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FLUX-FLOW INTERACTION IN ELECTROMAGNETIC BIOIMPEDANCE

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The electromagnetic field's morphing in interaction with blood flow may be used to propose a novel bioimpedance technique aimed at the non-invasive detection and mapping of large cerebral vascular networks, such as the dural venous sinuses, which collect the venous deoxygenated blood from the brain region and returns it to the heart through the internal jugular vein and the superior vena cava. In this impedance method, the position of the electrodes on the skull leads the incident flux (the electric current density) to outline the vascular flow and spot the venous sinuses noninvasively. It is crucial for some neurosurgical interventions that the venous sinuses are not accidentally damaged during the procedure since hemorrhage at this level is often fatal.

Keywords: Electromagnetic bioimpedance; Vascular flow; Electric current flow; Flux-flow interaction.

1. INTRODUCTION

The electrical impedance of a biological media (*e.g.*, cell cultures, living tissues) depends on the frequency of an electrical excitation signal (typically, a low-amplitude, high-frequency electrical current) applied from external sources to evaluate it. The response given by the electrical impedance variation provides information about physiological or pathological aspects of the investigated biological environments. A series of classical clinical investigation techniques based on electrical bioimpedance [1], such as electrical cardiometry (ECM) and impedance cardiography (ICG), used for evaluating the hemodynamic parameters of the heart, complement the information provided by the electrocardiogram and outline a global picture of the electrical activity of the myocardium. An incident electromagnetic field (EMF) is used to unveil lower impedance paths (*e.g.*, blood vessels) inside the body to gain helpful information on the body's rhythms and composition that vessel trees "echo".

EMF – blood flow morphing is used here to detect and map cerebral vascular networks. The dural venous sinuses [2–7] are blood vessels in the head's skull region that act as venous blood collectors, returning the deoxygenated blood to the heart through the internal jugular vein and the superior vena cava. Additionally, the superior sagittal sinus ensures the circulation of the cerebrospinal fluid. This bioimpedance method may be of interest in neurosurgery for high-precision detection of large blood vessels requiring brain surgery (tumor removal, aneurysm embolization, strokes).

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2. **MATERIALS AND METHODS**

A harmless electric current $O(10^2)$ mA with an $O(10)$ kHz frequency is applied as an excitation signal using a pair of electrodes conveniently fixed on the scalp. In contrast, another pair of electrodes measures the electrical impedance of the investigated anatomical region as a response (Fig. 1, left side). Since the largest blood vessels in the head region are the venous sinuses and the blood has a higher electrical conductivity value than the nearby tissue, these will become a preferential closing path for the electrical excitation current, signaling their presence and position. No such investigative techniques have been reported in the literature for morphological analysis of the cranial circulatory system.

The mathematical model of the electric field is:

$$\nabla \cdot (\sigma \mathbf{E}) = \nabla \cdot [-\sigma(\nabla V)] = -\sigma[\nabla \cdot (\nabla V)] = -\sigma \Delta V = 0, \quad (1)$$

where σ[S/m] is the electrical conductivity of the tissue, **E** [V/m] is the electric field strength, and V [V] is the electric potential. The boundary conditions that close the model consist of injecting a continuous electric current of 400 μA at one excitation electrode, a ground condition at the other, and floating electric potentials for the measurement electrodes. The exterior boundaries are electrical insulation, while the interfaces between different tissues are set as continuity.

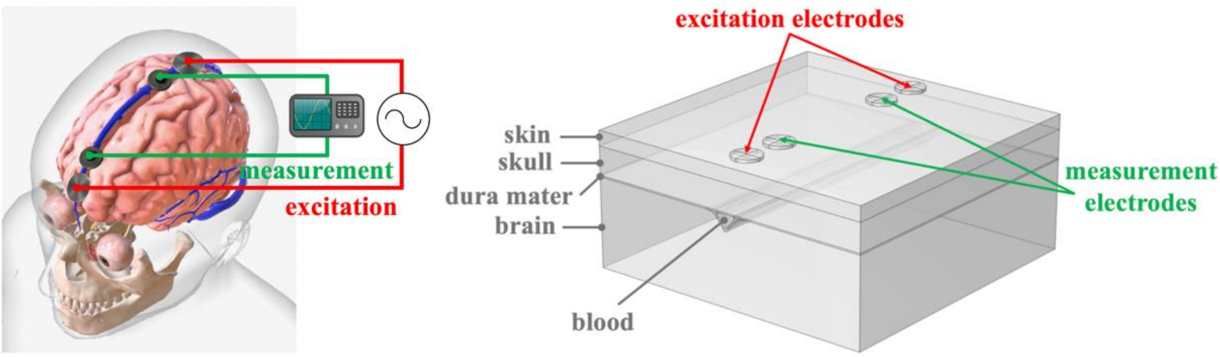


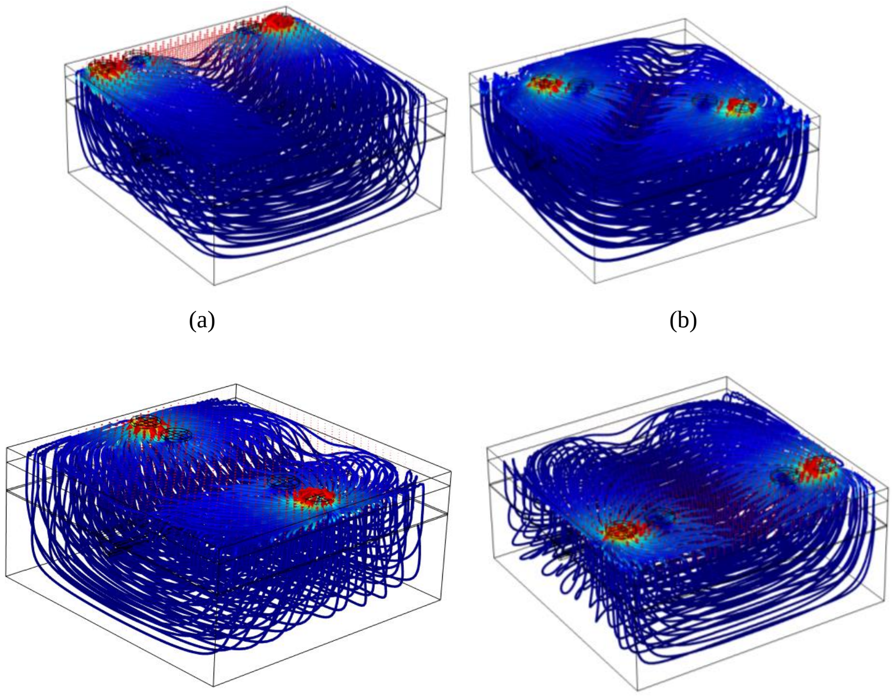
Fig. 1 – Principle of the electromagnetic bioimpedance technique (left side) and the idealized computational domain (right side).

3. **RESULTS AND DISCUSSION**

ICG and ECM, an incident electromagnetic field (EMF), are used to unveil lower impedance paths inside the body to unveil helpful information on the body's rhythms and composition that vessel trees reverberate. Here, the EMF is presented through a stationary electrical conduction problem governed by the mathematical model described in eq. (1), which was integrated numerically using the finite element method [8].

Figure 2 presents the electrical current density and the venous blood flow for several electrode positions on the scalp. Blood is a relatively good electroconductive medium compared to the surrounding biological media, so the electric current path is mainly through the vessel. Several electrode positions are used to adjust (morph) the EMF flux through the blood flow, and the minimum impedance position is found here by trial and error. More accurate methods can be easily defined.

The electrical bioimpedance was calculated by integrating the resulting electric potential at each measurement electrode. The values are presented in Table 1.



(a) (b)

(c) (d)

Fig. 2 – Flux-flow interaction for different electrode placement.

Table 1

Electrical bioimpedance evaluated for each setup

Electrode placement on the scalp [case]	Electrical bioimpedance value [Ω]
(a) – 4 cm distance from the superior sagittal sinus	423.25
(b) – electrodes are rotated 45° with respect to the superior sagittal sinus	279.10
(c) – electrodes are rotated 90° with respect to the superior sagittal sinus	278.99
(d) – 2.5 cm distance from the superior sagittal sinus	320.80

There is a close relation between the electrical bioimpedance values and the electrodes' placement: the presence of the blood vessels can be predicted regardless of the four electrodes' alignment to the vein (cases (c), (e), and (f) reveal similar low electrical bioimpedance value) if these are close enough to the low impedance path (the blood vessel).

Thus, the proposed method is suitable for the non-invasive detection of more prominent veins in the head region.

In our future work, we will also study a more realistic computational domain generated using medical image-based reconstruction techniques, which respects the anatomical morphology of the investigated area.

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