## High-Resolution Fetal Magnetometry: A Model-Based Analysis Approach for Imaging Fetal Well-Being

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New developments in adult brain imaging technology based on multi-channel low temperature superconducting quantum interference devices (SQUID) have made possible the development of a new imaging device for the functional assessment of fetal well-being. SARA (SQUID array for fetal assessment) is a stationary, floor-mounted instrument with an anatomically shaped sensing surface that allows a mother to lean her abdomen against 151 evenly distributed SQUID sensors.

The fetal magnetoencephalogram (fMEG) is measured in the presence of environmental noise and various near-field biological activity: maternal magnetocardiogram (mMCG), fetal magnetocardiogram (fMCG), uterine smooth muscle, motion artifacts, etc. After environmental noise cancellation, the mMCG and fMCG must be removed in order to observe the fetal MEG. The magnitudes of the averaged evoked fMEG signals are typically in the range from 10 to 80 fT while the fMCG and mMCG at the fetal head location can attain amplitudes as large as 10 pT. Closer to the maternal heart, the mMCG can be as large as 100 pT.

Evaluation of separation methods led to the following results: principal component based methods were shown to attenuate the fMEG signals; frequency dependent coherence-based methods depend on reference selection; independent component based methods generally work well, but due to their permutation uncertainty are difficult to automate; methods based on nonlinear dynamics contain large number of adjustable parameters; and finally, spatial filtering methods, such as beamformers, require knowledge of fetal brain conductive models, which are presently inadequately developed. We have successfully extracted reliable fMEG signals by all the above methods, however, we have settled on attenuation of the fMCG and mMCG interference using orthogonal projection operators. Interference elimination by projection was found to be robust and relatively easy to automate. This method introduces a redistribution of fetal brain activity to sensors distant to the fetal brain. This redistribution can be corrected under special assumptions.

To assure that the corrected fMEG signals originate within the fetal brain, we must assure that they are physiologically meaningful and that they are consistent with sources within the fetal head. We investigate the fMEG signal consistency by using two extreme fetal brain models: *Uniform abdomen model* and *Fetal head model*. We show that the measured fMEG signals are consistent with the hypothesis that they originate within the fetal head and that after the correction for the projection redistribution they satisfy the same model as before the correction. It was also found that the *Fetal head model* is preferred, because it accounts more accurately for the observed signals than the *Uniform abdomen model*.

In conclusion, our studies clearly show that fMEG (evoked fields and spontaneous activity) can be reliably recorded and the data analysis must be combined with modelling to validate the results. In addition, the inclusion of fetal heart signal analysis makes a multi-modal approach to the characterisation of fetal well-being possible.

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