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A NUMERICAL MODEL OF INTERNAL CARDIAC STIMULATION

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The present work is focused on the electromagnetic numerical modelling of artificial cardiac stimulation. A 3D stationary model of the internal cardiac stimulation is described and analysed. Each region of the domain was considered to be linear, time-invariant, isotropic, the subdomain conductivity being averaged over the tissue/organ volume. Specific characteristics of each model were computed, analysed or estimated, such as the optimal position of the internal electrodes, the current density in the myocardium and surrounding tissues, the potential variation in the nodes of the mesh, the cellular activating function, the spectrum of the current density, the equipotential lines etc. The results and the efficacy of the model were analysed for final conclusions.

1. INTRODUCTION

The past ten years, a lot of studies on internal artificial cardiac stimulation have been developed, more and more researches on optimization of the existent medical procedures are reported and new techniques and models, laboratory experiments or computer simulation are proposed.

The main development directions are based on the most important categories of internal electrical stimulation, such that internal sensing, defibrillation or pacing.

An indispensable aspect of the studies is the numerical modelling of the procedures, with the considerable advantage of the time and resources sparing, multiple posibilities of the problems approach, the direct transfer of the results.

Numerically, there are different methods that can be used (finite element, boundary element, finite difference); the geometry can be created in two or three dimensions, the anatomical domains could be simple or complicated, homogenous or not, isotropic or anisotropic, and the regime can be stationary or dynamic.

The present work is focused on the numerical model of the internal electrical stimulation of the heart.

2. A THREE-DIMENSIONAL STATIONARY MODEL OF THE INTERNAL CARDIAC STIMULATION

This study presents a model for internal cardiac stimulation, with a system of two floating electrodes of OLBI (Overlapping Biphasic Impulse) type, whose utility was proven in clinical investigations.

The generator considered within this work belong to the new generation of cardiac stimulators, characterised by a triple function: sensing (detecting of the cardiac rhythm disturbances), pacing (generating of periodical voltage pulses of low power) and defibrillation (generating of isolated voltage pulses of higher power, in case of fibrillation), with two electrodes placed on a rod [4].

An electrokinetical model based on a three-dimensional configuration was analysed, considering the DC terminal voltage applied on two electrodes placed in the right atrium has the same value as the amplitude of the terminal voltage applied in the dynamic regime.

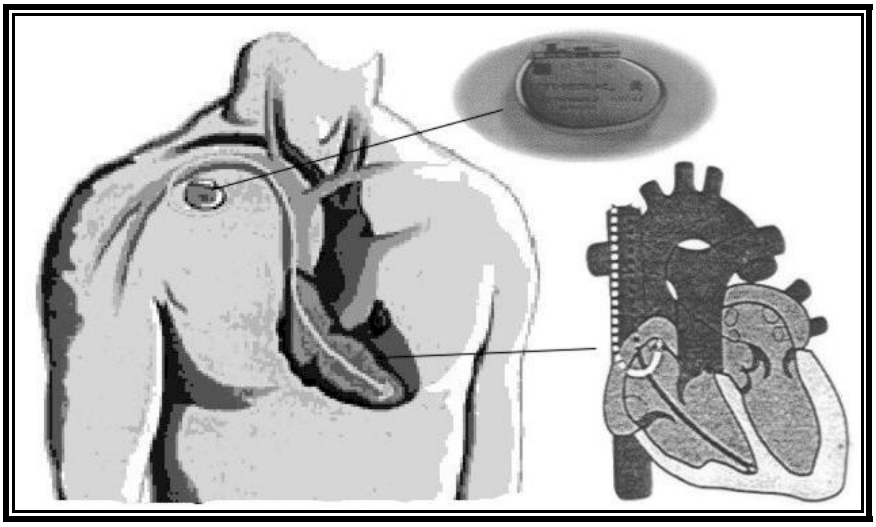

Fig 2.1. – The placement of the internal defibrillators

The anatomical structure was detailed at the heart level; for each considered biological tissue, an electrical conductivity was assigned; the thorax model was simplified, considering this region as a homogenous medium, with an averaged value of the conductivity. The nonhomogenous cardiac domain was divided in three subdomains (myocardium, blood and valve), each of them being considered continuous, linear, time-invariant, homogenous, isotropic, with an average value of the conductivity.

The electrodes and the generator (usually made by platinum and iridium) were considered superconductive media, with a high specified value of the conductivity $\sigma = 10^7$ S/m (to avoid the error messages).The exterior medium and the rod were considered perfect insulators ($\sigma = 0$).

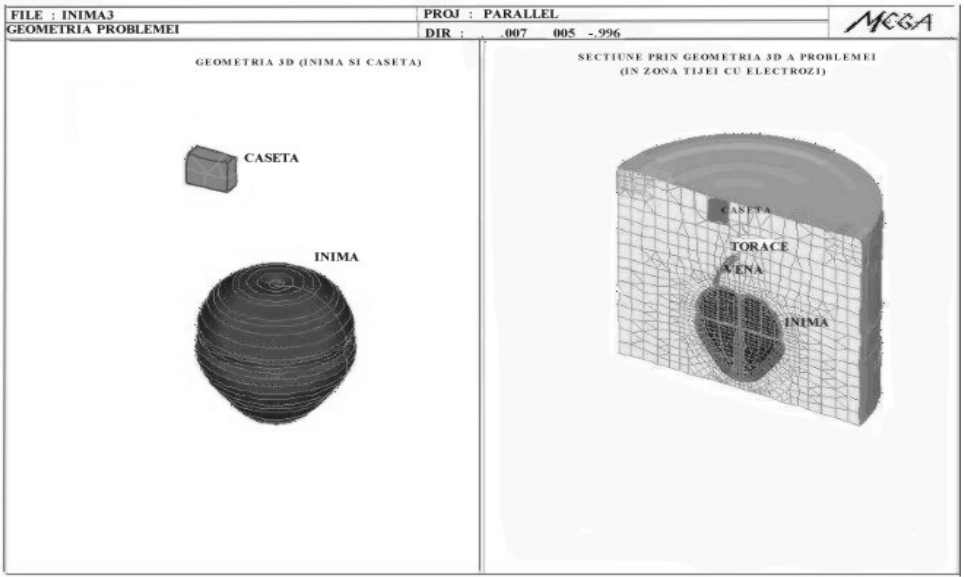

Fig. 2.2. – The 3D geometry of the heart and thorax

The equation to be solved on each subdomain:

$$\Delta V = 0 \tag{2.1}$$

This equation will be completed by the boundary conditions: Dirichlet (the positive electrode V_1 = 5.4V, the negative one V_2 = -5.4V, V = 0) and Neumann $\partial V/\partial n = 0$ on the rest of the boundary.

The 3D model has 19296 nodes and 20214 elements.

We tested three cases for each electrode (positive and negative), modifying the position of the electrodes related to the atrial wall, as well as the distance between the electrodes.

In order to validate the method, specific characteristics of the model were computed and analysed (in transversal sections of the 3D geometry), such as: equipotential lines; current density values and spectrum in the whole domain and then only in the myocardium, the potential variation in the nodes of the mesh, in the right atrium, the cellular activating function (defined as the second spatial derivative of the potential on the internal side of the myocardium), known to be an indicator of the internal stimulation efficacy.

For each case (out of six) we analysed the extreme values of the current density and we compared the results.

The maximal values of the current density in the myocardium were evaluated with respect to the threshold ($J_{threshold}$ = 250 A/m^2), known from the specialised literature [1, 3, 5].

The graphic of the activating function was compared with whose obtained by other research teams within some experimental studies [6].

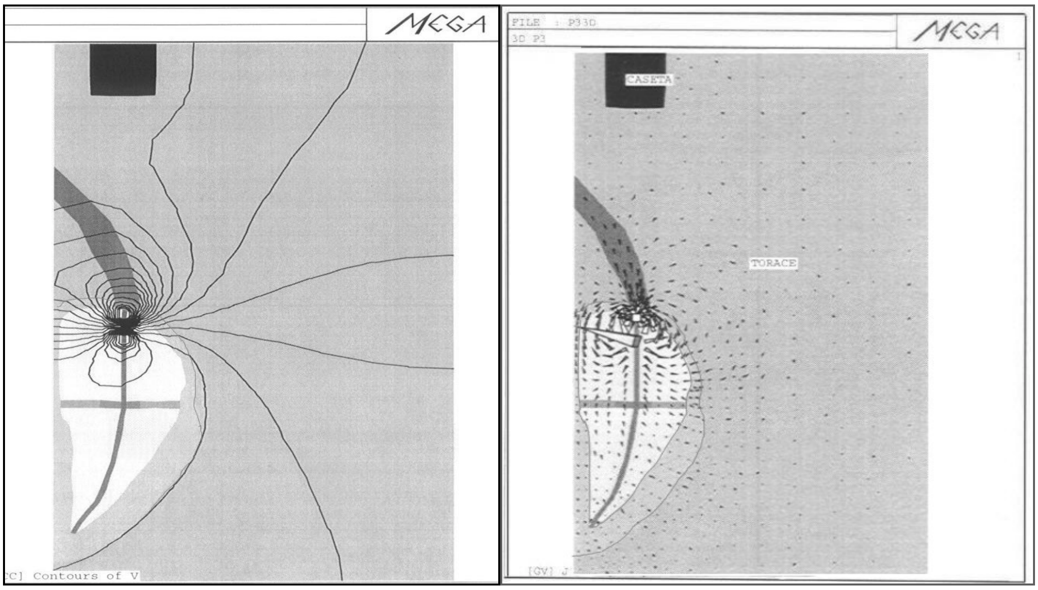

Fig. 2.3. - The equipotential lines and the current density spectrum

The table 2.1. presents the results concerning the maximal values of the current density in the whole domain and the minimal and maximal values in the myocardium.

Table 2.1.

Poz.	J_{maxdom} (A/m^2)	J_{maxmio} (A/m^2)	J_{minmio} (A/m^2)
1.1	2127.1	250.52	0.75
1.2	780.35	165.24	0.81
1.3	992.49	322.52	0.66
2.1	791.64	141.86	0.98
2.2	1353.2	217.12	0.57
2.3	2431.1	355.94	0.46

It is obvious that the values which are closed or exceed the threshold current density are obtained in the cases 1.1, 1.3 and 2.3, so we can conclude that the efficacy of the internal stimulation depends on the local position of the electrodes (with respect to the atria myocardium) and on maintaining constant the distance between them.

From the activating function point of view, we may notice that its amplitude stimulates the atria fibre far from the sino-atrial node for the cases 1.1 and 1.3; in the case 2.3, the maximal excitation activates the region of the SA node (that is a natural generator of impulses), that implies a higher efficacy of the electrical stimulation.

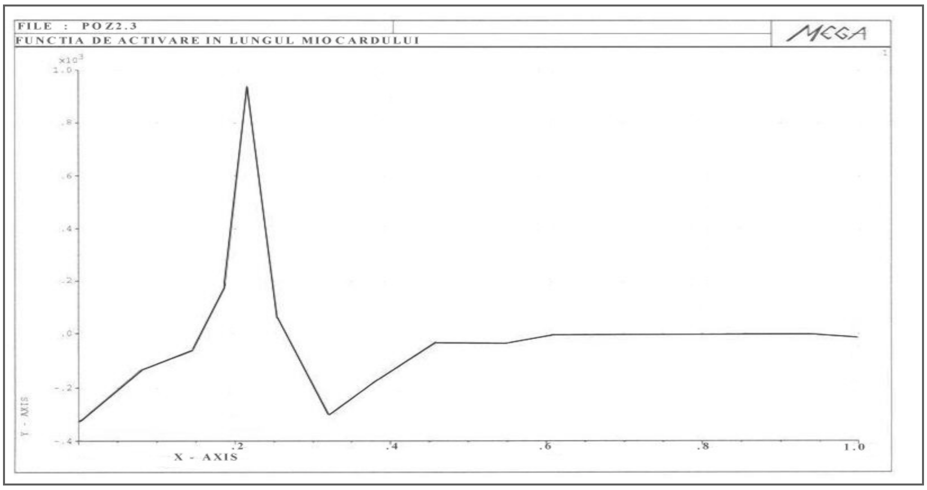

Fig. 2.4. – The activating function for the case 2.3.

.... CONCLUSIONS

The main conclusion of this paper is that the numerical modelling in internal artificial cardiac stimulation represents an indispensable aspect of the studies within this research area, not only for the advantage of the time and resources sparing, but for the multiple possibilities of the problems approach and the direct transfer of the results. All the models can be improved, using better approximations of the real situation, as regards all their aspects (geometry, electrical characteristics, regimes, optimization functions etc).

Also, what is more important in the numerical approach of the medical procedures is that, using a correct formulation of the problem, we can avoid the direct experiment on the human body, eliminating the risks and the side effects.

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