

Assessment of Fetal Growth on the Basis of Signal Strength in Fetal Magnetocardiography

Van Leeuwen, P, Beuvink, Y, Lange, S, Klein, A, Geue, D, Grönemeyer, D¹

Dept. Biomagnetism, Research and Development Center for Microtherapy (EFMT), Bochum, Germany

¹Grönemeyer Institute for Microtherapy, University of Witten/Herdecke, Witten, Germany

Corresponding Author: Peter Van Leeuwen, Universitaetsstr. 142, Dept. Biomagnetism, Research and Development Center for Microtherapy (EFMT), 44799 Bochum, Germany

Phone: +49-234-9780140; Email: petervl@efmt.de

ABSTRACT

Fetal magnetocardiography has shown that fetal P wave and QRS complex durations increase with gestational age, reflecting change in cardiac muscle mass. The latter should, in principle, be associated with an increase in signal strength. We examined two approaches for determining QRS signal strength in a healthy fetus on a weekly basis in the second and third trimester. Twenty-two fetal magnetocardiograms of the same fetus were obtained using a 61 channel Magnes 1300 biomagnetometer (20th - 42nd week of gestation). In the signal averaged fetal beat produced at each week, signal strength was assessed on the basis of 1) peak-to-peak QRS signal amplitudes and 2) strength of an equivalent current dipole (ECD) computed at R peak. The results were assessed on the basis of correlation to week of gestation and by comparison to changes in QRS interval duration. All values increased with advancing gestation and regression analysis suggested a nonlinear dependency on age. ECD strength reflected gestational age slightly more reliably ($r^2=0.93$) than signal amplitude values (mean, median, maximum: $r^2=0.89, 0.88, 0.85$, respectively). ECD strength and mean signal amplitude also correlated well ($r=0.97, p<0.0005$). Values calculated from QRS complexes determined immediately before and after a clear change in fetal position (acquisition week 24) demonstrated a certain instability in both approaches. Nonetheless, the overall correlation of the amplitude to gestational age compared favorably with that of QRS complex duration. This indicates that not only magnetocardiographically determined fetal cardiac time intervals but also signal strength may be used to assess fetal growth.

KEY WORDS

Fetal magnetocardiography, Gestational age, Signal amplitude, Equivalent current dipole, QRS complex.

INTRODUCTION

The assessment of the growth and development of the fetus using magnetocardiography (MCG) is usually based on the duration of fetal cardiac time intervals. Numerous studies have shown that, in particular the P wave and QRS complex increase in length as pregnancy progresses, e.g. [Quinn, 1994] [Stinstra, 2002A]. These changes are presumed to reflect the increase in cardiac muscle mass associated with fetal growth [Van Leeuwen, 2004]. This enlargement should be associated with increased MCG signal strength and a number of studies have described corresponding findings using signal amplitude [Li, 2002] and dipole strength [Kandori, 1999]. However, determination of signal strength is not quite unequivocal as a number of confounding factors affecting measured signal strength exist. These include the orientation and distance of the fetal heart relative to the sensing system and the geometry of the volume conductors [Stinstra, 2002B]. Furthermore, examining signal strength interindividually of fetuses at varying gestational ages will increase the overall range of values and make it more difficult to estimate the variance within the single fetus. In order to examine intraindividual changes, we performed close

meshed fetal MCG acquisition over the second and third trimester in a single pregnancy and estimated QRS signal strength and compared changes over gestation to those in QRS duration.

METHODS

Twenty-two fetal magnetocardiograms of the same fetus in a healthy pregnancy were obtained on a weekly basis between the 20th and 42nd week of gestation. All data acquisitions were performed using a 61 channel Magnes 1300 biomagnetometer (Magnes 1300C, 4D Neuroimaging, San Diego). With the mother in a supine position, the slightly curved, circular sensor (diameter 104 cm, radius of curvature 52cm) enabled the complete coverage of her abdomen from the pubis to the xyphoid. With the sensor just above the abdomen, data were recorded for at least 5 min. at a sampling rate of 1 kHz and with a bandpass of 1-200 Hz. Extraneous noise was minimized by performing data acquisition in a standard shielded room (AK3b, Vacuumschmelze, Hanau).

In each set of data, after digital subtraction of the maternal artifact, fetal beats were identified on the basis of a good match ($r \geq 0.90$) with a representative fetal QRS signal template (generally $\gg 300$ beats). In the averaged data, the onsets and ends of the QRS complex were marked according to standard criteria and its duration calculated as $QRS_{end} - QRS_{onset}$. Signal strength was estimated in two ways. Peak-to-peak QRS signal amplitude was determined in each channel and characterized for the data set by the mean, median and maximum value, expressed in pico Tesla (pT). Secondly, at R peak a best fitting equivalent current dipole (ECD) was localized in a homogeneous sphere (radius 50cm) and its magnitude in nano-ampere-meters (nAm) was determined. In one data set (in week 24), there was a single marked change in fetal position part way through the acquisition with a concomitant change in QRS amplitudes and morphology. This data set was divided into two traces, one before and one after the change, and both were examined separately.

The relationship of these parameters to gestational age was examined using linear and nonlinear regression analysis and the coefficient of determination (r^2) was used to quantify the goodness of fit. The relationship between signal strength parameters and QRS duration was also investigated.

RESULTS

All values increased with advancing gestation (Fig. 1a, 1b, 1c) and regression analysis suggested a nonlinear dependency on gestational age which could, more often than not be appropriately characterized by $\ln(y) = a + b \cdot \ln(\text{age})$. The r^2 was high for signal amplitude values with the central variables for

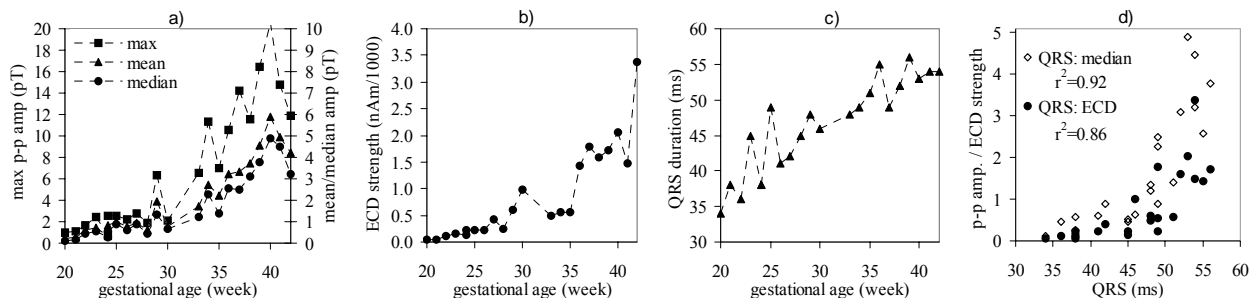


Figure 1. Changes over gestational age in a) QRS maximum, mean and median peak-to-peak signal amplitude, b) ECD strength at R peak and c) QRS interval duration; d) scatter plot comparing QRS duration and median QRS amplitude as well as ECD strength.

location, the mean ($r^2=0.89$) and the median ($r^2=0.88$), performing better than the maximum ($r^2=0.85$). ECD strength reflected gestational age slightly more reliably ($r^2=0.93$) than signal amplitude values. Although in itself dependably reflecting gestational age, QRS duration ($r^2=0.81$) performed poorly in comparison. The changes in duration and signal strength also associated well (QRS vs. mean, median and maximum amplitude as well as ECD strength: Spearman $r = 0.92, 0.93, 0.88$ and 0.86 respectively, Fig 1d). Signal strength values calculated from QRS complexes determined in different fetal positions (acquisition in week 24, Fig. 1a, 1b) displayed substantial relative differences in peak-to-peak amplitude (mean: 0.3 vs. 0.8 pT, median: 0.3 vs. 0.6 pT, maximum: 0.7 vs. 2.6 pT) and ECD strength (127 vs. 231 nAm).

The results suggest that not only magnetocardiographically determined fetal cardiac time intervals but also signal strength may be used to assess fetal growth reliably. Indeed, in the one case we studied here, the parameters used to quantify strength demonstrated a better association with gestational age than QRS duration. This was surprising, as confounding factors not related to developmental status - in particular fetal location - have the potential to strongly influence the measured quantities. This was demonstrated clearly in the values obtained from one acquisition, determined immediately before and after an apparent change in fetal position. They showed the instability of both the signal amplitude and the ECD approaches, although the latter not affected as strongly. In contrast, the change in QRS morphology in individual channels resulting from the re-positioning did not lead to a change in measured QRS duration.

In spite of the sensitivity to extraneous factors, the relationship of signal strength to week of gestation was fairly stable in this individual. Overall ECD reflected signal strength changes with respect to fetal age best and maximum peak-to-peak amplitude showed the weakest association. ECD calculation makes specific assumptions in the interpretation of the data and, as long as the magnetic field has a sufficiently dipolar character, ECD strength may come closer to reflecting true signal magnitude than the amplitudes measured at the abdominal surface. The biomagnetometer system used in this study had excellent coverage of the frontal maternal abdomen and assured clear dipolar fields in most acquisitions. Furthermore, the curvature of the measurement plane permitted the partial registration of field components in the maternal caudal-cranial / left-right plane. On the other hand, an accurate estimation of absolute fetal cardiac signal strength on the basis of magnetometer cannot be expected [Stinstra, 2002B]. Nonetheless there is a value in the relative change of the estimated signal strength and the results suggest that it can be used to estimate fetal growth and development. Further work must be done to examine the parameters intra- and interindividually in larger groups of subjects in order to determine the potential for clinical applications.

REFERENCES

Kandori A, Miyashita T, Tsukada K, Horigome H, Asaka M, Shigemitsu S, et al. Sensitivity of foetal magnetocardiograms versus gestation week. *Med Biol Eng Comput* 1999;37:545-8.

Li Z, Wakai RT. Amplitude of the P and QRS components of the fetal MCG in normal and fetal arrhythmia subjects. In: Nowak H, Haueisen J, Giessler F, Huonker R, editors. *Biomag 2002. Proceedings of the 13th International Conference on Biomagnetism*; 2002 Aug 10-14; Jena, Germany. Berlin, Offenbach: VDE Verlag; 2002. p. 636-8.

Quinn A, Weir A, Shahani U, Bain R, Maas P, Donaldson G. Antenatal fetal magnetocardiography: a new method for fetal surveillance? *Br J Obstet Gynaecol* 1994;101:866-70.

Stinstra J, Golbach E, van Leeuwen P, Lange S, Menendez T, Moshage W, et al. Multicentre study on the fetal cardiac time intervals using magnetocardiography. *Br J Obstet Gynaecol* 2002A;109:1235-43.

Stinstra JG, Peters MJ. The influence of fetoabdominal tissues on fetal ECGs and MCGs. *Arch Physiol Biochem* 2002B;110:165-76.

Van Leeuwen P, Lange S, Klein A, Geue D, Grönemeyer DHW. Dependency of magnetocardiographically determined fetal cardiac time intervals on gestational age, gender and postnatal biometrics in healthy pregnancies. *BMC Pregnancy Childbirth* 2004;4:6.