Proceedings of
the 12th International Conference on Biomagnetism

August 13–17, 2000

Helsinki University of Technology, Espoo, Finland

Biomag 2000

Edited by
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Reference values for fetal MCG/ECG recordings in uncomplicated pregnancies

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1 Introduction

Fetal electro- and magnetocardiograms can be used to classify arrhythmias, to study congenital heart disease, to observe fetal well being during growth retardation or (abnormal) twin pregnancy. In order to discriminate between pathological and healthy fetuses, a database with normal values of the parameters describing the cardiograms are needed. Hence, a database is set up for parameters extracted from fetal MCG and ECG. These cardiograms were recorded in uncomplicated pregnancies, which means that no maternal or fetal complications were noticeable. The database is partly composed of data taken from the literature [1 - 7] and partly of data that is not published before and is contributed by collaborating centers. The database is a compilation of data measured at the various centers using different measurement grids, flux transformers, magnetic field components, signal processing techniques, or locations of the reference electrode. Hence, the amplitudes are not comparable and only time intervals are included in the database.
The contributing centers are

- Department of Biomagnetism, Research and Development Center for Microtherapy (EFMT), **Bochum**, Germany
- Departments of Internal Medicine II, Obstetrics and Gynecology, and Pediatric Cardiology, University of **Erlangen**, Germany
- Wellcome Biomagnetism Unit, Southern General Hospital, **Glasgow**, UK
- Biomagnetic Centre, Dep. of Gynaecology and Obstetrics, Friedrich Schiller University, **Jena**, Germany
- Perinatal Unit, First Institute of Obstetrics and Gynecology, University of **Milano**, Italy
- Biomedical Engineering Program, Faculty of Engineering, University of **Tel Aviv**, Tel Aviv, Israel
- Department of Pediatrics, Institute of Clinical Medicine, University of **Tsukuba**, Ibaraki, Japan
- Departments of Medical Physics and Obstetrics and Gynecology, University of **Wisconsin**, Madison, USA
- Biomagnetic Centre Twente, Faculty of Applied Physics, University of **Twente**, Enschede, The Netherlands

2 Methods

The time intervals recorded are the RR-interval, the duration of the P-wave, the duration of the QRS-complex, the duration of the T-wave, the PR-interval, the PQ-interval, the QT-interval, and the ST-interval. These time intervals are defined in Fig. 1. The database is composed of individual and averaged records. The latter represent the average duration of a certain time interval, averaged over a period of 4 or 5 weeks of gestation. The database consists of 466 individual records and 48 records that are based on a total of 765 cardiograms. The database is accessible on Internet so that every user can add and extract data:

http://bct.tn.utwente.nl/database.

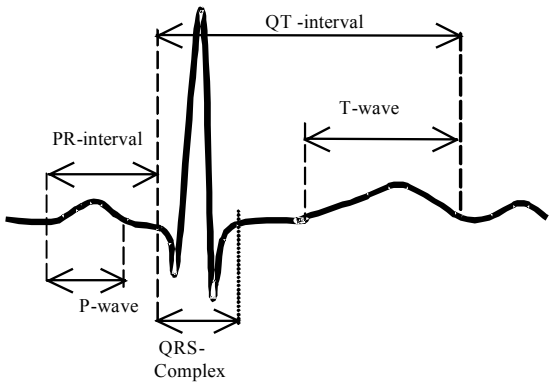

Figure 1**:** *Definition of the various time intervals in a cardiogram*

3 Results

3.1 Individual records

Scatter plots of the individual records of the duration of the P-wave, the QRS-complex, the PR-interval,

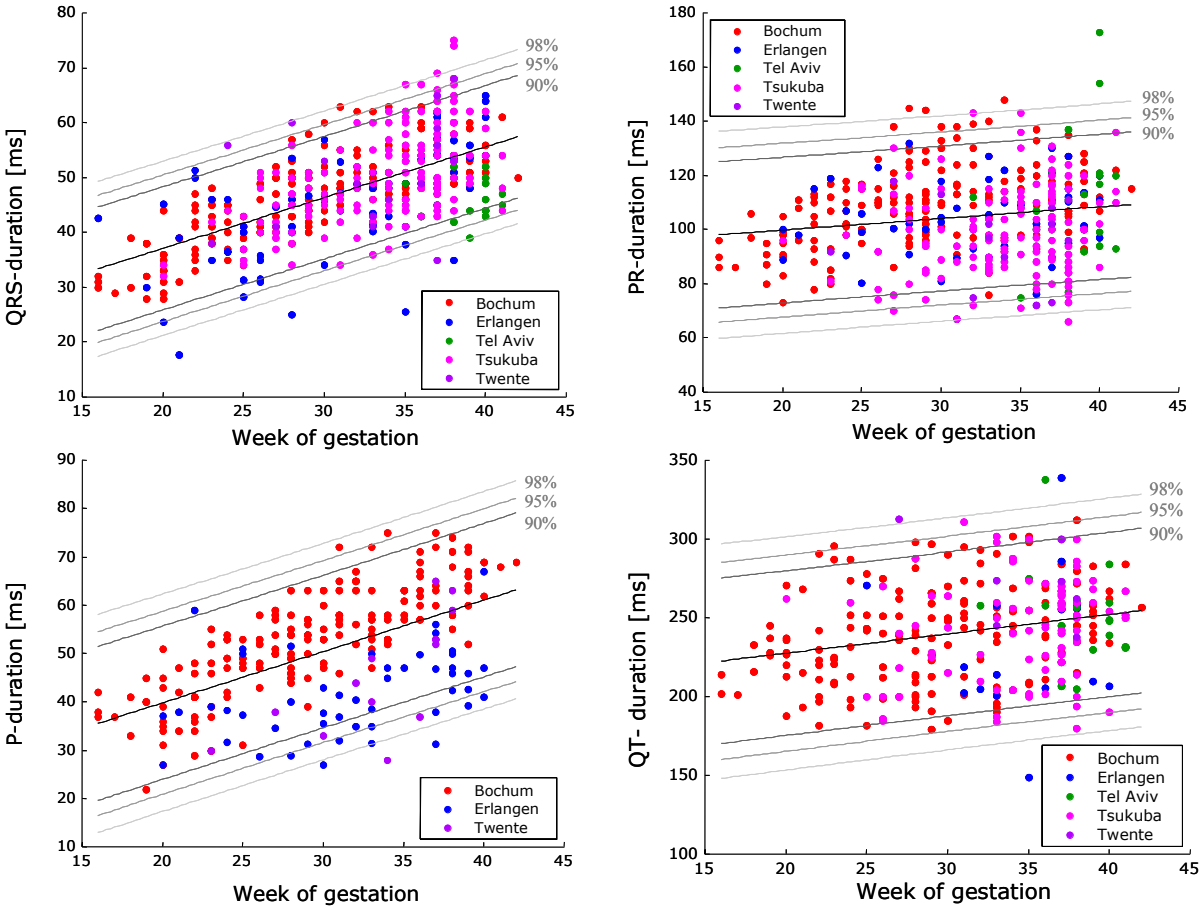

Figure 2: *Scatter plots of the duration of the various waves as a function of the gestational week. Superimposed are the linear regression lines given in table 1 and the prediction intervals for 90, 95 and 98 %. The prediction interval is the range in which a new observation is expected, expressed in percents.*

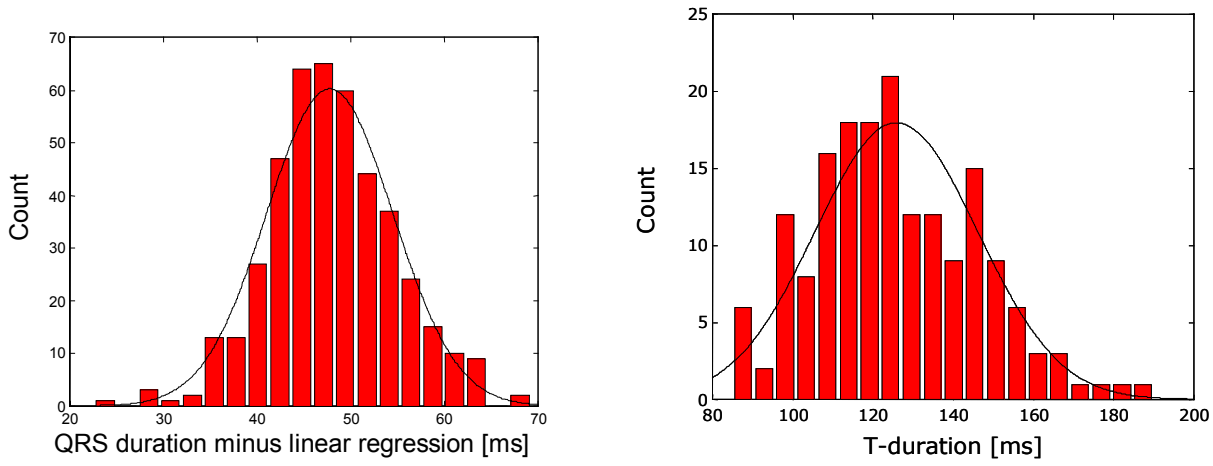

Figure 3: *Histograms of QRS-complex and T-wave, the normal distribution is indicated.*

and the QT-interval versus the gestational week are shown in Fig. 2.
Using a linear regression model, the dependence on the gestational week is analyzed. By assuming that the only independent variable is the week of gestation, the model reads

$$D = \beta_0 + \beta_1 \times \text{week} + e,$$

where $e \sim N(0,\sigma)$ and D is the duration of the interval. The variability e has a normal distribution with a mean zero. This distribution is assumed to be independent of the week. The regression coefficients (β_0 and β_1) for the four intervals are given in the table 1.

Table 1: *The linear regression model describing the duration of the various waves as a function of the gestational week, N is the number of records used for the model and p is the probability that the regression model is false.*

wave	β_0	β_1	N	p [%]
P	18 ± 3.0	1.06 ± 0.10	437	< 0.001
QRS	19 ± 1.7	0.93 ± 0.05	234	< 0.001
PR	91 ± 4.4	0.43 ± 0.14	389	1.2
QT	202 ± 9.6	1.23 ± 0.30	292	<0.001
T	120 ± 7.4	0.20 ± 0.25	174	43

It is checked by means of the F-test whether the regression parameter (β_1) is needed to explain the data. The probability that the linear regression model is false is expressed by p. From the given probability values one can conclude that the duration of the P-wave, PR-interval, QRS-complex and QT-interval are indeed adequately described by the linear regression model, while the duration of the T-wave is not.
In Fig. 3 at the left hand side, a histogram is shown of the deviation of the observed duration of the QRS-complex from the regression line. At the right hand side of Fig. 3, a histogram is given of the duration of the T-wave. The best fit for a normal distribution curve is shown as well. In case of the QRS-complex a standard deviation of 6.7 ms is found and in case of the T-wave a value of 20 ms is found.

3.2 Averaged records

In the database of the averaged values, the individual data is included after averaging these values over successive periods of five weeks. For the duration of QRS-complex this database consists of a considerably larger number of measurements (N = 1386) than the individual database. In Fig. 4, the averaged data for the duration of the QRS-complex is depicted.

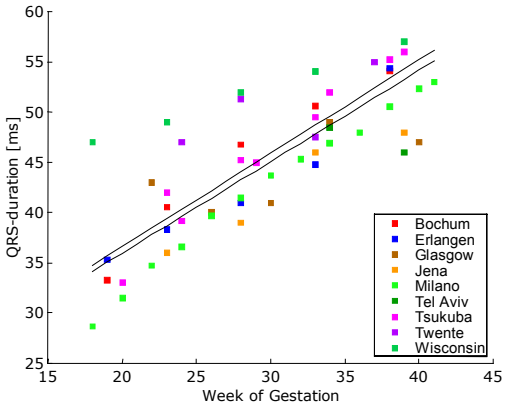

Figure 4: *A scatter plot of the duration of the QRS-complex versus the gestational week based on all records (i.e. the individual plus the averaged ones). The solid line represents the linear regression, where averaged records are weighted with the number of measurements. The dotted line is the regression line found for the individual records given in table 1.*

4 Discussion

Looking at the results, it is evident that the data are widespread and has a tendency to be observer dependent. There are three different reasons to explain these phenomena namely, a) the interpretation of the researcher, b) the physiology, and c) the signal processing. For diagnostic purposes, it is to be preferred that the variability would be smaller. Therefore it makes sense to scrutinize the reasons for the observed range of variations.
The P-wave and the QRS-complex can be easily identified whereas the detection of the T-wave is difficult. The beginning of the P-wave is often hardly definable, as it may be biphasic and its shape varies from channel to channel. The duration of the P-wave, the QRS-complex, the PR-interval and the QT-interval increases with gestational age. This can be explained by the fact that the myocardial mass and the cardiac dimensions increase with gestational age. The observed systematic difference between results of different research groups may be partly due to the fact that the cardiac mass at a certain gestational age may differ in different countries. This is expected from the fact that the average birth weight depends for instance, on the ethnic group, the fact that the mother smokes or the fact that the

country has a high altitude [8]. A difficult question to answer is whether a pregnancy is uncomplicated or not. For instance, Leuthold et al. [6] included mothers with diabetes, gestational diabetes and low amniotic fluid when the birth weight was normal. However, the thickness of the cardiac walls increases faster for fetuses of diabetic mothers than for normal fetuses irrespective of fetal size [9] and therefore the duration of various waves may grow faster with gestational age than normally. Movements of the fetus may lead to a different cardiogram as the distance to the fetal heart may change. Especially in the early weeks of gestation the fetus is able to move freely within the uterus.

Beside the physiological circumstances, the diversity in results can partly be ascribed to the various measurement methods. Burghoff et al. compared an MCG measurement recorded with different gradiometers and found an impressive influence of the gradiometer on the duration of the QRS-complex of an adult heart patient [10]. A large number of channels simplifies the measurement, because it is easier to detect an appropriate measuring position. Moreover, the P-wave or QRS-complex may start or end at different time instance in different leads and thus the PR-interval in different leads may vary a little.

Signal processing starts with triggering R-peaks from the recorded signal and with this information an averaged complex can be calculated. Distortion of the signal does not occur so long as the times of occurrence of the R-peaks are known exactly. Inevitably trigger jitter will occur due to noise in the QRS-complexes. Trigger jitter produces a smoothing effect on the signals of interest at averaging. In order to determine the amount of beats to be averaged, one has to consider that more beats will improve the signal-to-noise ratio if the beats are alike. Therefore most researchers use the correlation coefficient between beats and only those beats where the correlation coefficient is larger than a chosen value are accepted.

Acknowledgements

This work would not have been possible without the cooperation and help of the various centers measuring fetal MCG or ECG.

References

1. B. Brambati and G. Pardi, “The intraventricular conduction time of fetal heart in uncomplicated pregnancies”, *Br. J. Obstr. Gynaecol.* **87**, 941-948, 1980.
2. S. Abboud, G. Barkai, S. Mashiach and D. Sadeh, “Quantification of the fetal electrocardiogram using averaging technique”, *Comput. Biol. Med*. **20**, 147-155, 1990.
3. A. Quinn, A. Weir, U. Shahni, R. Bain, P. Maas, G. Donaldson, “Antenatal fetal magnetocardiography: a new method for fetal surveillance? ”, *Br. J. Obstr. Gynaecol.* **101**, 866-870, 1994.
4. T. Menendez, S. Achenbach, W. Moshage, M. Flug, E. Beinder, A. Kollert, A. Bittel and K. Bachmann, “Prenatal recording of fetal heart action with magnetocardiography”, *Z. Kardiol.* **87**, 111-118, 1998.
5. P. van Leeuwen, S. Lange, B. Hailer, M. Hartmann, L. Lajoie_junge, W. Hatzmann and D. Grönemeyer, “Assessment of fetal development on the basis of fetal magnetocardiography”, in *Recent Advances in Biomagnetism*, T. Yoshimoto et al. Eds. Sendai: Tohoku University Press, 1999, pp. 955-958.
6. A. Leuthold, R.T. Wakai, and C.B. Martin, “Noninvasive in utero assessment of PR and QRS intervals from the fetal magnetocardiogram”, *Early Human Development* **54**, 235, 1999.
7. H. Horigome, M.I. Takahashi, M. Asaka, S. Shigemitsu, A. Kandori and K. Tsukada, “Magnetocardiographic determination of the developmental changes in PQ, QRS and QT intervals in the foetus”, *Acta Paediatr* **84**, 64-67, 2000.
8. J. Gardosi, M. Mongelli, M. Wilcox and A. Chang, “Screening and assessment of fetal growth”, in *A critical appraisal of fetal surveillance,* H.P. van Geijn and F.J.A. Copray Eds. Elsevier Science, 1994, pp. 437- 448.
9. C. Romanini, G. Rizzo, and D. Arduini, “Cardiac function in fetuses of insulin dependent diabetic mothers”, in *Fetal cardiac function*. D. Arduini et al., Eds. The Parthenon Publ. Group, New York, 1995, pp. 109-118.
10. B. Burghoff, U. Steinhoff, W. Haberkorn and H. Koch, “Comparability of measurement results obtained with multi-SQUID-systems of different sensor configurations”, *IEEE Trans. on Appl. Superconductivity* **7**, 3465-3468, 1997.