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The influence of fetoabdominal volume conduction on the fetal MCG

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Introduction

Fetal magnetocardiograms (MCG) can be measured non-invasively. From these measurements the duration of the various waves in the fetal cardiogram can be obtained as well as the fetal heart rate. Hence, the fetal MCG can, for instance, be used to classify arrhythmias. However, the amplitudes within the measured cardiogram depend on the fetoabdominal anatomy. For instance, the position of the measurement position relative to the fetal heart as well as the current distribution in the tissues surrounding the fetal heart are of influence. As this influence is not well known, the amplitudes cannot be used for diagnostic purposes.

In order to use amplitudes for diagnostic purposes, models of the fetoabdominal volume conductor have to be created and tested that can be used to reconstruct the strength of the current source (*i.e.* the heart vector). In this paper five volume-conductor models are compared to estimate its influence on the fetal MCG and to determine whether a standardized model can be used to reconstruct the heart vector. For example, near term about two thirds of the fetuses is lying in a left occipital lateral position and one third in the right. Hence, two models, one describing the fetus in a left occipital lateral position and one mirrored in the sagittal plane, may be sufficient to reconstruct the heart vector.

Simulations can provide a means to calculate the influence of the volume conductor [1]. To construct a realistically shaped model of the volume conductor, information on the fetoabdominal anatomy is needed. This information can, for instance, be obtained from ultrasound images or MR-images. In this paper the fetoabdominal anatomy is subdivided into compartments with a homogeneous conductivity.

The volume conductor changes during gestation. When the fetus is covered by a layer of vernix caseosa, an electrically insulating layer, the appropriate model seems a one-compartment model with the shape of the fetus. A three-compartment model describing the fetus, the amniotic fluid, and the maternal abdomen may be appropriate, for instance, before the 28th week of gestation when the layer of vernix is not present [2], or whenever the vernix is not present.

Another approach may be the half-space model, as it does not require extensive computations.

Simulations can also be of help to optimize the fluxtransformer used to measure the fetal (vector) MCG.

Methods

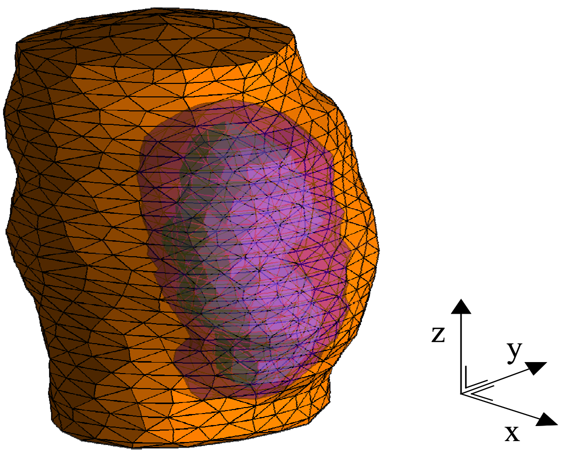
Five different models are taken for the simulations, namely two three-compartment models, two one-compartment models, and a half-space model. These models are constructed using MR-images taken of two pregnant women in the 36th week of gestation. The images were taken at the University of Nottingham. In both sets of images the fetuses are both lying in a right occipital lateral position. Fetus 2 is lying more to the center of the maternal abdomen than fetus 1. In the latter case the amniotic fluid is distributed more asymmetrically.

From each set of images two models have been created, one model consisting of three compartments being the fetus, the amniotic fluid and the remainder of the maternal abdomen, and one model only consisting of the fetus. In this latter case, it is assumed that due to the insulating effect of the vernix caseosa no volume currents are present outside the fetus. The interfaces between the compartments have been manually tessellated. The number of triangles used for the first fetoabdominal volume conductor model is 2928 and for that of the second 3538. A conductivity of 0.22S/m is assigned to the fetal compartment, of 1.4S/m to the amniotic fluid, and of 0.05S/m to the maternal abdomen.

The first three-compartment model is displayed in Fig. 1a. As fetal MCGs are normally measured a few centimeters from the maternal abdomen, a spherical surface is created in front of the maternal abdomen at a distance of about 2cm. This surface is taken to evaluate the magnetic field, and the positions where the field is calculated are pictured (see Fig. 1b).

Figure 1: Overview of model 1

a) Three-compartment model: Fetus (0.22S/m) – Uterus (1.4S/m) – Maternal abdomen (0.05S/m)



b) Positions where the magnetic field is evaluated

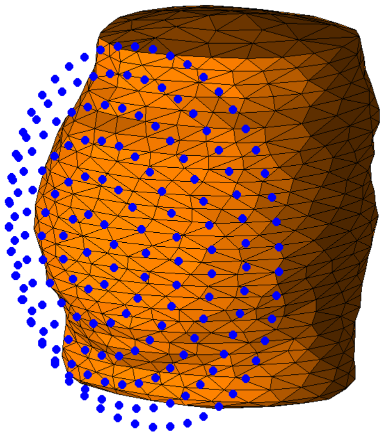


Figure 2: Transfer function of the fetoabdominal volume conductor (Model 1). In each column one of the three components of the magnetic field is displayed. In each row the contribution of one of the three dipoles is depicted.

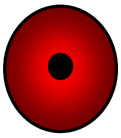
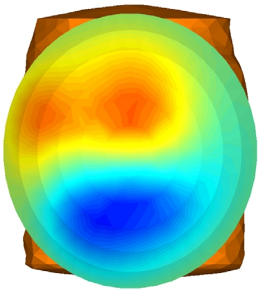
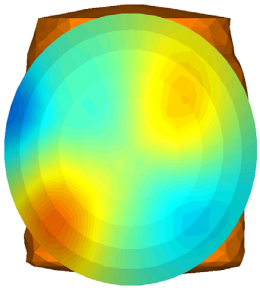
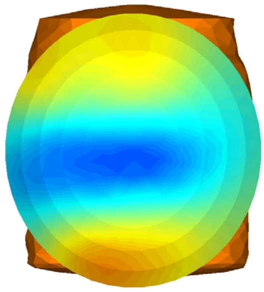
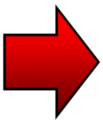
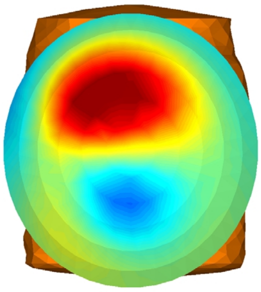
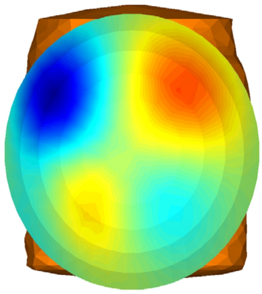
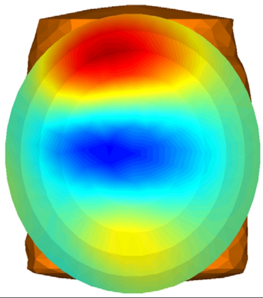
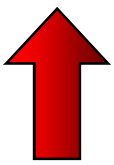
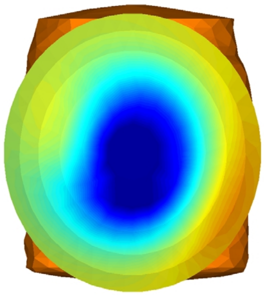
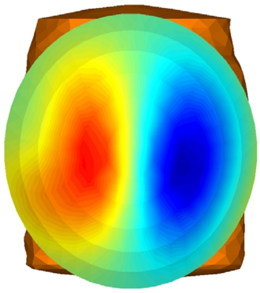
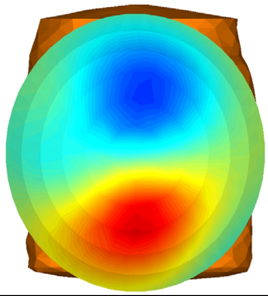
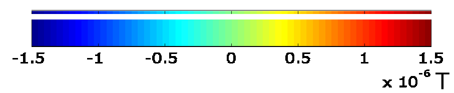
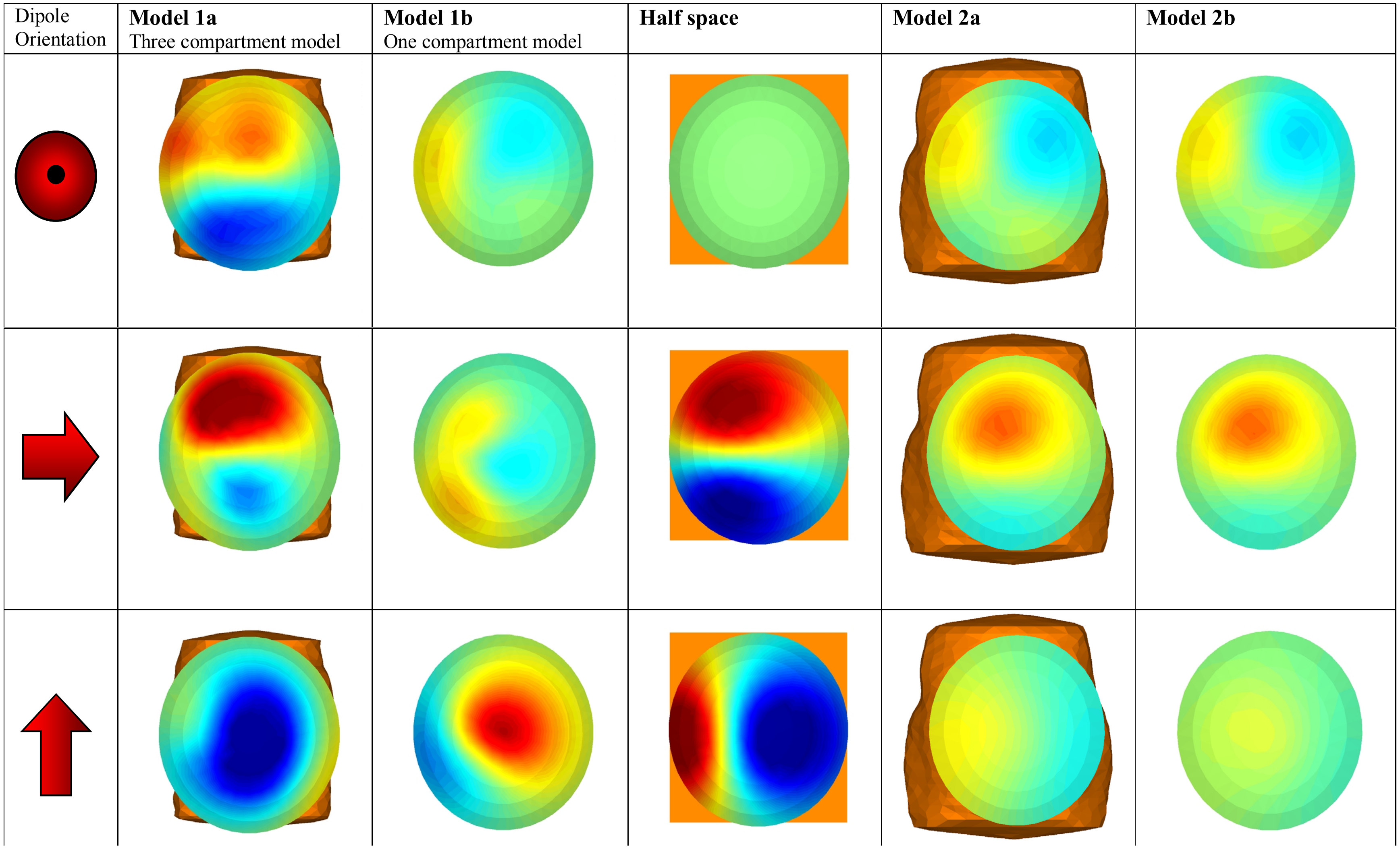
Dipole Orientation	**Model 1a** X-component magnetic field	**Model 1a** Y-component magnetic field	**Model 1a** Z-component magnetic field
			
			
			

Figure 3: The magnetic field component perpendicular to the observation surface for five fetoabdominal volume conductor models. Each row displays the field due to one of the dipoles oriented along the x, y, or z-axis.





To determine the influence of the fetoabdominal anatomy, the magnetic field of three perpendicular dipoles located at the position of the heart are evaluated. All dipoles have a strength of 1Am and are oriented in either the x, y, or z-direction. The coordinate system is aligned with the axes of the maternal body (see Fig. 1a). The magnetic field is computed by means of the boundary element method.

Results

The influence of the fetoabdominal anatomy is depicted by means of transfer functions. The transfer functions describe the distributions of the magnetic field over the maternal abdomen due to each of the three perpendicular dipoles located in the fetal heart. As the current source, describing the fetal heart, can be decomposed in these three perpendicular directions, the heart cycle will describe a linear combination of the distributions given by these transfer functions.
The distribution of the magnetic field component perpendicular to the measurement grid is computed for all five models using the three perpendicular dipoles as a source. The magnetic maps are shown in Fig. 3. All maps have the same color-index for the strength of the magnetic field. In the first column the dipole components are pictured.
In order to estimate the magnitude of the other components of the magnetic field, the x, y, and z-component of the field are calculated for the three-compartment model of fetus 1. The results are displayed in Fig. 2.

Conclusions

As shown in Figs. 2 and 3, the various models give rise to different transfer functions. The realistically shaped models give results that differ from those using the half-space. In other words, the contribution of the volume currents to the fetal MCG is substantial. The transfer functions for the models based on the images of fetus 1 differ from those based on the images of fetus 2. This means that the information of the fetal position is not enough to ensure the same results; hence an individual model might be needed for reconstruction of the heart vector. Comparing the results for the three-compartment model and the one-compartment model of the same fetus leads to the conclusion that the model used has to be the appropriate one for the gestational age of the fetus. Validation of the models is needed to determine which model is adequate for which week of gestation.
The amplitudes of the x, y, and z-components of the field for the three-compartment model as displayed in Fig. 2 are comparable. This is in accordance with measurements carried out with a vector magnetometer [3].

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