MEASUREMENT OF THE IMPEDANCE OF A VOLUME CONDUCTOR WITH VARYING CONDUCTIVITY BY IMPLEMENTING ELECTRICAL IMPEDANCE TECHNIQUES

Mahjabin Mobarak

***Abstract*—**Different sorts of electrical impedance method have been utilized by the analysts in bioimpedance estimation. Tetrapolar (4-electrode) impedance estimations (TPIM) technique may be a cheap and basic procedure. Focus Impedance Measurement (FIM) technique which reduces the negative sensitivity zone in TPIM is accomplished by combining two orthogonally set Tetrapolar (4-electrode) impedance estimations (TPIM). Recently proposed 4-electrode FIM and 6-electrode TPIM where the electrodes are put front and back increase the sensitivity in the deeper zone. Here we have inserted a rectangular object of different conductivity inside the rectangular volume conductor and measure the total transfer impedance and percentage of change of the total impedance by implementing Comsol Multiphysics software simulations which use finite element method. Conductivity of the volume conductor is taken 1.2 S/m and conductivity of the object is taken -0.12 S/m, 1.2 S/m and 12 S/m. This variation of conductivity provides us an idea how these different conductivities of inserted object have impact on the total impedance. This measurement is useful in implementing the two newly proposed method for measuring the impedance of different deeper zone human organs specially lung, stomach, heart, liver whose impedance changes for various conditions. These two newly proposed techniques can be implemented to detect the disorders of these organs implementing very cheap and non-invasive electrical impedance measurement devices.

***Keywords*-** COMSOL Multiphysics, Focused Impedance Method (FIM), Tetrapolar (4-electrode) impedance measurements (TPIM), Volume conductor.

I. INTRODUCTION

Each component of the human body contains an electric property related with the resistance against a substituting current stream, are called bioimpedance. Subsequently electrical impedance measuring strategies have pulled in researchers all over the world for a long time for physiological study and diagnosis as human body could be a volume conductor [1,2]. In ordinary tetra-polar electrical impedance estimation procedure, a pair of electrode is implemented to infuse current into a volume conductor and another pair of electrode is used to measure the voltage. From the property of Ohm's law, he extent of the deliberate voltage to the associated current gives the transfer impedance [3], which is measured in ohms. The bioimpedance measurement technique is noninvasive, nonionizing additionally the instrumented is simple and low cost.

Sensitivity is defined by the contribution of the measured transfer impedance owing to deviation in conductivity of a point inside the volume conductor. According to Reciprocity theorem, if the current and the voltage electrode pairs are interchanged in the system, the detected values remain the same which is applied to find the point sensitivity inside the volume conductor. Thus, the sensitivity is attained by considering only current driven through both the pairs of electrodes. Hence, if we assume J1 and J2 as the current density vectors at a point within the volume conductor due to application of current I across the compelling and sensing electrode pairs respectively, then the sensitivity of the point is expressed as [4],

$$Sensitivity = \frac{J1.J2}{I^2} \text{..................(1)}$$

TPIM implemented one pair of electrodes for application of current and another pair for measuring voltage. Electrical Impedance Tomography (EIT) implemented the principle of TPIM where array of electrodes is used. The setup is more complex and

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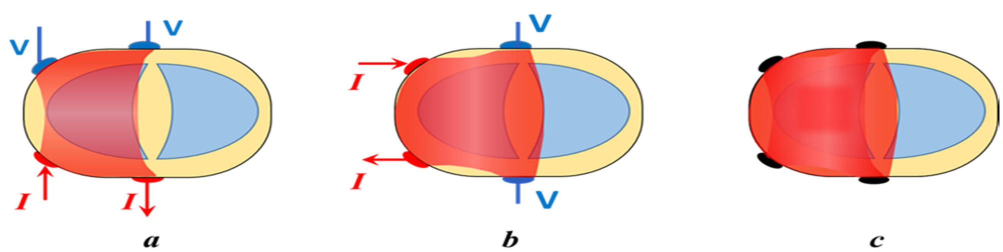
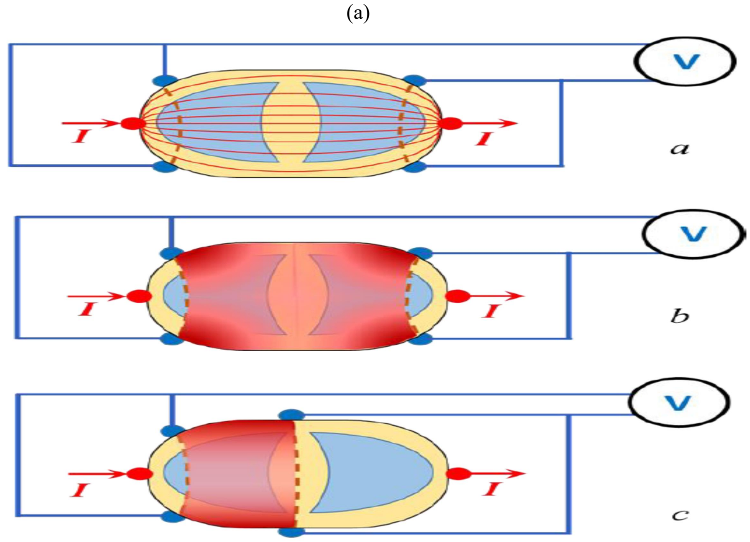
impedance is represented in image [5]. However, EIT has exceptionally complex configuration and costly. An invention of group at the University of Dhaka named as Focused Impedance Method (FIM), is a link between TPIM and EIT where two TPIM measurements techniques are applied orthogonally near a section of interest [6]. The sum of the transfer impedances has improved sensitivity within the zone of interest and hence can measure the variation in transfer impedance of a indicated target zone inside a volume conductor reducing the contribution from the adjacent regions [7]. Most of the studies done so far implementing FIM used electrodes on single side of the body taking sensitivity down to a small depth [8]. In recent times Rabbani proposed some arrangements of electrodes intended probing deep within the body, aiming different parts of the human body of interest [9]. One of these used four electrodes

two toward the front of the body and two at the back, along a level plane as displayed in Figure 1(a). Two current electrodes are placed on side of the volume conductor and two sets of potential electrodes are utilized rather than one sets in ordinary TPIM. One pair of these two pairs is positioned in front, and the other pair is positioned behind, in opposition to the pair in front. A standard TPIM procedure was then used to short the front and back potential electrodes that corresponded. This was called a 6-electrode TPIM because it was expected to have higher sensitivity at the front and back, as well as moderately high sensitivity in the central deep region. This was expected to enhance the sensitivity at deeper regions. Roy et al.'s simulation and phantom experiments on a cylindrical phantom supported Rabbani's predictions [9,10]. Mobarak et. al performed simulated sensitivity measurements using COMSOL for 4-electrode configurations which supported the prediction, giving enhanced sensitivity in the deeper regions [11,12].



(a)

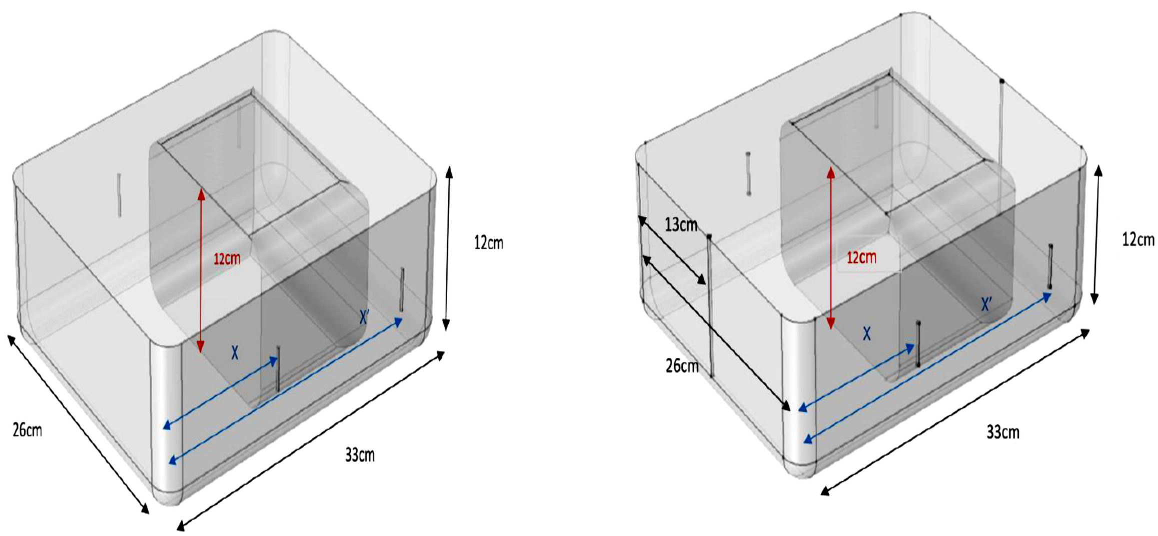


(b)

Figure 1: Probing deeper regions of lungs using TPIM /FIM using electrodes at front and back of thorax (A qualitative proposal from Dhaka University). (a) 4-electrode TPIM / FIM (b) 6-electrode TPIM [9].

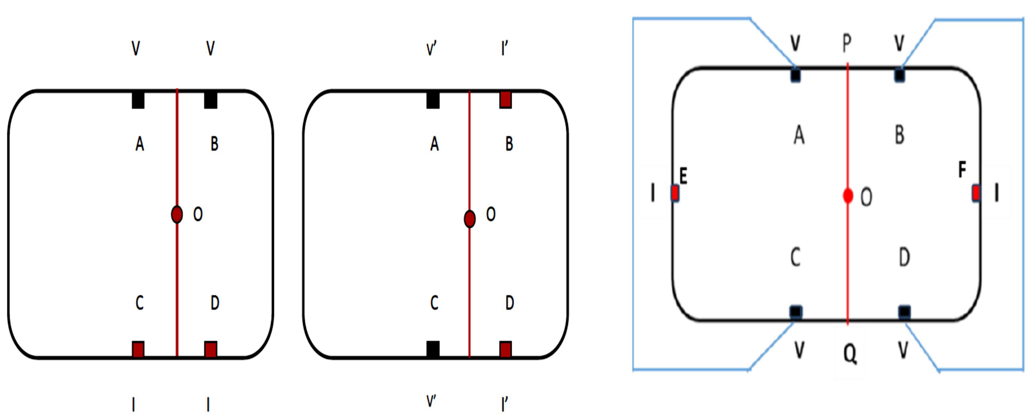
II. Materials and Methods

A rectangular box worked of plastic and aspect 33 cm x 26 cm x 12 cm was utilized in this work. Electrodes made of stainless steel of 3 cm length and 0.3 cm diameter were set. For 6-Electrode 12 cm long current electrodes are put on two side of the apparition. Places of front and back anode are 13 cm and 28 cm from the left i.e., 15 cm separated (figure 2(a) and (b)) .For this simulation, a rectangular object with length 13 cm, width 18 cm and height 12 cm (Figures 1(a) and 1(b)) was inserted inside the box. One side of the rectangle was curved with 2cm radii. The lower edge of the object was placed at a similar height of the box. It was put towards the left half of the volume conductor, its left edge set a way off of 6 cm from the left surface and the front edge put a way off of 4 cm from the front surface and 4 cm from the back surface as appeared in Figure 2(a) and (b).



(a) (b)

Figure 2: The simplified model of volume conductor and an embedded object as used in the simulation (a) 4-electrode configuration (b) 6-electrode configuration.



(a) (b)

Figure 3: Cross sectional view showing scheme for (a) 4-electrode configuration: 1st step- measuring Tetrapolar Impedance-1 (TPIM 1, left hand figure), 2nd step – measuring Tetrapolar Impedance-2 (TPIM 2, right hand figure), 3rd step – averaging the above two transfer impedance values to get FIM. (b) 6-electrode TPIM.

Figure 3 (a) and (b) shows the potential and current electrodes configuration of 4-electrode configuration and 6-electrode TPIM respectively. In figure 3 A-B, C-D electrodes are front and back electrode pair. E-F electrode pair is current electrode for 6-electrode TPIM (figure 3(b). O indicates the centre point of the zone of interest. Therefore, if current density vectors Jec and Jec2, Jec3 and Jec4 at a point within the volume conductor for injection of current I and current I' shown in the figure 3(a) then the sensitivity at the point is represented by the following equation,

$$FIMSensitivity = \frac{Jec.Jec2 + Jec3.Jec4}{2I^2} \ldots (2)$$

In case of 6-electrode TPIM if current density vectors Jec and Jec2 for injection of current I as shown in figure 3(b) then the sensitivity is given by the following equation,

$$TPIM\ Sensitivity = \frac{Jec.Jec2}{I^2} \ldots (3)$$

For Comsol simulation the electric current interface in AC/DC module is applied. In this study 1 A alternating current was applied through the electrode pairs.

III. RESULTS AND OBSERVATIONS

The geometrical parameters appropriate for the chosen model are shown in Table I. Here the volume and cross-section are is 27.27% which close to one third of the total.

Table I: Geometrical parameters appropriate for the chosen model.

Volume of whole volume conductor (including object)	10296 cm^3
Volume of the object	2808 cm^3
Object volume with respect to whole volume	27.27 %
Horizontal Cross-Sectional Area of Volume	858 cm^2
Horizontal Cross-Sectional Area of Object	234 cm^2
Area of Object with respect to Area of Volume conductor (cross-sectional)	27.27%

Table II : Simulation results for σ_v=1.2S/m, σ_o is varied.

Conductivity of the object in S/m		TPIM1	TPIM2	FIM	6-electrode TPIM
0.12	Total impedance Ω	4.23	4.42	4.32	8.8
	Object impedance Ω	1.22	0.71	0.963	2.07
	% Contribution of object	28.77	16.09	22.29	23.56
1.2	Total impedance Ω	1.17	1.96	1.57	3.37
	Object impedance Ω	0.94	1.12	1.03	1.85
	% Contribution of object	80.25	56.94	65.65	54.83
12	Total impedance Ω	0.16	0.28	0.22	1.12
	Object impedance Ω	0.090	0.217	0.15	0.35
	% Contribution of object	55.97	77.88	69.87	31.64

In this work, electrode separation of 4-electrode configuration is 15 cm and for 6-electrode TPIM electrode separation between potential electrodes is 15 cm. Conductivity of the background σ_v is taken 1.2 S/m (0.9% saline water) [13]. Conductivity of object σ_o is taken same as the background (1.2 S/m), ten times less (0.12S/m) and ten times more than that (12S/m). This investigation edifies us how this wide variation of conductivity influences in level of contribution of the object in total transfer impedance.

Table II shows the simulation results of total impedance of the volume conductor including the object with various conductivity, impedance of the object and percentage contribution of the object in total impedance.

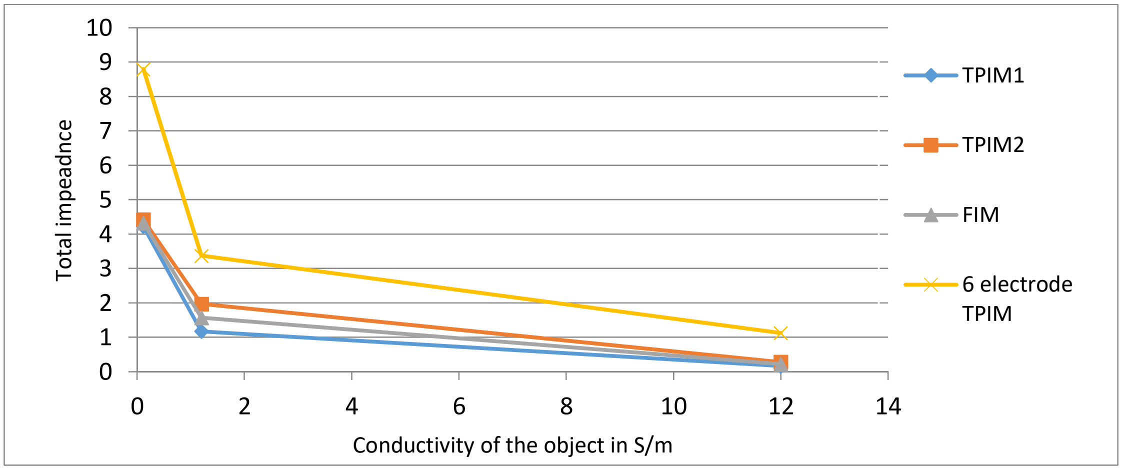


Figure 3: Total impedance of the phantom model for different configuration with various conductivity of the object.

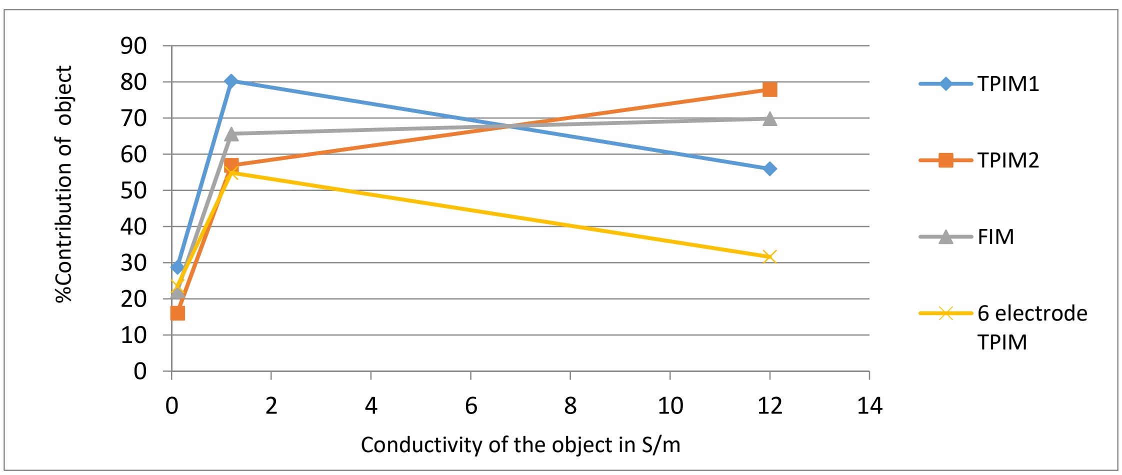


Figure 4: Comparing the percentage contribution of object for different configuration with various conductivity of the object.

From figure 3 total impedance of the volume conductor is higher for lower conductivity. As the conductivity increases the impedance decreases in all the configurations. For 6-electrode TPIM impedance is slightly higher than the 4-electrode configurations. From the above investigation shown in figure 4 it is observed that for TPIM 1 and 6-electrode TPIM the contribution of the object is highest when the object has a similar conductivity as the background. In case of TPIM 2 the contribution of the object shows increment as the conductivity increases though the total impedance decreases as the conductivity increases. A further observation is the impedance of the object in highest when the conductivity is same as the background.

IV. DISCUSSION

This study has measured the contribution of an inserted object with different conductivity. In table 2 it is observed as the conductivity of the object increases the total impedance decreases in all the cases. But the impedance of the object does not follow this in case of TPIM 2 where it is observed that the object impedance is less for 0.12 S/m than 1.2 S/m. From the TPIM 2 configuration showed in figure 3(a) (right side) the current and potential electrodes pair were placed front and back so the current line mainly passing through the region where the object was placed According to the characteristics of current lines, they avoid any low conductive object in their path. So, the measured impedance of the object is less for lower conductivity for TPIM 2 configuration. In case of the contribution of the object impedance in total transfer impedance when the conductivity is less the percentage contribution of the object is very less, when the conductivity increases to same as back ground the contribution also increases. If the conductivity of the object further increases the contribution of the object also increases for TPIM 2 but in case of TPIM 1 the contribution of the object decreases.

V. CONCLUSION

The techniques which we have suggested and analyzed can easily be adapted for deep probing organs like dynamic functional analysis such as inflated and deflated states of lung where the conductivity of the lung varies during respiration. Also, for other organs like heart, stomach, liver, bladder, these two-sided electrode techniques may be useful as well. Hence to study the deep organs this newly propose two procedures are expected to be suitable and useful.

ACKNOWLEDGEMENTS

The author acknowledges the Dr. K Siddique-e Rabbani, Honorary Professor, department of Biomedical Physics and Technology, University of Dhaka for his active support with the research work.

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