3 차원 유한요소 모델을 이용한 임피던스 카디오그래피에서의 여러 전극형태

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Various Electrode Configurations in Impedance Cardiography by a Three-Dimensional Finite Element Model

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1. INTRODUCTION

For most biomedical instrumentation, one kind of transducer is generally used between instrument and object, which can be muscle, blood vessel, or body surface etc.. In impedance cardiography, biopotential electrodes are used to measure the potential difference on the body surface. Since the sensitivities of the impedance changes to the various origins vary widely as shown in Kim et al. [1], each electrode configuration will pick up a different signal depending on the locations and dimensions of both the potential and current electrodes. Another importance of the electrode configuration is that this is a very first part of the input to the instrument. Thus even a very small impedance change due to an undesirable origin can deteriorate considerable the accuracy of the output signal especially if the output is a derivative like dz/dt.

Mohapatra [2] and Sakamoto [3] studied experimentally various electrode configurations of both potential and current band electrodes, and with spot electrode arrays respectively. However, it is almost impossible to investigate optimal electrode configurations with experimental studies since the origins of the impedance change can not be identified. The numerical method has an advantage over the experimental method in the study of electrode configurations. To date, there has been no three-dimensional studies on the various electrode configurations.

2. MODEL DESCRIPTION

The model of the thorax and neck was constructed from horizontal cross-sections taken from anatomical maps [4] using eight-node trilinear cubic elements. The three-dimensional model consists of 22 elements on each of 29 layers. The layers were parallel to the x-y plane and nonuniformly spaced for a total of 880 nodes and 658 elements. The constant potentials, 202 and 0mV, measured between the current electrodes on the author using a conventional impedance cardiograph were assigned to the current electrodes to drive the solution.

Each circumferential potential measuring electrode was simulated by ten thin elements having high conductivities of 100 S/m as shown in Fig.1. Thus a layer containing a potential electrode has 10 electrode elements in addition to the 22 elements of other layers. The height of the model was 47.5 cm, extending 5 cm beyond each current electrode. The widths of the potential and current electrodes were 0.7 and 1.2 cm respectively. The distance between the potential and the current electrodes on the neck and on the abdomen were 4 and 6 cm respectively. Fig.2 shows the levels of the 29 layers.

The governing equation of this study is Laplace's equation. Then,

$$\nabla \bullet \mathbf{J} = 0$$

where **J** is current density and V is potential.

$$\partial/\partial x(\sigma_x \partial V/\partial x)+\partial/\partial y(\sigma_y \partial V/\partial y)+\partial/\partial z(\sigma_z \partial V/\partial z) = 0$$

where σ_x, σ_y, and σ_z are conductivities of material in the x, y, and z direction respectively. This is the generalized form of Laplace's equation and can be solved subject to the boundary conditions. The assumptions and boundary conditions can be found in Kim et al. [1].

3. RESULTS

In this study, the thoracic model was modified to provide the major arteries with blood volume increase of 30 ml during systolic period. And the blood volume change was calculated for various electrode configurations using the following equation.

$$\Delta V = -\rho(L / Z)^2 \Delta Z$$

where ΔV = the blood volume change (ml)

ρ = the resistivity of blood (Ω-cm)

L = distance between potential electrodes (cm)

Z = basal impedance of the thorax (Ω)

ΔZ = impedance change (Ω)

In the above equation both ρ and L are known, and Z and ΔZ were calculated from the program for each electrode configuration. The blood volume increase was calculated to be 24 ml for the conventional electrode configuration. The following five electrode configurations were investigated for the blood volume change in the major arteries.

1) Wide current electrode on the abdomen

The width of the abdominal current electrode was increased from 1.2 cm to 1.8 cm while the distance between the potential electrodes remained unchanged. The blood volume change calculated in this configuration was 26.3 ml compared to 24 ml in the conventional configuration while the actual blood volume change was 30 ml. Therefore this configuration is to be preferred to the conventional one since 26.3 ml is closer to the actual blood volume change of 30 ml.

2) Narrow potential electrodes

The width of both the potential electrodes was reduced from 0.7 cm to 0.35 cm while the distance between the potential electrodes was maintained at 25 cm. The blood volume change was calculated to be 27.5 ml, which is closer to the actual blood volume change of 30 ml. Thus this configuration is also preferred to the conventional one. However, if the width of a potential electrode is too narrow, the interface impedance between skin and electrode increase, resulting in a reduced common mode rejection ratio (CMRR).

3) Partial band current electrode on the forehead

For a person with a short neck or a neonate, the current electrode is put on the forehead instead of the neck to avoid high current density near the potential electrode on the neck. This location is desirable as it makes the current distribution more uniform between the potential electrodes. To simulate this arrangement the band current electrode on the neck was replaced by a partially encircling band electrode and moved up by 2.5 cm. The blood volume change in the large arteries was calculated to be 26.4 ml. Therefore this configuration is preferred to the conventional one in terms of uniform current distribution and more accurate estimation of the blood volume change.

4) Partial band potential electrodes on the anterior neck and thorax

For this specific configuration, the electrode elements on the back were replaced by the muscle or thoracic wall in order to modify the band electrode to a semi-circular electrode. The blood volume change was found to be 25.6 ml.

5) Partial band potential electrodes on the posterior neck and thorax

This configuration was investigated to see if there were any significant effects on both basal impedance (Z) and impedance change (ΔZ) since this configuration can be used in some surgical procedure in which the full band electrodes cannot be applied. ΔZ was relatively unchanged compared to that of the conventional configuration. The blood volume change was calculated to be 24.4 ml, which is approximately the same as that of the conventional one. Hill and Lowe [5] showed from measurements on human that this configuration did not significantly affect the calculated value of the stroke volume.

4. DISCUSSION

All the electrode configurations investigated in this study except the partial posterior one are preferable to the conventional one. The narrow potential electrode (ΔV=27.5ml), the current electrode on the forehead (ΔV=26.4ml), and the wide current electrode (ΔV=26.3ml) configurations were all superior to the conventional one (ΔV=24ml) in measuring the actual blood volume change (30ml). If these three electrode configuration were adopted simultaneously, the calculated blood volume change would be closer to the actual one thus they will give us more accurate measurement of stroke volume in impedance cardiography.

Using this model we can apply this technique to the problems associated with cardiac defibrillation, optimal electrode configuration for impedance pneumography in the future.

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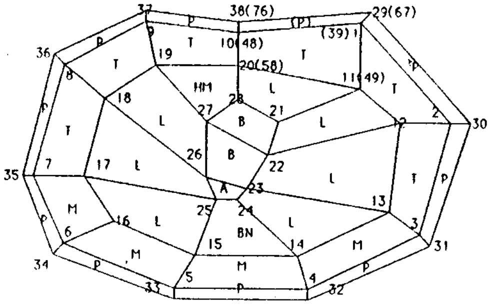

A-Aorta B-Blood BN-Bone HM-Heart muscle L-Lung
M-Muscle T-Thoracic wall P-Potential electrode

Fig.1 A grid containing the potential electrode at the level of heart.

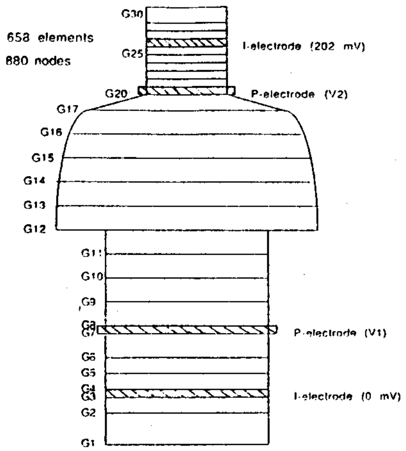

Fig.2 The levels of the 29 layers of the model