COMSOL Multiphysics® Simulation of Electrical Bioimpedance Impedance in a Simplistic Model of Human Thorax

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INTRODUCTION: Electrical bioimpedance in tissues varies with the ionic concentration of intracellular fluid, extracellular fluid, and dispersion. Performing electrical bioimpedance measurements on human subjects yield a quantitative impedance value but fail to give us insight into the contribution of each tissue to overall impedance or change in impedance with tissue conductivity. This paper describes a simplistic model of human thorax created and analyzed entirely using electrostatics interface in AC/DC module of COMSOL Multiphysics® simulation software to yield information about tissue-specific impedance contribution.

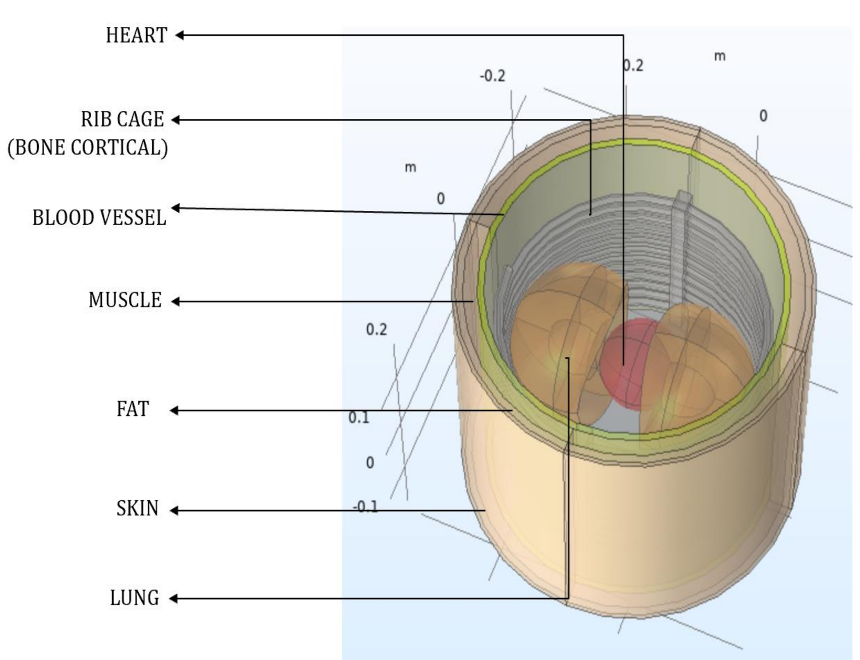

Figure 1. Tissue structures included in the geometric model

Tissue	Conductivity (S/m)
BloodVessel	3.19E-01
BoneCortical	2.08E-02
Fat	2.44E-02
Heart	2.15E-01
LungDeflated	2.72E-01
LungInflated	1.07E-01
Muscle	3.62E-01
SkinDry	4.51E-04

Table 1. Tissue conductivity values at 100 kHz used for simulation

COMPUTATIONAL METHODS:

$$\boldsymbol{J} = \boldsymbol{\sigma E}$$

J: current density, σ : conductivity, E: electric field intensity

Sensitivity maps the change in measured impedance to change in conductivity. The value of sensitivity is used to calculate the overall impedance. Mathematically, it is defined as,

$$S = \frac{J_{ce} * J_{ve}}{I^2}$$

- J_{ce}: current density due to current-driven between the driving electrodes
- J_{ve} : current density due to current-driven between the sensing electrodes
- I : current density due to current electrodes
- $*$: Inner dot product of J_{ce} and J_{ve}

$$\boldsymbol{Z} = \int \boldsymbol{S \rho \, dv}$$

Z : Overall impedance, S: Sensitivity, ρ: Resistivity

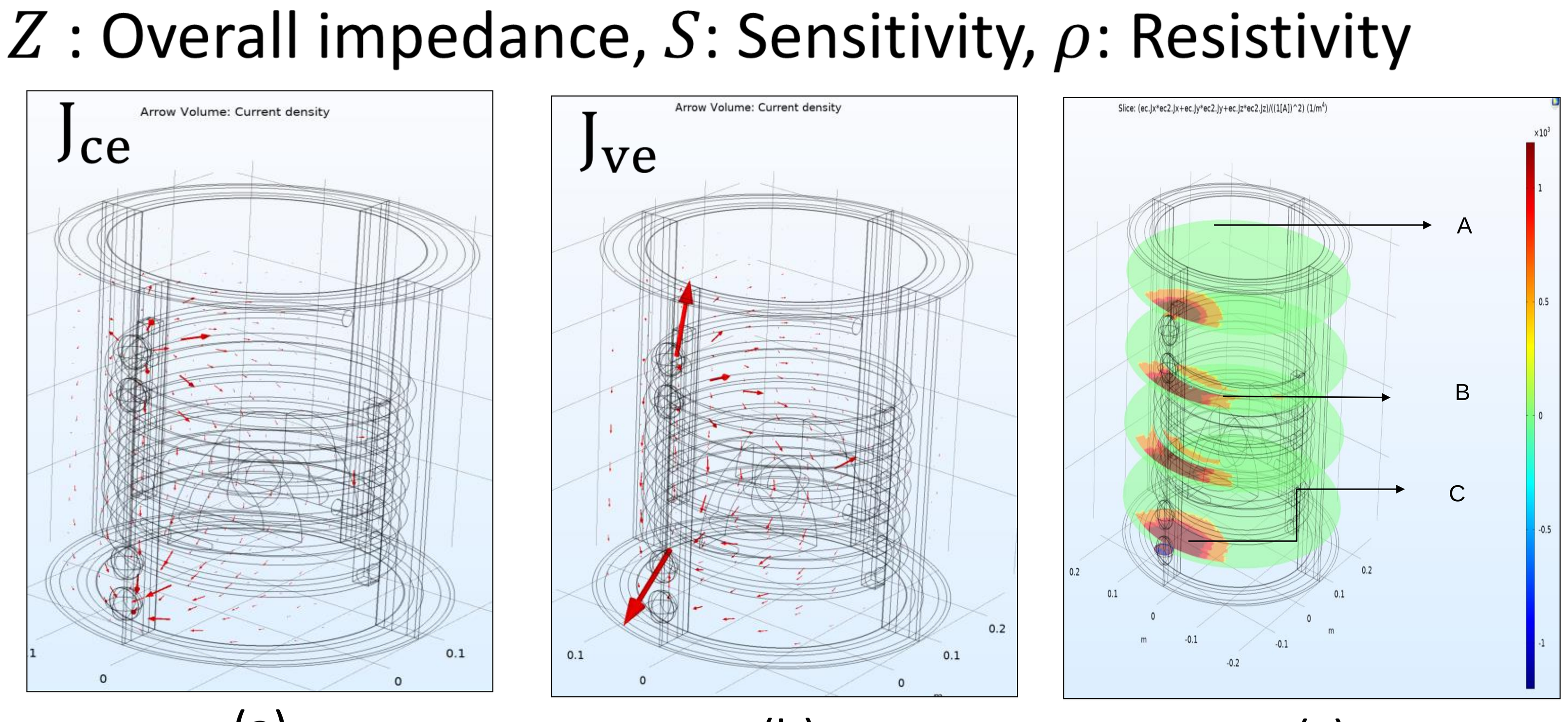

Figure 2. (a) Current density due to driving electrode (b) Current density due to sensing electrode (c) Sensitivity: Conductivity in region C impacts overall impedance most strongly

HYPOTHESIS:

- With an increase in length and width between electrodes, the overall impedance as well as percentage contribution of lungs, should increase.
- The transthoracic overall impedance for a model corresponding to dimensions of an average human thorax should be between 10 – 30 Ω.
- Between inflation and deflation change in overall impedance should be not greater than one percent.

RESULTS: A four-electrode horizontal and crossed configuration was used to measure the overall impedance of the model as well as the percentage contribution of lung tissue for different combinations of lengths and widths. The results were studied for trends in change of overall impedance, maxima, and minima that corresponded well with our hypothesis.

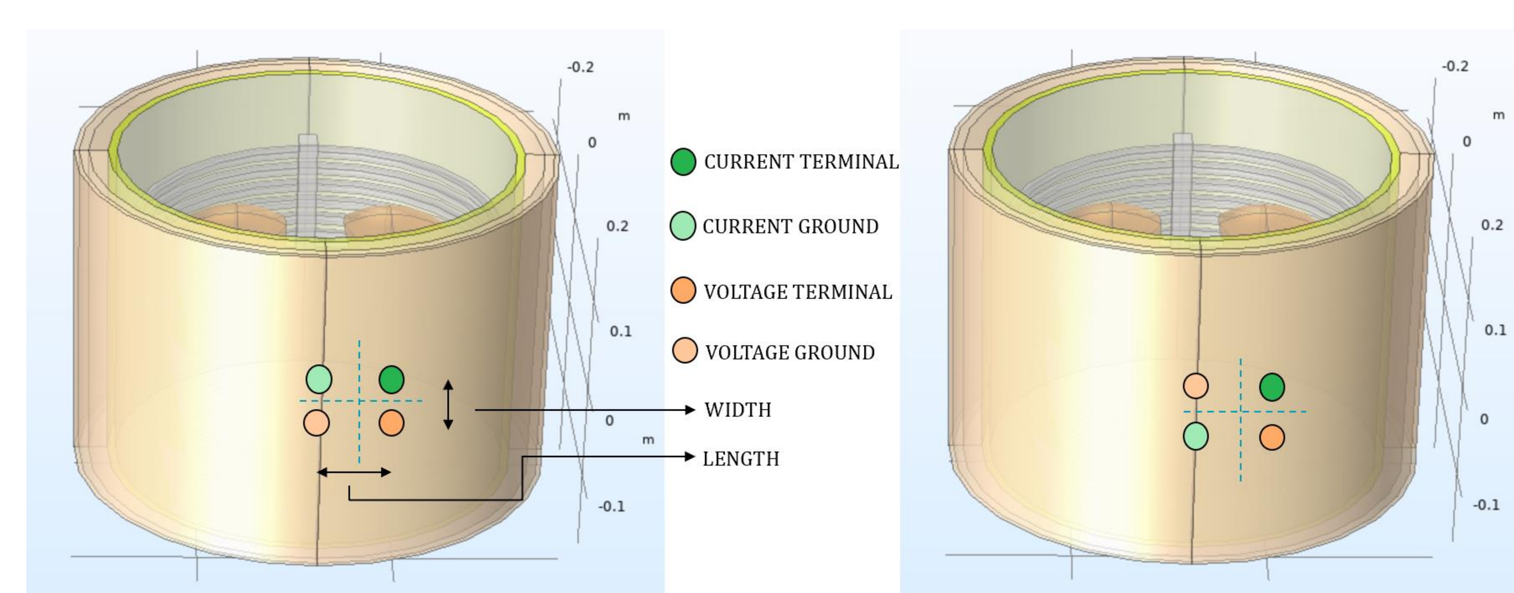

Figure 5. Four electrode configuration used to verify validity of the model (a) Horizontal configuration (b) Crossed configuration

	TI	% LUNG CONTRIBUTION	TI	% LUNG CONTRIBUTION	TI	% LUNG CONTRIBUTION	TI	% LUNG CONTRIBUTION	TI	% LUNG CONTRIBUTION
LENGTH	5		10		15		18.6		51.6	
WIDTH										
3	76.270∠10.886°	0.021547135	85.638∠10.497°	0.113492842	90.775∠9.8562°	0.388543101	92.007∠10.416°	1.093395068	79.914∠12.280°	2.501814451
6	4.7622∠9.3128°	0.311809668	10.024∠5.1720°	0.866011572	14.099∠3.5692°	2.173913043	17.865∠2.8358°	✓ 4.82261405	21.661∠2.0212°	✓ 7.984857578
9	1.4947∠0.93637°	0.863116344	4.4298∠0.94654°	1.649419838	7.3760∠0.57578°	3.375406725	10.737∠0.32214°	✓ 6.468194095	14.138∠0.49931°	✓ 9.889659075
12	0.68564∠0.90900°	1.571232717	2.3752∠0.52529°	2.494737285	4.1752∠0.030507°	4.453918375	7.2746∠0.17876°	7.435047975	10.522∠0.21917°	✓ 10.40771716
15	0.36768∠1.0360°	2.380167537	1.4088∠1.2689°	3.328293583	1.9354∠0.48680°	5.736281906	5.2341∠-0.0087544°	8.031944365	8.2220∠-0.11607°	10.33227925

MINIMA - same ratio between length and width is a case of voltage being measured between points on an equipotential surface

✓ Point of interest

Data follows an increasing trend

TI Total impedance

Points with extremely low magnitude

Data follows an decreasing trend

Table 2. Total impedance and percentage contribution of lung tissue to overall impedance

CONCLUSIONS: The model created shows correspondence with our hypothesis. The results were verified against measurements from a tissue phantom that showed correlation. This model may allow biomedical engineers to rapidly test a hypothesis or study electrode configurations before investing time in developing or procuring a precise model, thus saving them time and resources.

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