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Effect of the Human Heart Material Anisotropy on Modeling of the Body Surface Potential Map

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Abstract: This study investigates the effect of assuming isotropic properties for the heart's myocardium on the Body Surface Potential Map (BSPM) under both homogeneous and inhomogeneous torso volume conductor models. The human torso was modeled as an inhomogeneous volume using CT data, and the heart as a volume source based on diffusion tensor imaging (DTI), incorporating both anisotropic and isotropic conductivity assumptions. Using the Monodomain Reaction-Diffusion Equation (MD-RDE), excitation propagation isochrones were computed. Results show that simplifying the heart as an isotropic material introduces notable discrepancies in activation patterns and BSPM characteristics. Quantitative assessment using correlation coefficient and relative error metrics confirms that heart anisotropy plays a critical role in generating accurate BSPMs.

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1. Introduction

The conduction system represents the initial excitation points of the heart's Myocardium which in turn generate excitation propagation through the heart Myocardium. The potential difference between activated spaces and inactivated spaces inside the heart produces volume current sources (volume sources) that generate both potential and magnetic fields, which can be observed on the body surface and outside the body respectively [1].

The scope of much of the work deals with identifying the ventricular conduction system. The most common models that are used to identify the ventricular conduction system are those described by Tawara [2], Massing et. al.[3], and Durrer et. al.[4]. Modeling of the ventricular conduction systems involves either assigning the early activation sites according to the measurements of Durrer et. al. [5–10], or building a network according to the anatomical structure and activation isochrones [11–15].

The heart Myocardium has strong anisotropic properties that affect both the electrical and the mechanical functions of the heart. Modeling the Myocardium as isotropic material is addressed in some models [5,16–18], but most of the other models consider the Myocardium as an anisotropic material [11,19–25]. Excitation propagation of the heart is usually modeled in tissue scale based on Monodomain Reaction Diffusion Equation (MD-RDE) [17,20–29].

The body can be modeled either as a homogenous or as an inhomogeneous volume conductor. For a homogenous volume conductor, it is assumed that all organs including the blood volume inside ventricles have the same physical parameters. In contrast, for an inhomogeneous volume-conductor, each organ has its own parameters. Inhomogeneity of the body affects the produced surface potential as introduced by Gulrajani and Mailloux [30], where it was shown that the blood mass has the largest effect on the body surface potential.

All of the organs in reality are anisotropic materials. Some tissues such as the skeletal muscles have strong anisotropic properties while others like liver and lungs have almost isotropic properties [1]. Including organ anisotropy requires a huge amount of data that describes the composition of each

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organ. However, considering the organs to be an isotropic material is acceptable and this will simplify the modeling [1].

Some models describe the volume conductor (the body) in terms of an approximate shape, but the most widely used is the realistic torso shape. The realistic torso shape models are either a homogenous volume conductor [11,16,24,25,31,32] or the widely used inhomogeneous volume conductor [8,13,17,18,20,33–36]. Most models employ the body surface potential [6,8,10,12,13,16,20,23–25,32,35,37], while a minority of models use the heart's magnetic field map [38].

This study focuses on measuring the effect of considering the heart's myocardium an isotropic material on the BSPM. The analysis is done for both homogeneous and inhomogeneous body.

2. Methods

2.1. The Human Torso and the Human Heart Modeling

Human torso (Figure 1) has been modeled as inhomogeneous volume conductor using CT-Scans [36] and human heart is modeled as anisotropic volume source [19] using DTI images. The ventricles conduction network is extracted as well based on DTI images [15].

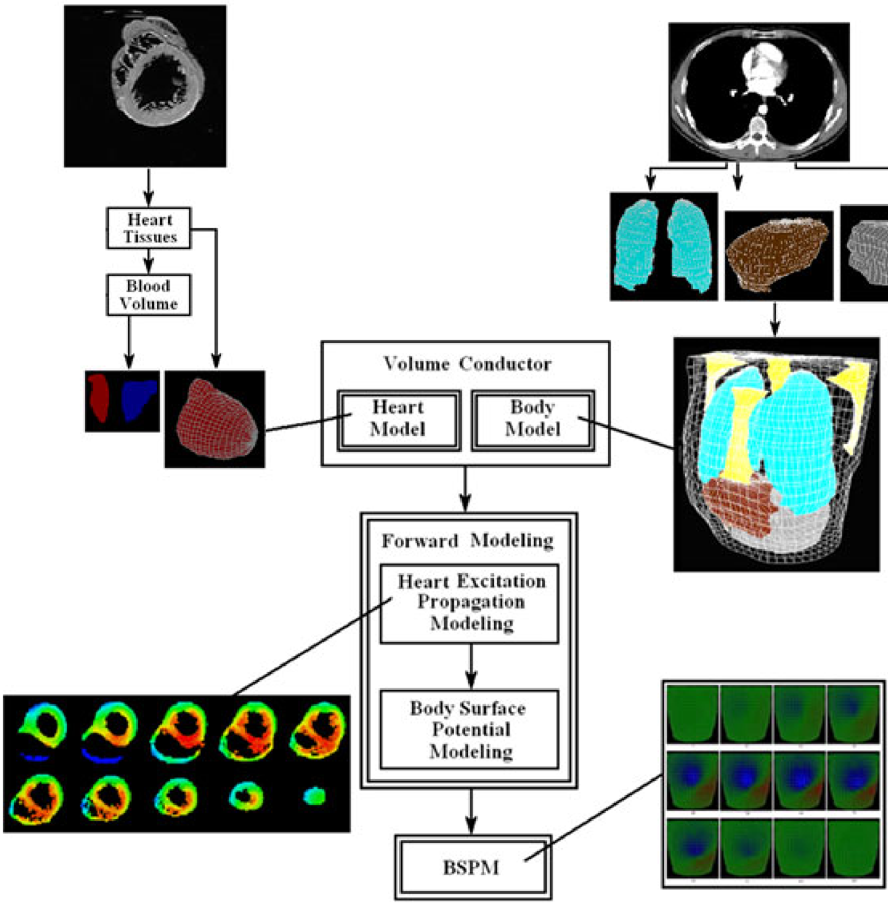

Figure 1. System's layout [37].

2.2. Activation Isochrones Modeling

The excitation propagation isochrones for both the anisotropic heart materials (Figure 2) and the isotropic heart material (Figure 3) are constructed using Monodomain Reaction Diffusion Equation (MD-RDE) where the conductivity of the isotropic heart material is taken to be the average of both materials (where σ_l =34.4 mS/mm and σ_t =5.96 mS/mm then σ_{AVG} =20 mS/mm) [28]. It was reported that excluding the anisotropy information about the heart material will significantly affects the

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produced excitation propagation [29] where there are significant differences in activation time between the two cases.

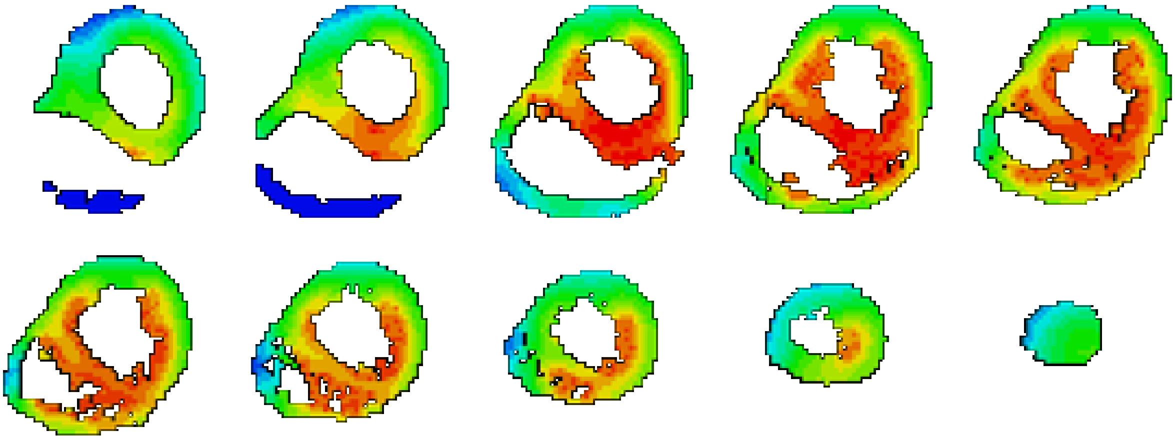

Figure 2. The isochrones for the excitation propagation of the heart when it is considered an Anisotropic material [28].

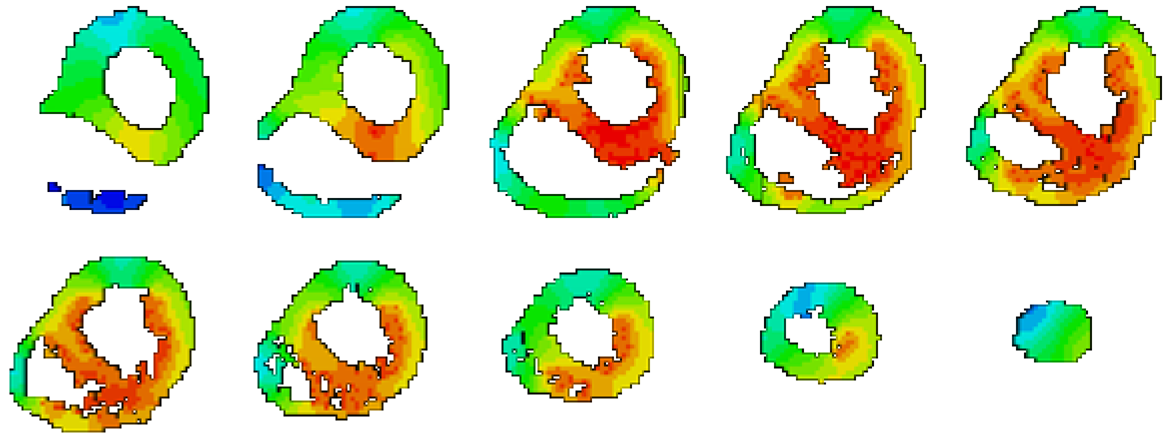

Figure 3. The isochrones for the excitation propagation of the heart when it is considered an Isotropic material [29].

3. Results

As the reference configuration, the heart is considered anisotropic material and the body is an inhomogeneous volume conductor where the Body Surface Potential Map (BSPM) has been constructed [19]. The effect of the heart material isotropy on the BSPM is measured based on Coefficient Correlation (CC) and Relative Error (RE) between the reference configuration to the following 2 configurations (Table 1, Figure 4 and Figure 5):

Conf. 1: Isotropic heart / homogeneous body.

Conf. 2: Isotropic heart / Inhomogeneous body.

Table 1. CC and RE between the reference configuration and the two heart's configurations.

	CC			**RE**	
ID	**Conf. 1**	**Conf. 2**		**Conf. 1**	**Conf. 2**
1	0.611	0.634		0.845	0.810
2	0.857	0.835		0.577	0.577

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3	0.830	0.797		0.567	0.603
4	0.708	0.574		0.710	0.862
5	0.818	0.502		0.581	0.966
6	0.891	0.625		0.562	0.874
7	0.930	0.739		0.560	0.747
8	0.963	0.814		0.573	0.660
9	0.983	0.869		0.582	0.608
10	0.974	0.900		0.559	0.597
11	0.955	0.931		0.497	0.565
12	0.954	0.963		0.417	0.506
13	0.971	0.979		0.332	0.504
14	0.983	0.981		0.284	0.578
15	0.985	0.977		0.304	0.712
16	0.983	0.980		0.328	0.835
17	0.968	0.981		0.299	0.927
18	0.924	0.981		0.387	0.966
19	0.873	0.975		0.488	0.885
20	0.805	0.971		0.598	0.751
21	0.749	0.960		0.665	0.799
22	0.601	0.954		0.802	0.884
23	0.068	0.967		1.015	1.014
Mean	0.843	0.865		0.545	0.749
SD	0.200	0.146		0.180	0.156

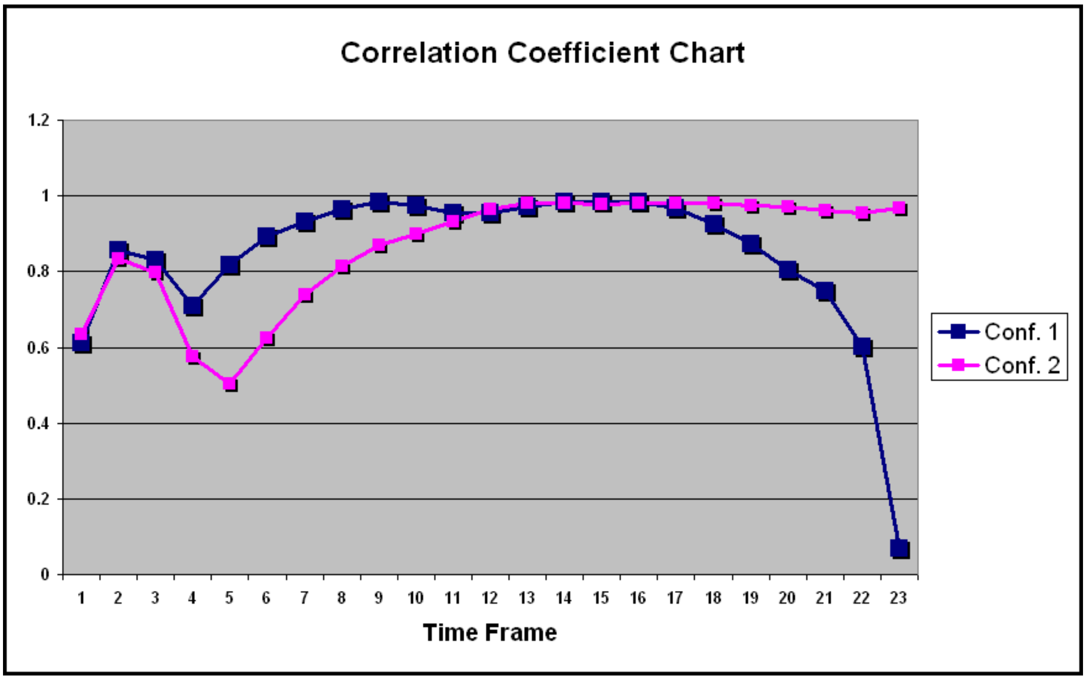

Figure 4. CC chart of the isotropic/anisotropic heart's configurations.

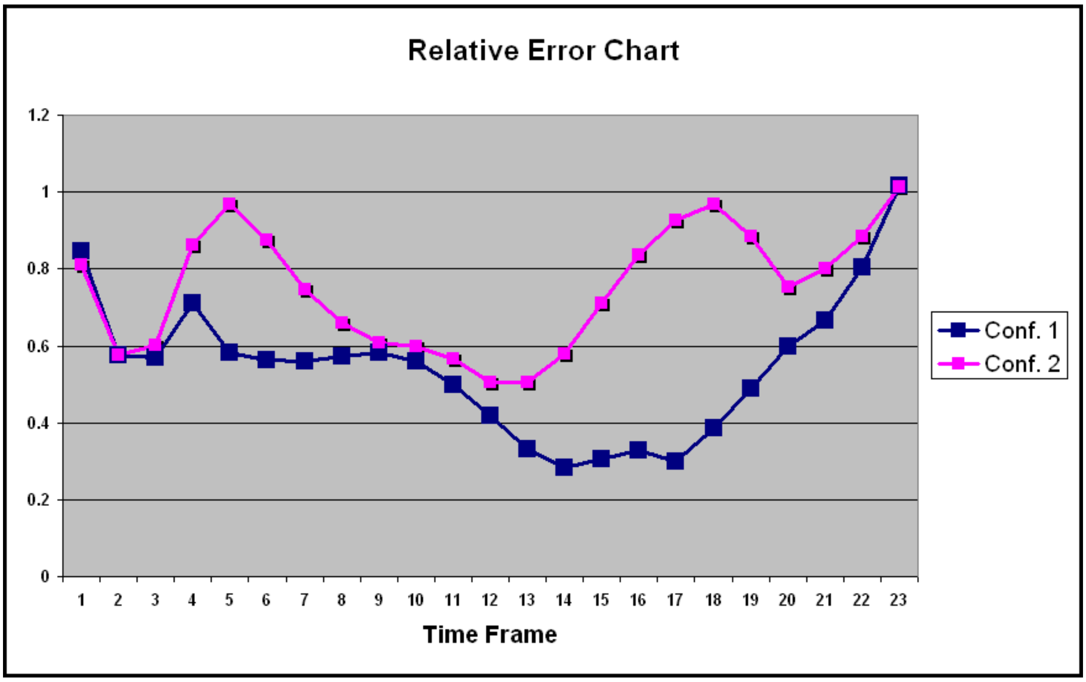

Figure 5. RE chart of the isotropic/anisotropic heart's configurations.

Finally, the relatively low CC and the relatively large RE of both configurations confirm that heart anisotropy significantly affects the produced BSPM.

4. Conclusions

The study demonstrates that the myocardial anisotropy has a significant influence on the accuracy of BSPM simulations. When the heart is modeled as an isotropic material, notable differences in excitation propagation and surface potential distributions are observed, especially when compared to the reference configuration of an anisotropic heart within an inhomogeneous torso. The relatively low correlation coefficients and high relative errors in simplified configurations confirm that omitting anisotropy leads to less accurate BSPMs. These findings highlight the importance of preserving myocardial fiber orientation in cardiac modeling for clinical and research applications.

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