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Comparison of fetal and maternal heart rate measures using electrocardiographic and cardiotocographic methods

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ABSTRACT

Purpose: To determine the reliability at term of: (1) two methods of measuring fetal heart rate (HR), electrocardiographic (ECG, the 'gold standard') and cardiotocographic (CTG) and (2) two ECG methods of measuring maternal HR variability over relatively brief periods of time (s–min).
Methods: During 20 min of rest ($N = 39$) and during 2 min of auditory stimulation (mother's recorded voice, $n = 19$), fetal HR data were collected using an ECG (Monica AN24) and a Hewlett-Packard Model 1351A CTG. Simultaneously, maternal HR data ($n = 37$) were collected using the same ECG device (Monica AN24) and a second stand-alone cardiac monitor (Spacelab 514T cardiac monitor with a QRS detector).
Results: During 20 min of maternal rest, correlations of individual fetal CTG with ECG measures of HR at each second were moderate to high ($r = .57–.97$) for 77% of fetuses. Correlations of HR averaged over fetuses and over each of the 20 min were high ($r = .93–.97$); fetal HR averaged over 20 min varied between devices from 0.0 to 0.8 bpm. During 2 min of maternal voice presentation, correlations of fetal HR over each second were moderate to high ($r = .54–.99$) for 95% of fetuses and high (all $rs = .99$) when averaged across fetuses in 30 s or 2 min epochs. Average fetal HR between devices over the 2 min voice varied from 0.0 to 0.6 bpm. Correlations and/or % agreement between the two ECG methods of measuring maternal HR were high. Average maternal HR over 10 min showed 81% of pairs with a difference of ≤ 1 bpm; correlations for HR variability measures varied from $r = .89$ to .97.
Conclusions: Good reliability was demonstrated between individual spontaneous and auditory induced fetal CTG and ECG with high correlations when HR data were averaged over fetuses or in 30–120 s epochs. High reliability of maternal HR measures was obtained using two ECG devices.

1. Introduction

Heart rate measures are one of the few readily available, non-invasive measures for the study of human fetal neurological and behavioral development. For research with infants, children, and adults, cardiac measures including heart rate [HR; in beats per minute (bpm)] and HR variability (i.e., measures of the balance between the sympathetic and parasympathetic branches of the autonomic nervous system influencing heart rate) are extracted from the R–R interval (the time, in ms,

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between two successive ventricular contractions) of an electrocardiogram (ECG) using an electrocardiographic instrument. Although an ECG is considered the 'gold standard' for heart rate measures, for fetal research during gestation when the membranes are intact, often cardiac measures are obtained using a cardiotocograph (CTG) which measures muscular contraction of the heart and employs autocorrelation techniques to compare successive Doppler ultrasound heart beat signals and provide a measure corresponding to the R–R interval of an ECG (Cesarelli, Romano, & Bifulco, 2009). ECG technology has not been readily available for fetal studies because of difficulties inherent in reliably separating the maternal and fetal electrocardiograms (for a technical discussion of fetal HR signal processing issues such as relatively low signal-to-noise ratio and limited knowledge of cardiac function and development see, e.g., Andreotti et al., 2014; Clifford, Silva, Behar, & Moody, 2014; Sameni & Clifford, 2010). As well, from about 24 to 34 weeks gestational age (GA), the vernix caseosa on the fetal skin impedes conduction of fetal electric signals to the maternal surface (e.g., Oostendorp, Oosterom, & Jongsma, 1989). Although the use of in-house ECG technology (e.g., Groome et al., 2000) and commercial equipment (e.g., FEMO, David, Hirsch, Karin, Toledo, & Akselrod, 2007) occasionally have been reported in fetal psychobiological research, little is known regarding the relationship between fetal HR measures collected using CTG vs. ECG (the gold standard) in non-laboring women. See Footnote #1. In uneventful pregnancies during the third trimester of pregnancy, only one report (Ibrahimy, Mohd, Zahedi, & Tsuruoka, 2002) could be found of a direct comparison between ECG and CTG measures. Ibrahimy et al. simultaneously collected FHR data for 10 min during maternal rest from 5 fetuses between 35 and 40 weeks gestation using three ECG electrodes (above and below the maternal umbilicus, right wrist) and a commercial Doppler fetal monitor (IFM-500, BioSys Co., Ltd). The authors reported that the two fetal HR measurements varied ±5 beats per minute (bpm) for 84% of recording. The purpose of the present study was to replicate and extend this earlier work using a larger sample size ($n = 39$) at term and comparing heart rate measures collected using two commercial fetal HR machines (Monica AN24 ECG vs. Hewlett-Packard CTG) during maternal rest using a longer rest period (20 min) as well as during fetal auditory stimulation which could increase fetal movement activity and interfere with signal detection. In addition, given that the Monica AN24 simultaneously captures and separates both the maternal and fetal ECG, a second maternal ECG was obtained using a stand-alone standard Spacelab 514T cardiac monitor (with a QRS detector) to compare two maternal ECG measures (Monica AN24 ECG vs. Spacelab ECG).

Knowledge and understanding of the reliability between fetal ECG and CTG measures collected for relatively brief periods of time (seconds or minutes) are especially relevant for the interpretation of research findings in studies of fetal neurobiological development because the equipment was designed and is most often used and tested for clinical monitoring of heart rate over extended periods of time (hours).[1] Studies employing the two different technologies, CTG before birth with ECG measures after birth, have shown a relationship between spontaneous fetal HR and HR variability from 24 weeks GA through the second year of life (DiPietro, Costigan, Pressman, & Doussard-Roosevelt, 2000; DiPietro, Bornstein, Hahn, Costigan, & Achy-Brou, 2007). Moreover, a continuity between term fetal and newborn elicited cardiac responses to similar kinds of stimulus materials has been demonstrated (Kisilevsky & Muir, 1991). Such findings suggest that the two fetal measures yield similar results and that such comparisons are reliable. See example, Footnote #1.

2. Material and methods

2.1. Participants

A total of 39 maternal–fetal pairs at term provided the data for this study. Participants were recruited from antenatal clinics at a community teaching hospital in southern Canada. Inclusion criteria were a maternal age of at least 18 years and a low-risk, uneventful, singleton pregnancy at term with delivery of a healthy newborn. Exclusion criteria were any pharmacologically treated co-morbid conditions (e.g., diabetes, hypertension, thyroid disease, depression). Gestational age was calculated from the first day of the last menstrual period if periods were reliable (accuracy rate 75–85%) or from early ultrasound (SD ± 1 week). Data from an additional 15 fetuses were not included because the fetal HR could not be reliably captured by the ECG ($n = 14$) or CTG ($n = 1$) technology.

Testing of fetuses and newborns was conducted in the Maternal-Fetal-Newborn Studies Laboratory located adjacent to the obstetrical outpatient and inpatient services of the hospital. Sex of the infant was determined at birth. Information on race and socio-economic status are not routinely collected in the Canadian health care system and were not collected for this study. The study was carried out according to ethics approval from the University and Affiliated Teaching Hospitals Research Ethics Board. Women provided informed, voluntary, written consent prior to participation.

2.2. Equipment/stimuli

Maternal blood pressure (BP) was obtained using a Lifesource One Step Auto-Inflation Blood Pressure Monitor Model UA-767. The User Manual reports a SD = 3 mmHg.

[1] There is a substantive literature examining fetal CTG and/or ECG [obtained from the maternal abdomen (e.g., Reinhard et al., 2013) or fetal scalp electrode (e.g., Clifford, Sameni, Ward, Robinson, & Wolfberg, 2011)] during labor. The studies are conducted for clinical purposes (e.g., see reviews by Amer-Wahlin & Kwee, 2015; Neilson, 2013; commentary by Sholapurkar, 2014) rather than to elucidate normal fetal psychobiological development. They are carried out during a time of substantial physiological stress for the mother and fetus rather than under resting conditions and are not reviewed here.