

Methods

This study was conducted at the Department of Neurology, Children's Hospital Boston, and the Department of Obstetrics and Gynecology, Brigham and Women's Hospital, both in Boston, MA, USA.

Fetal electrocardiogram data were collected during labor using a General Electric Corometrics® 120 fetal monitor, from 30 women who had a scalp electrode placed for a clinical indication, and after analog-to-digital conversion, were recorded digitally at 2000 Hz. Autocorrelation was used to identify the precise peak of the R-wave for each heart beat, and the R–R interval was then calculated, and instantaneous FHR determined calculated for each fetal heart beat.

Mean FHR was calculated over a single 10-min time-period for each subject, and the variance of the heart rate was calculated for the same period. The standard deviation, which is the square root of the variance, was used as the computed measure of FHR variability.

Four perinatologists with recognized expertise and extensive experience in fetal monitoring were provided with printouts of the FHR tracings from the 10-min datasets. The tracings were printed from archived clinical data using the WatchChild™ software system. These clinicians were blinded to the subjects' identifying information, and were unaware of the subjects' clinical outcomes. They had not seen the remainder of the subjects' FHR recordings, and were not shown the corresponding tocometry tracings. Unbeknownst to the expert reviewers, each reviewed 8–12 FHR tracings twice, at least one week apart.

The clinicians were asked to quantify variability for each 10-min tracing (see example, Figure 1). They were also asked to characterize FHR variability during each period using NICHD criteria (absent, minimal, moderate, marked, or sinusoidal). They were provided with a copy of the NICHD criteria to guide their ratings [10].

Intra-rater reliability was calculated using Pearson's r correlation analysis, and a weighted kappa

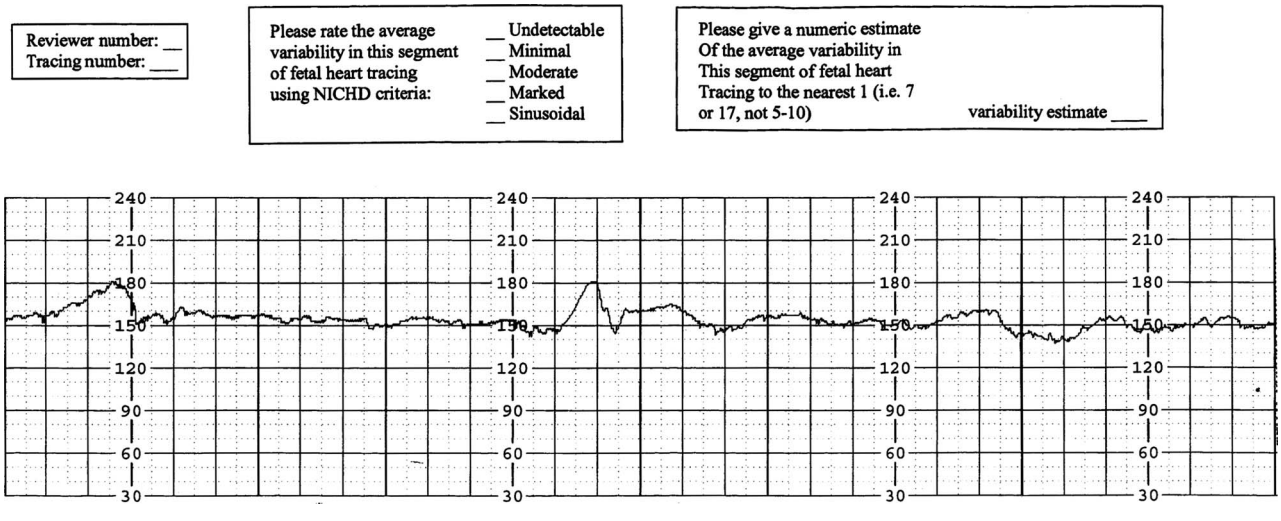

Figure 1. Sample fetal heart rate tracing scored by expert perinatologists.

coefficient was calculated to evaluate intra-rater correlation for the NICHD categorical data, as well as for inter-rater correlation of the categorical data. Intra-class correlation analysis was used to calculate inter-rater correlation for quantitative data, and to correlate the algorithm with the perinatologists' interpretations of the data. Receiver–operator curve analysis was used to compare the algorithm with the perinatologists' categorical interpretations.

This study was approved by the human research committee at our institution.

Results

All subjects were between 35 and 41 weeks estimated gestational age, with a singleton pregnancy. All had a fetal scalp electrode placed for a clinical indication. The Apgar scores at 1 and 5 minutes were greater than 6 for all newborns, and there were no neonatal complications for any of the newborns.

FHR variability ranged from 1.9 beats per minute (bpm) to 19.9 bpm in each 10-min epoch. The perinatologists' assessment of average FHR variability ranged from 1 to 30 bpm. In a few instances, individual perinatologists rated individual tracings as having absent, marked, or sinusoidal variability. However, a majority of the perinatologists' assessments rated each tracing as having either minimal or moderate variability.

The intra-observer reliability when the same reviewer scored the same FHR tracing on separate occasions varied widely, with correlation coefficients ranging from 0.08 to 0.98. Grouping the reviewers together, the intra-observer reliability was 0.77. Similarly, the consistency with which reviewers assigned the same NICHD category of variability to the same tracing ranged from a weighted kappa score of 0.18 to 1.0.

The agreement between reviewers interpreting the same FHR tracing was poor, with a correlation coefficient of 0.44 (range 0.33–0.72). The perinatologist reviewers were also in moderate agreement when assigning NICHD criteria to the tracings, with an overall weighted kappa score of 0.54 (range 0.30–0.58).

There was moderate agreement between the computer algorithm assessment of FHR variability and that of the perinatologists, with a correlation coefficient of 0.62 (range 0.27–0.68) (Table I).

Receiver–operator characteristic analysis demonstrated that a cutoff of 5.0 bpm correctly distinguished minimal from moderate variability approximately 80% of the time when compared to the average assessment of the perinatologists – the gold standard (Figure 2).

Discussion

Poor reliability is perhaps the most glaring weakness in the current system of FHR monitoring. This report is only the most recent in a series of studies over the past three decades demonstrating that even using the same criteria to interpret the same FHR tracing, expert clinicians don't agree with each other, and often don't agree with themselves. For this reason, an algorithm that standardizes the measurement of variability is a useful development – for research on FHR monitoring, and for clinical management of patients during the antepartum and intrapartum periods.

Previous papers have described systems to quantify FHR variability, however most do so in isolation, without direct comparison to human interpretation of the same data [13,15,16,19,20]. Our data demonstrate that it is possible to develop an algorithm for the assessment of variability that is as reliable as the current gold standard of subjective variability assessment – flawed as that system is.

Because nearly 40 years of research has demonstrated that FHR variability is neither sensitive nor specific for hypoxic-ischemic fetal injury, it seems unlikely that a system for quantifying FHR variability would alone make this single test of fetal wellbeing more predictive of an adverse event in labor. However, a more accurate method of describing FHR variability may be useful to clinicians who seek to increase the reliability of their assessment of variability, and to investigators working on advanced monitoring techniques such as ST analysis [21], investigations into power spectrum of FHR [22], and other measures of autonomic status exhibited in the fetal cardiac signal [23].

We are optimistic that ongoing research initiatives will reveal features of the fetal cardiac signal that

Table I. Correlation of numeric variability assessment by expert reviewers and a computer algorithm's assessment of variance (*p*-values).

	Expert average	Expert 1	Expert 2	Expert 3	Expert 4
Computer	0.62 (<0.01)	0.27 (0.19)	0.54 (<0.01)	0.45 (0.03)	0.68 (<0.01)
Expert Avg		0.50 (<0.01)	0.90 (<0.01)	0.86 (<0.01)	0.84 (<0.01)
Expert 1			0.33 (0.07)	0.40 (0.03)	0.37 (0.04)
Expert 2				0.72 (<0.01)	0.72 (<0.01)
Expert 3					0.55 (<0.01)

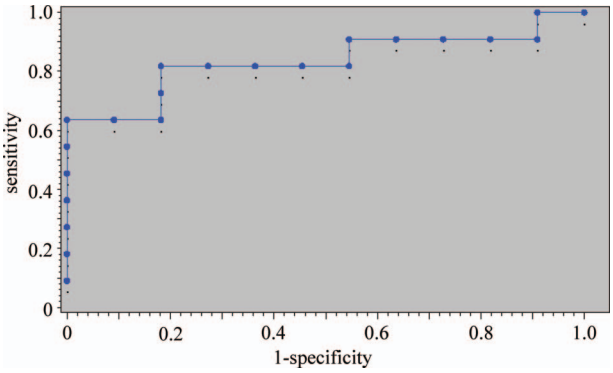

Figure 2. Receiver–operator characteristic analysis of fetal heart rate variability to distinguish minimal from moderate variability.

identify the presence of insult and imminent injury at the level of the myocardium, the brainstem, or the cerebrum. Such endeavors will be quantitative, and we are hopeful that this simple system for quantifying FHR variability will facilitate these important initiatives designed to wring more clinical value from the fetal cardiac signal – the only continuously accessible fetal physiologic signal during labor.

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