INFLUENCE OF ANISOTROPIC COMPARTMENTS ON MAGNETIC FIELD DISTRIBUTION CREATED BY ARTIFICIAL CURRENT DIPOLES

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Abstract: The influence of an anisotropic compartment on the orientation of the magnetic field distribution generated by an artificial current dipole was investigated. We modeled a volume conductor with an anisotropic compartment and a dipolar current source by means of a glass phantom and artificial current dipoles. The anisotropic compartment was build from single skeins with a different conductivity. We recorded the magnetic field data from this experimental setup with the vector biomagnetometer ARGOS 200. The current dipole was rotated in relation to the anisotropic skeins and the magnetic field was recorded for different angles between anisotropic skeins and current dipole. We found a strong dependency of the field orientation from the orientation of anisotropic skeins. The anisotropic skeins forces the current along its direction and thus the measured magnetic field is pulled in the direction of the anisotropic skeins. We conclude anisotropic structures must be considered in volume conductor modeling, when dipole orientations are of interest.

Introduction

One of the main goals of biomagnetic measurements is source reconstruction, which requires a volume conductor. Commonly, volume conductors consist of isotropic compartments (such as e.g. boundary element model compartments) and neglect anisotropic tissue conductivity [1]. The purpose of this study is the analysis of the influence of anisotropic conductivity on biomagnetic fields assessed with the help of phantom measurements.

Materials and Methods

As volume conductor a glass phantom was used, which was filled with saline solution with a conductivity of 0.13 S/m. The anisotropy was modeled by skeins built from guar gum solved in saline solution with a conductivity of 1.35 S/m. This corresponds to the conductivity situation in muscle fibers, like the myocardium [2]. The skeins had a diameter of 1.5 mm and were arranged in a bulk pointing in the same direction. The bulk was placed in the middle of the phantom (see figure 1). The artificial dipole used for generating the magnetic field, was build from Platinum with a length of 10 mm, and was driven by a sinusoidal current of 0.5 mA. The current dipole was placed in the middle of the skein arrangement. To realize different angles between the skeins and the dipole, the dipole was rotated parallel to the plane of the measurement sensors.

This experiment was repeated in another configuration. Instead of an anisotropic skein arrangement, a homogeneous compartment with approximately the size and shape of the anisotropic skeins bulk was inserted into the glass phantom. This compartment had the same conductivity like a single skein. The artificial current dipole was rotated inside this compartment and the orientation of the magnetic field was assessed.

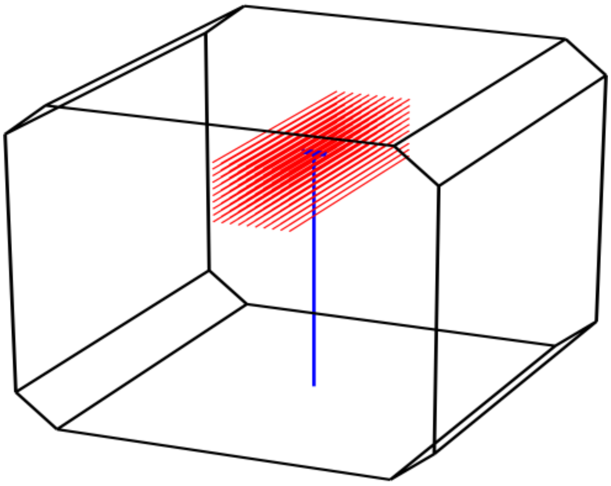

Figure 1: The glass phantom with the anisotropic skeins arranged in a bulk. The artificial current dipole is inside the skeins bulk and here the angle between dipole and anisotropy is 90 °.

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The magnetic field for nine different angles between the dipole and the anisotropic skeins bulk and also for nine different angles between the dipole and the compartment of different conductivity was recorded.

The data were recorded with the vector biomagnetometer ARGOS 200 at the Biomagnetic Center Jena. The sensors were arranged parallel to the surface of the conductivity solution. The midpoint of the measurement array, consisting of 168 magnetometers, had a distance of approximately 45 mm from the artificial current dipole.

The orientation of the measured magnetic field pattern was calculated from the direction of the maximum ingoing and the maximum outgoing field values of the isocontour plots. This calculated direction was compared to the direction of the original current dipole and the angle between the two directions was analyzed.

Furthermore the change of the amplitude of the magnetic field depending on the orientation of the current dipole was analyzed. The amplitude is the sum of the absolute values of the channel with the maximum magnetic field and the channel with the minimum magnetic field.

Results

Figure 2 shows the obtained magnetic field pattern and the orientation of the original current dipole for five different recordings. The orientation of the magnetic field in subfigure (a) is almost equal to the orientation of the current dipole. In this part of the measurement the original dipole and the anisotropic skeins had the same direction. The next subfigures show increasing angles between the artificial current dipole and the anisotropy with steps of 22.5 °. In subfigure (b) there is a small difference between the direction of the dipole and the measured magnetic field. The subfigure (c) shows a slightly bigger difference between these two directions.

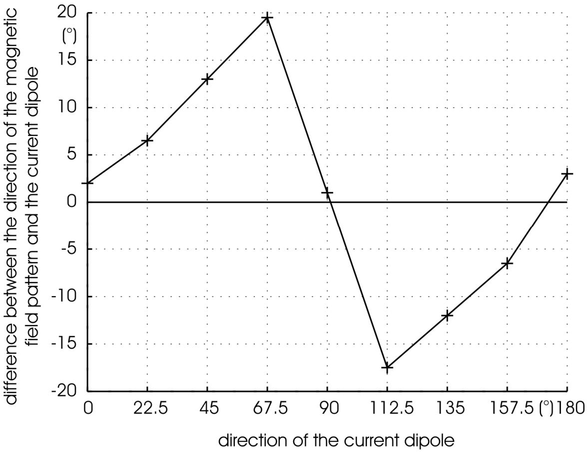

Figure 3: Difference of the direction between the magnetic field pattern and the direction of the original current dipole with the dipole rotating in an anisotropic bulk of skeins.

The biggest difference of about 20 ° is shown in subfigure (d), where the direction between original current dipole and anisotropic skeins bulk is 67.5 °. In subfigure (e) the orientation of the dipole is perpendicular to the direction of the anisotropy. Here the orientation of the magnetic field is almost not influenced by the anisotropy.

Figure 3 shows the angle differences between the magnetic field orientation and the orientation of the original current dipole. At the starting point, where the dipole direction is parallel to the bulk of anisotropic skeins, the angle is 2 °. The difference is increasing up to 67.5 ° between dipole and anisotropy, where it reaches its maximum value of 19.5 °. From that point on, a very steep decrease of the difference in direction can be observed. For the orthogonal orientation between the dipole and the anisotropic skeins the difference between the magnetic field and the dipole direction is

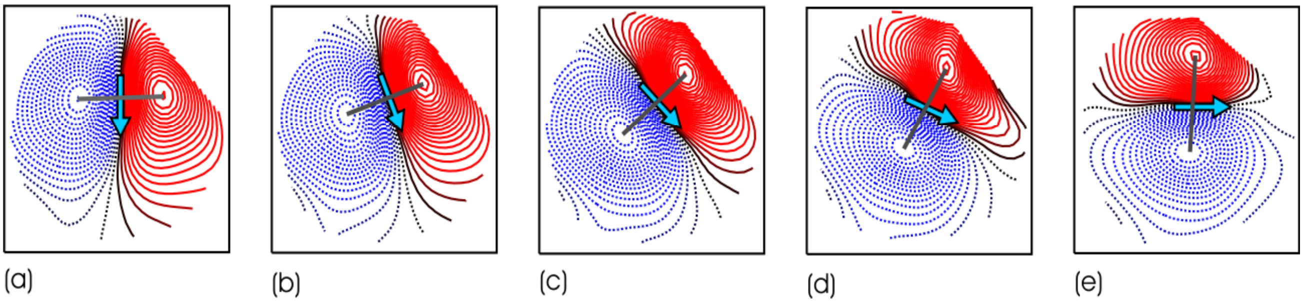

Figure 2: Isocontour plots of the magnetic field for the first five orientation of the current dipole. The arrow in the middle of each subfigure indicates the direction of the source dipole. The subfigures corresponds to angles between the anisotropic skeins bulk and the source dipole of (a) 0 °, (b) 22.5 °, (c) 45 °, (d) 67.5 °, and (e) 90 °. The differences between dipole orientation and magnetic field orientation increases with bigger angles between dipole and anisotropy. The maximum is reached in subfigure (d). At the orthogonal orientation of the dipole and the skeins bulk, the difference is almost zero.

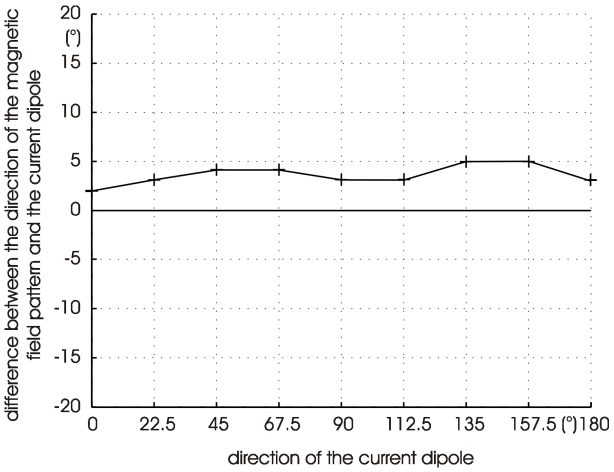

Figure 4: Difference of the direction between the magnetic field pattern and the direction of the original current dipole with the dipole rotating in a compartment of a different conductivity.

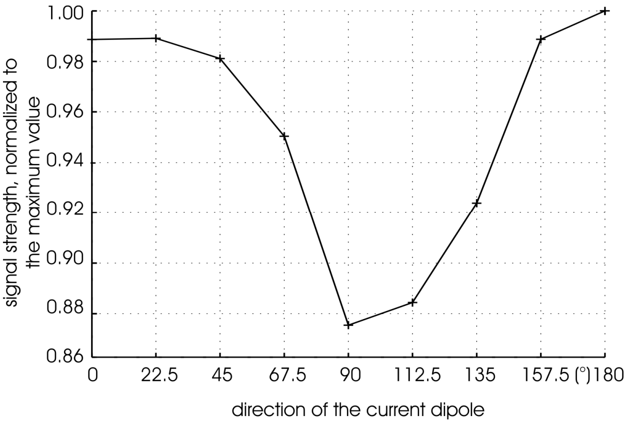

Figure 5: Signal strength of the measured magnetic field over the angle between the anisotropic bulk and the original current dipole.

almost zero. The ongoing change of the angle between current dipole and anisotropic skeins of more than 90 ° shows an equivalent behavior in reverse direction.

The same analysis of the change of the magnetic field orientation from the original current dipole was made with the dipole rotating inside a compartment of a higher conductivity. The results are shown in figure 4. All values are equal or below 5 °, which could be considered as noise. Therefore here is no dependency of the orientation of the magnetic field from the orientation of the current dipole.

The signal strength of the magnetic field from an artificial current dipole inside an anisotropic bulk is shown in figure 5. The values are normalized to the maximum. With higher angles between the current dipole and the anisotropy the signal strength is decreasing. The decay of the amplitude reaches the maximum value of around 12 percent at the perpendicular orientation of the dipole.

Discussion

A current dipole rotating in an anisotropic bulk generates magnetic field with orientations differing from the expected orientation in a homogeneous conductivity compartment. The difference of the angle increases with higher angles between dipole and anisotropic structure, up to the perpendicular orientation of the dipole. The change in the direction of the magnetic field is caused by higher conductivity along the direction of the skeins. The current flows in that direction ten times higher than in the other directions. Thus, the magnetic field lines are forced in the direction of the skeins and the resulting magnetic field has a different orientation than the source dipole. At the perpendicular and the parallel orientations the field distributions points in the same direction like the source dipole. In this case the same field orientation would be generated without an anisotropic compartment.

The analysis of the change of the field orientation depending from a dipole rotating inside a compartment of different conductivity showed no influence of the compartment on the orientation of the magnetic field.

The signal strength of the measured magnetic field decreases with higher angle between dipole and anisotropy up to 90 °. This is caused by the elongated field in the direction of the anisotropy. The current flows more into the direction of the skeins, therefore the amplitude is decreasing, if the maximum and the minimum field values are along the direction of the anisotropic skeins.

Conclusions

In our study we modeled experimentally anisotropic skeins as macroscopic representation of fibers. They were arranged in a bulk inside a homogeneous volume conductor. The magnetic field pattern obtained from this experimental setup shows that the directions of dipolar fields are strongly influenced by anisotropic compartments. The same experiment was performed with a homogeneous compartment of a different conductivity than the surrounding. Here we found no such effect.

We conclude anisotropic structures must be considered in volume conductor modeling, when dipole orientations are of interest. Volume conductor modeling based on finite element method (FEM) [3, 4] can take anisotropy into account.

Similar experiments should be performed for testing the influence of anisotropic compartments onto the source reconstruction based on data assessed from artificial current dipoles.

References

[1] TENNER U, HAUEISEN J, NOWAK H, LEDER U, and BRAUER H (1999): ‘Source localization in an inhomogeneous physical thorax phantom‘, *Phys Med Biol*, **44(8)**, pp. 1969-1981

[2] GUCCIONE JM, MCCULLOCH AD, and WALDMAN LK (1991): ‘Passive material properties of intact ventricular myocardium determined from a cylindrical model‘, *J Biomech Eng-T ASME*, **113(1)**, pp. 42-55

[3] WOLTERS CH, GRASEDYCK L, and HACKBUSCH W (2004): ‘Efficient computation of lead field bases and influence matrix for the FEM-based EEG and MEG inverse problem‘, *Inverse Probl*, **20(4)**, pp. 1099-1116

[4] HAUEISEN J, TUCH DS, RAMON C, SCHIMPF PH, WEDEEN VJ, GEORGE JS, and BELLIVEAU JW (2002): ‘The influence of brain tissue anisotropy on human EEG and MEG‘, *Neuroimage*, **15(1)**, pp. 159-166