A NUMERICAL MODEL OF EXTERNAL CARDIAC STIMULATION

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The present work is focused on the electromagnetic numerical modelling of artificial cardiac stimulation. A 2D model of transcutaneous defibrillation 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 external electrodes, the current density in the myocardium and surrounding tissues, the potential variation in the nodes of the mesh, 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 external 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 optimization, such that electrodes postion, number and size, stimulation stimulus etc 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 external electrical stimulation of the heart.

2. A 2D ELECTROKINETICAL MODEL FOR OPTIMIZATION OF THE POSITION OF THE ELECTRODES IN CARDIAC DEFIBRILLATION

This model considers the optimization of the electrodes position in order to obtain less side effects on the human tissues, especially on the thorax wall which is in direct contact with the defibrillator paddles.

The heart caption and cardiac function restoring should be made in good conditions that supposes a minimization of the quality factor represented by the ratio R of the maximum current density in the thorax with respect to the maximum value in the myocardium, ratio that will be calculated for different positions of the electrodes.

We consider the 2D stationary model of three real crossection of the human thorax, a non-homogenous domain containing eight regions (tissues and organs), each of them being considered continuous, linear, time-invariant, homogenous, isotropic (excepting the muscles), with an average value of the conductivity.

The goal of this study is to find out, using Finite Element Method (FEM), how the discomfort and the efficacy of the transcutaneous cardiac defibrillation depends on electrode position.

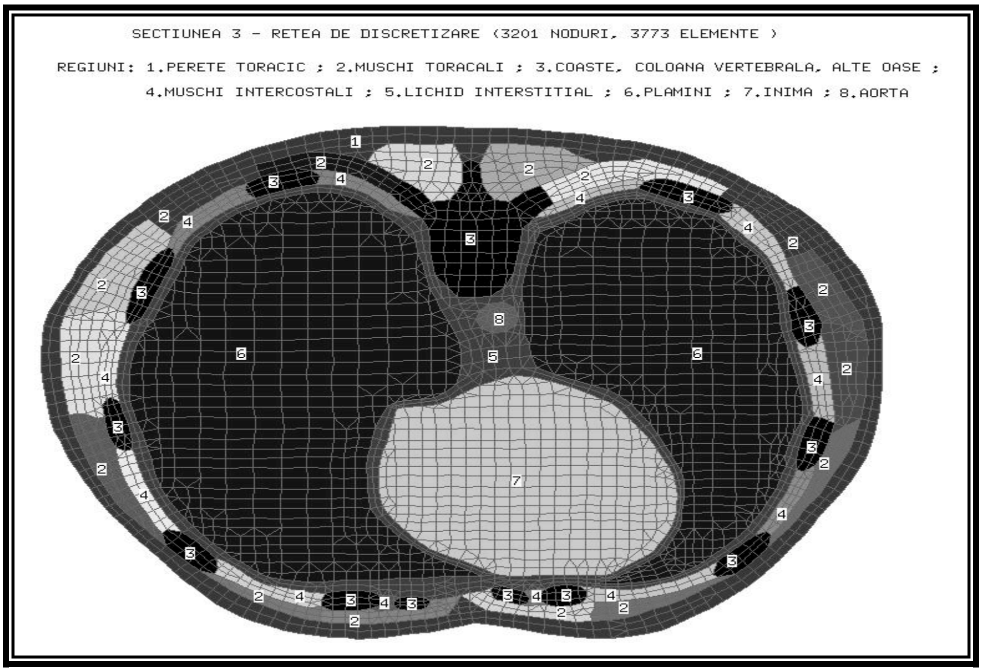

Fig. 2.1. - Mesh of the crossection no. 3

The electrodes were considered as a superconductive media and the exterior as a perfect insulator. In order to simulate the anisotropy of the thoracic muscles and predicting the direction of the current density in the vicinity of the electrode, we assigned isotropic resistivities as follows: the transverse resistivity for the muscles underneath the electrodes and the longitudinal resistivity for the muscles far apart from the electrodes.

The resistivities of the organs and tissue were assigned based on Table 2.1.

Table 2.1

Organs and tissues	Resistivity (Ω cm)
Thoracic wall	2300
Thoracic muscles	transverse 2300 longitudinal 150
Ribs, backbone, other bones	16600
Intercostal muscles	transverse 2300 longitudinal 150
Interstitial fluid	150
Lungs	1100
Heart (myocardium)	230
Esophagus	200

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 $V_+ = 120V$, the negative one $V_- = 0V$) and Neumann $\partial V/\partial n = 0$.

After several tests, we chose the optimal mesh with 3201 nodes.

For each crossection of the thorax, we tested 9 positions for the positive electrode, varying its angle α_1 from 3,1° to 87,1°, and 6 positions for the negative electrode, varying its angle α_2 from 1,5° to 15,62° (next to the cardiac apex).

Comparing all the 15 tested positions, we found a minimum value of the ratio R for α_1=30,04° and α_2=2,4° (Table 2.2).

Table 2.2.

No.	**α_1 (°)**	**$\lvert J_{dom} \rvert_{max}$ (A/m^2)**	**$\lvert J_{ini} \rvert_{max}$ (A/m^2)**	**$\lvert J_{tor} \rvert_{max}$ (A/m^2)**	**R**
1	3,1	472,69	69,24	472,69	6,8
2	19,55	342,13	58,28	180,83	3,1
3	30,04	185,05	63,94	146,94	2,29
4	38,5	209,56	60,35	142,32	2,35
5	45,67	220,65	60,57	146,08	2,41
6	66,6	264,2	54,58	136,37	2,5
7	72	260,17	56,37	142,05	2,52
8	75,57	222,9	55,45	141,48	2,55
9	87,1	177,11	52,96	138,22	2,6
	α_2 (°)				
1	1,5	185,05	63,94	146,94	2,29
2	2,2 (L)	200,58	67,84	135,19	1,99
3	2,4 (R)	184,29	81,92	137,62	1,67
4	3,57	241,15	63,05	138,35	2,19
5	13,9 (R)	282,82	30,04	172,91	5,68
6	15,62 (L)	205,85	38,71	148,7	3,84

Comparing the crossections of the thorax, we obtained the following results:

Table 2.3.

No	**α_1 (°)**	**α_2 (°)**	**$\lvert J_{dom} \rvert_{max}$ (A/m^2)**	**$\lvert J_{ini} \rvert_{max}$ (A/m^2)**	**$\lvert J_{tor} \rvert_{max}$ (A/m^2)**	**R**
1	88,2 (R)	1,78 (L)	148,3	42,41	89,04	2,09
2	86,4 (R)	3,14 (R)	171,4	57,52	108,92	1,87
3	30,04 (L)	2,4 (R)	184,29	81,92	137,62	1,67

We found out that the maximum values of the current density were in the interstitial fluid (close to the cardiac apex and the back bone and all around the lungs) and the minimum values were inside the lungs and the bones.

For the first two crossections we obtained similar optimal positions of the electrodes, but there are considerable differences between the current densities and the ratio R. Anyway, the maximum values of the current density in the cardiac muscle are to small (with respect to the threshold [3]) to obtain an efficient stimulation.

For the third crossection (with more important changes of the anatomical structure), the optimal position is totally different from that one obtained in the case of the first two crossections (the negative electrode is placed on the right parasternal area, the positive electrode is placed under the left shoulder). We obtained a double value of the current density in the heart and a ratio R=1,67, that means a better stimulation of the heart with less side effects on the thoracic wall.

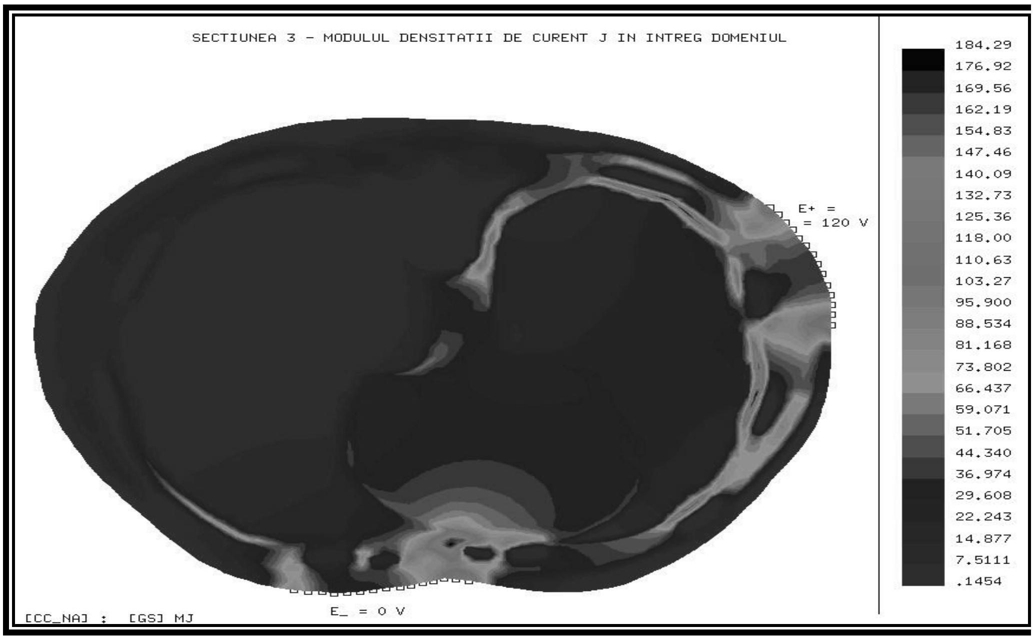

Fig. 2.2. – The current density for the crossection no. 3

The final conclusion of the study is that the efficacy of the medical procedure is increased and the negative effects on the patient's thorax are reduced at the same time with the descent of the transthoracical level from the top to the bottom of the sternum.

.... CONCLUSIONS

The main conclusion of this paper is that the numerical modelling in external 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, stimulation 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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