The Feasibility of Evaluating the Effect of Curative Mud on the Human Skin by the Means of Electrical Bioimpedance

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European Union
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CENTRE OF EXCELLENCE IN HEALTH PROMOTION AND REHABILITATION

„Quo Vadis Estonian Curative Mud“, 15 November 2018, Haapsalu, Estonia

Presentation outline

- Introduction to the measurement of electrical bioimpedance
- Human skin through the prism of electrical bioimpedance
- Electrical bioimpedance as a tool for monitoring the skin
- Initial results of my measurements of the human skin
- Uncertainties related to the measurement of electrical bioimpedance and the effect of curative mud on the human skin

1. Introduction to the measurement of electrical bioimpedance

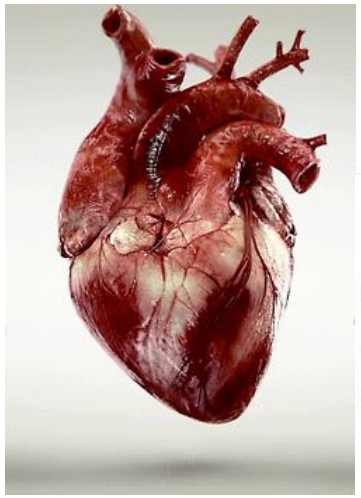
Electrical bioimpedance

Electrical bioimpedance measurement is a method for studying the passive electrical properties of biological matter

Source: Mesa Studios, http://www.mesaschumacher.com/animated-gifs/

- **Object is excited and the response is measured**

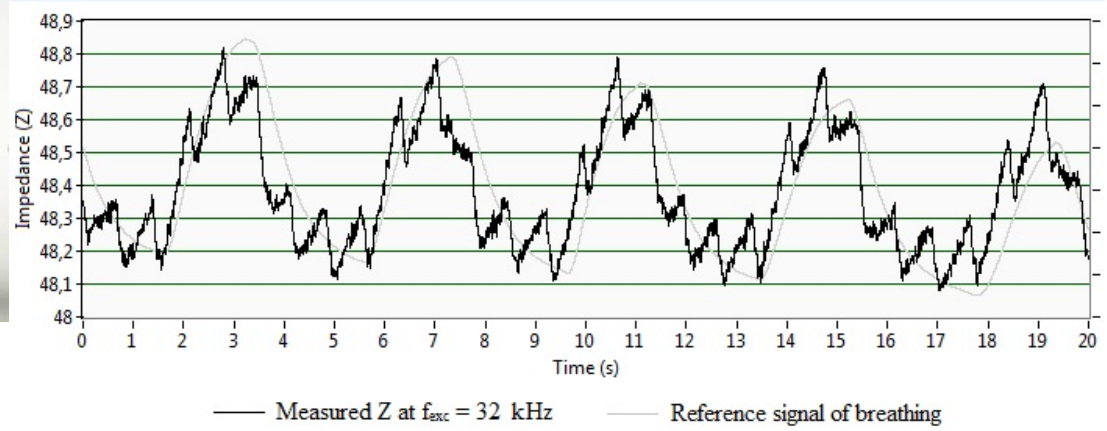
Source: Giphy, https://giphy.com/gifs/creepy-heart-real-HkwWUJfE9R6fu



Electrical bioimpedance is **used to describe the ability of biological matter to oppose electric current flow**

The measurement of **static vs. dynamic parameters** and processes

Source: M. Metshein, „Wearable Solutions for Monitoring Cardiorespiratory Activity," PhD Thesis, Tallinn University of Technology, Tallinn 2018



Electrical impedance

Impedance is expressed as complex impedance (**Z**) that consists of resistance (**R**) and reactance (**X**):

$$\boldsymbol{Z = R + jX}$$

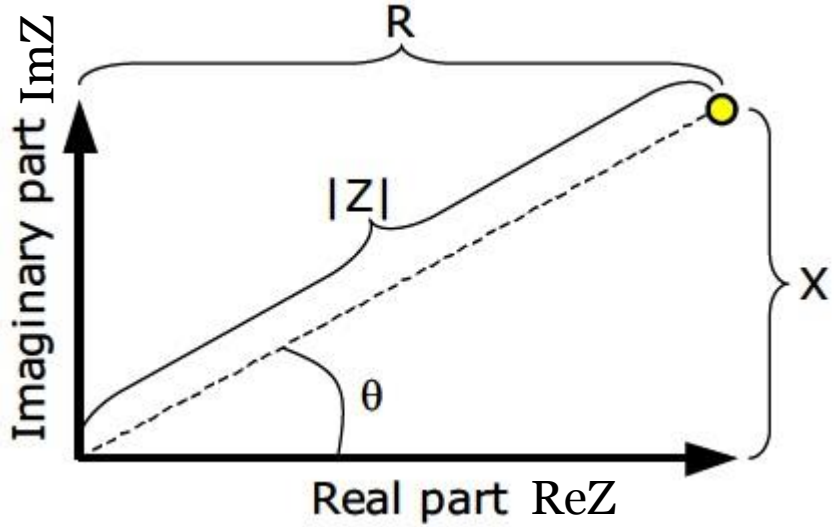
Source: P. Åberg, „Skin Cancer as Seen by Electrical Bioimpedance“, PhD Thesis, Karolinska Institutet, Stockholm 2004

Z can be divided into real (**ReZ**) and imaginary part (**ImZ**)

$$\boldsymbol{Z = ReZ + jImZ}$$

The phase angle can be given as:

$$\varphi = \arctan\left(\frac{ImZ}{ReZ}\right)$$



EBI and its components

The inverse of impedance (Z) is admittance (Y):

$$Z[\Omega] = \frac{1}{Y[S]}$$

Complex term	Real part	Imaginary part
Impedance Z	Resistance R	Reactance X
Admittance Y	Conductance G	Susceptance B

$$Y = G + jY$$

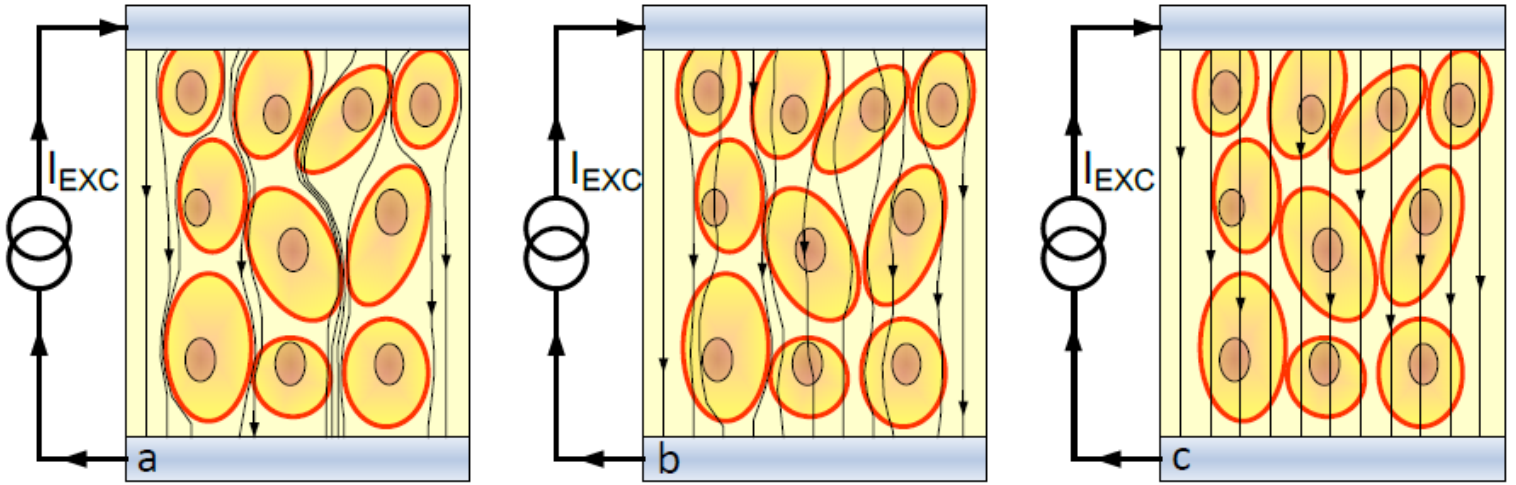
The combined term for impedance and admittance is immittance

Electrical bioimpedance basics

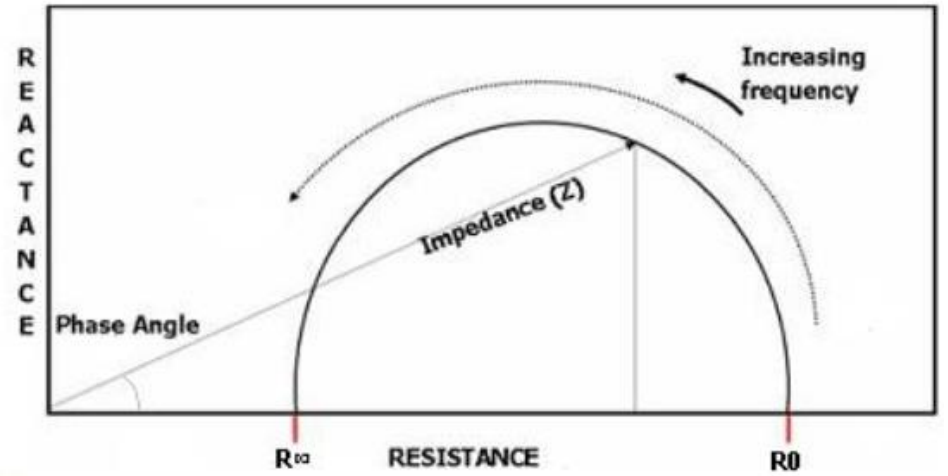
a. **Low frequency currents** are flowing in extracellular space

b. **Medium frequency currents** are penetrating into the cells

c. **High frequency currents** are not opposed by the cell membranes



Source: M. Rist, „Principles for the Design of Impedance Spectroscopy Devices for Identification of Dynamic Bio-Systems“, PhD Thesis, Tallinn University of Technology, Tallinn 2018



Source: S. L. York, L. C. Ward, S. Czernice, „Single Frequency Versus Bioimpedance Spectroscopy for the Assessment of Lymphedema“, Breast Cancer Research and Treatment, Vol. 117(1), 2009

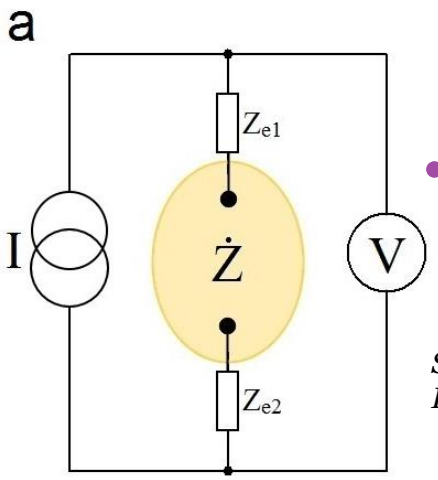
Measurement of EBI

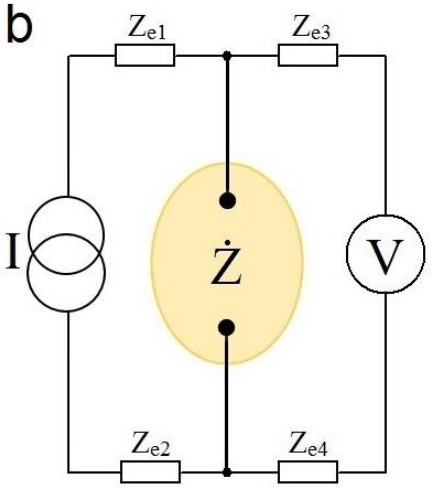
EBI methods use electrodes that are in galvanic connection to object:

- Charge carriers flowing in wires – **electrons**
- Charge carriers flowing in object – **ions**
- Conversation from electrons to ions and vice versa takes place in electrodes

Two classical impedance measurement systems:

- **Two electrodes**
- **Four electrodes**

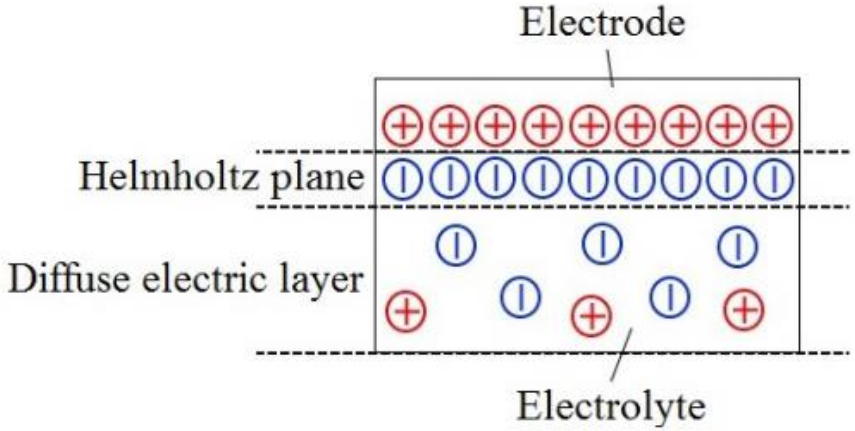




Source: M. Metshein, „Wearable Solutions for Monitoring Cardiorespiratory Activity," PhD Thesis, Tallinn University of Technology, Tallinn 2018

Charge distribution in volume conductors

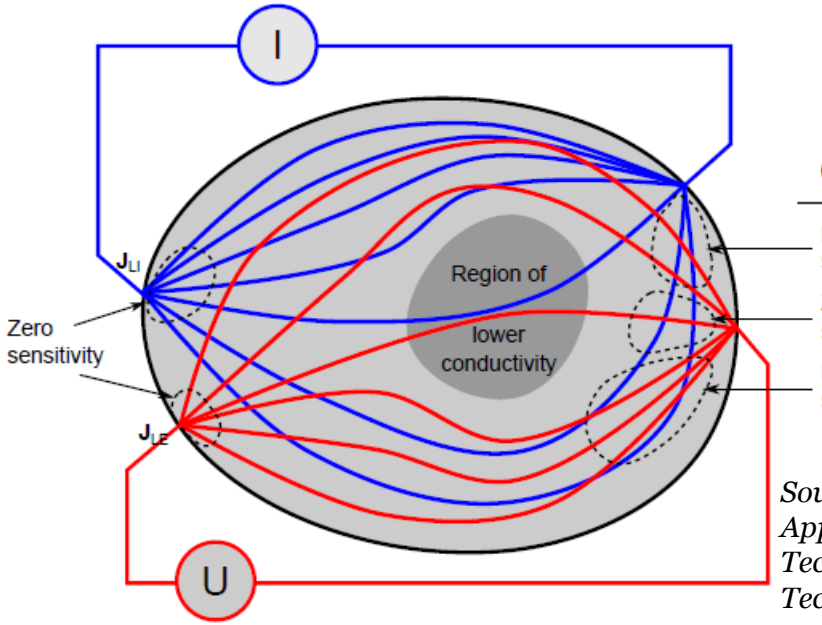
Electrical double layer – the emergence of counterion layer on the surface of an object



Source: M. Metshein, „Wearable Solutions for Monitoring Cardiorespiratory Activity," PhD Thesis, Tallinn University of Technology, Tallinn 2018

Polarization – the effect of electrical double layer

Angle of $\mathbf{J}_{LI}$ and $\mathbf{J}_{LE}$	Sensitivity
$> 90°$	Negative
$0°$	Zero
$< 90°$	Positive
Only other field present	Zero



Source: V.-P. Seppä, „Development and Clinical Application of Impedance Pneumography Technique," PhD Thesis, Tampere University of Technology, Tampere 2014

Sensitivity distribution

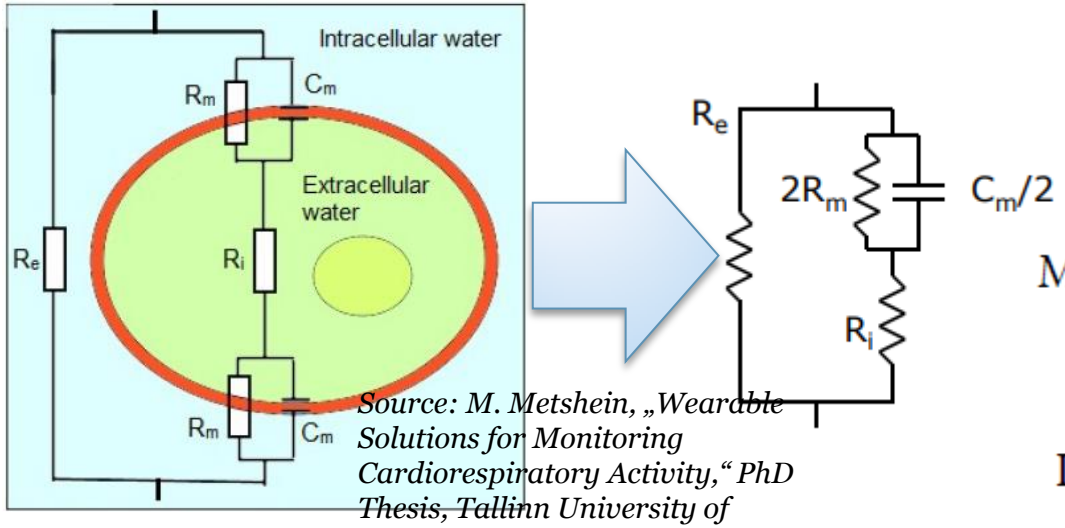
In the areas of negative sensitivity, the ↑ of impedance contributes as ↓ of in the total measured Z

Numerical analysis of impedance data

Problems in analysing bioimpedance spectra:
- the data are multivariate
- the impedance is complex

Cole-Cole modeling

- fitting the impedance dispersion to equivalent circuits

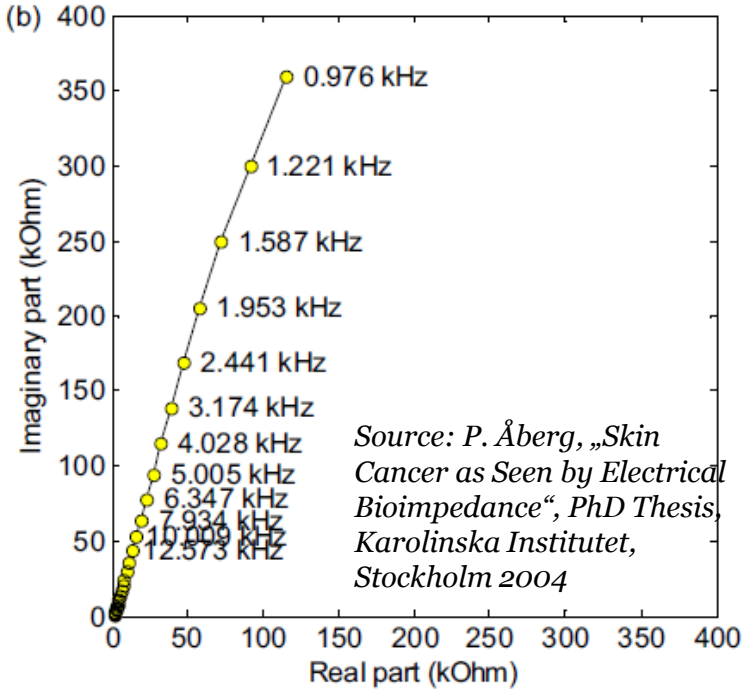


Source: M. Metshein, „Wearable Solutions for Monitoring Cardiorespiratory Activity," PhD Thesis, Tallinn University of Technology, Tallinn 2018

Impedance indexation

- finding the ratio between the impedances at low and high frequency

$$MIX = |Z_{20\,kHz}| \;/\; |Z_{500\,kHz}|$$
$$PIX = \theta_{20\,kHz} - \theta_{500\,kHz}$$
$$RIX = R_{20\,kHz} \;/\; |Z_{500\,kHz}|$$
$$IMIX = X_{20\,kHz} \;/\; |Z_{500\,kHz}|$$



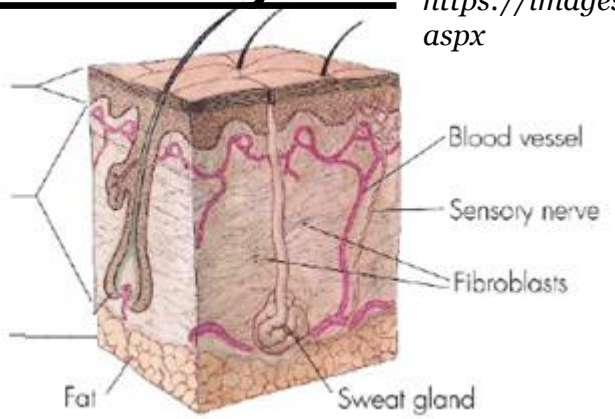
Source: P. Åberg, „Skin Cancer as Seen by Electrical Bioimpedance", PhD Thesis, Karolinska Institutet, Stockholm 2004

2. Human skin through the prism of electrical bioimpedance

The skin and its simple equivalent circuit

The skin generally consists of three layers:

- Epidermis (conductivity ↓↑)
- Dermis (conductivity ↑)
- Hypodermis (conductivity ↓)

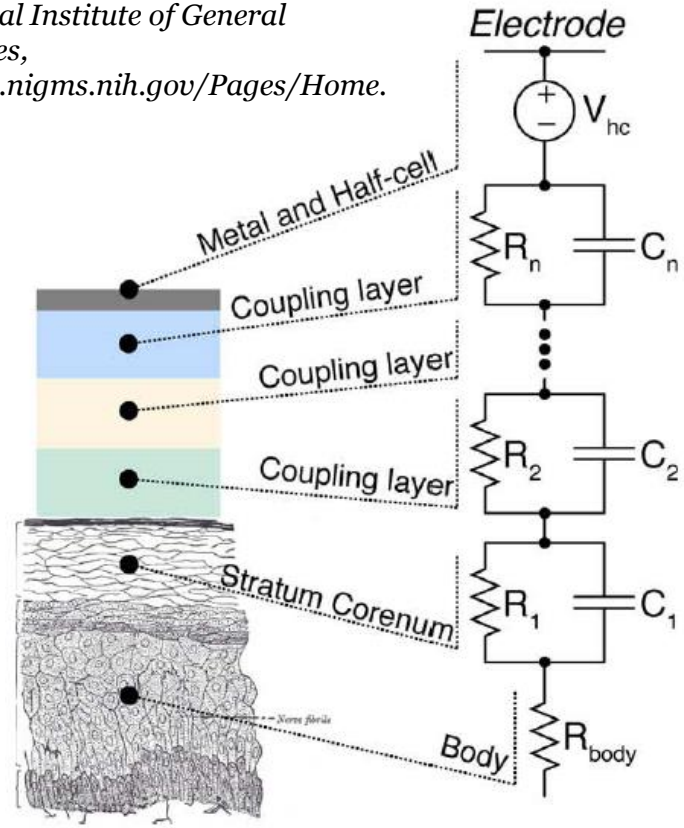


Source: National Institute of General Medical Sciences, https://images.nigms.nih.gov/Pages/Home.aspx

The coupling between skin and electrode can be described as:

✓layered conductive and capacitive structures

✓series combinations of parallel RC elements



Source: Y. M. Chi, T.-P. Jung, G. Cauwenberghs, „Dry-Contact and Noncontact Biopotential Electrodes: Methodological Review," IEEE Rev. In Biomed. Eng., Vol. 3, Oct 2010

More equivalent circuits of the skin

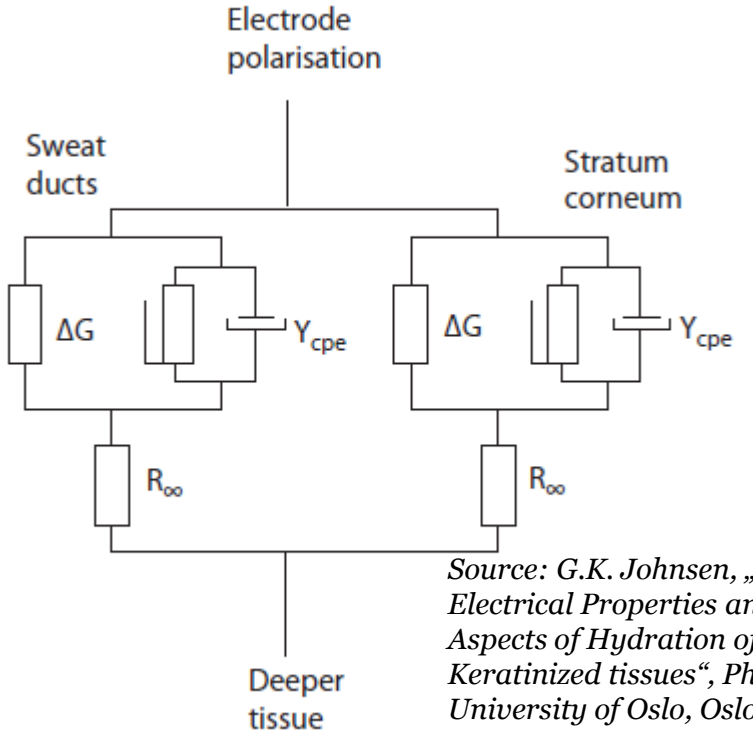
The Cole model (and equation) is found to be able **to model the measurements of skin**

$$Z = R_\infty + \frac{R_0 - R_\infty}{1 + (i\omega\tau)^\alpha}$$

The inclusion of **constant phase element –** frequency dependent imperfect capacitor

The measured impedance can contain contributions from:

- electrode polarization
- stratum corneum
- sweat ducts
- viable tissue



Source: G.K. Johnsen, „Skin Electrical Properties and Physical Aspects of Hydration of Keratinized tissues“, PhD Thesis, University of Oslo, Oslo 2010

Source: Ø. G. Martinsen, S. Grimnes, „On Using Single Frequency Electrical Measurements for Skin Hydration Assessment“, Innov. Techn. Biol. Med., Vol 19(5), 1998

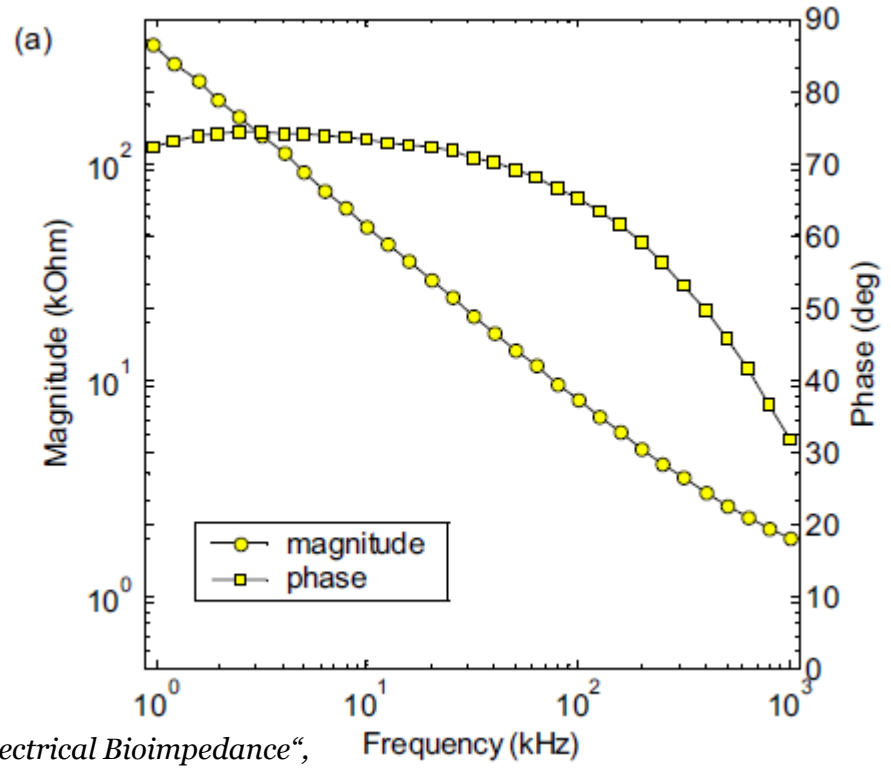
The impedance of healthy skin

The **measured impedance of skin is affected by biological variations**

- Gender
- Age
- Body location

<u>Measuring depth depends on frequency</u>

- **Low frequency measurements (< 1 kHz)** are dominated by stratum corneum
- **High frequency measurements (> 10 kHz)** reflect the deeper layers of the skin



Source: P. Åberg, „Skin Cancer as Seen by Electrical Bioimpedance“, PhD Thesis, Karolinska Institutet, Stockholm 2004

3. Electrical bioimpedance as a tool for monitoring the skin

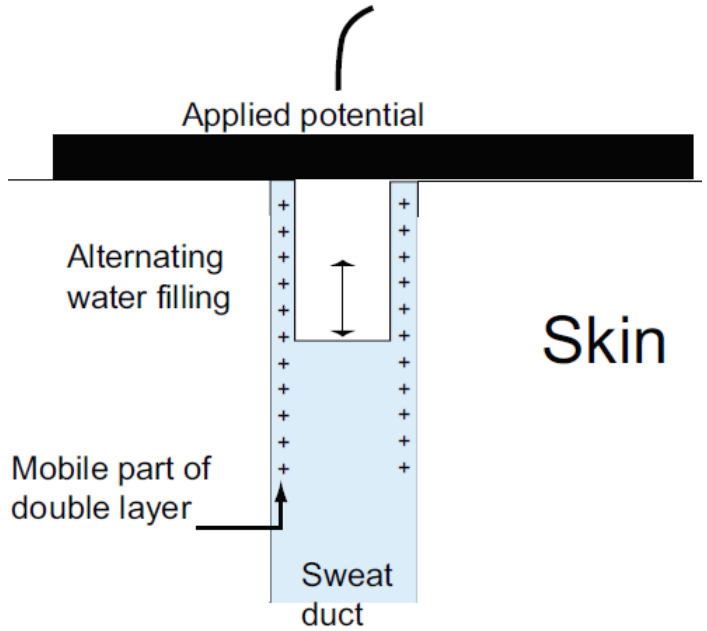
Skin conductance (sweating activity)

Electrodermal activity (EDA) – variations in skin conductance varies with the state of sweat glands in the skin

The source of EDA signal is considered as:

- Endogenous – high conductivity sweat brings the negative potential of the duct in contact with electrode
- Exogenous – the filling of sweat ducts increase the conductance of skin

EDA is a possible tool for predicting hyperhidrosis



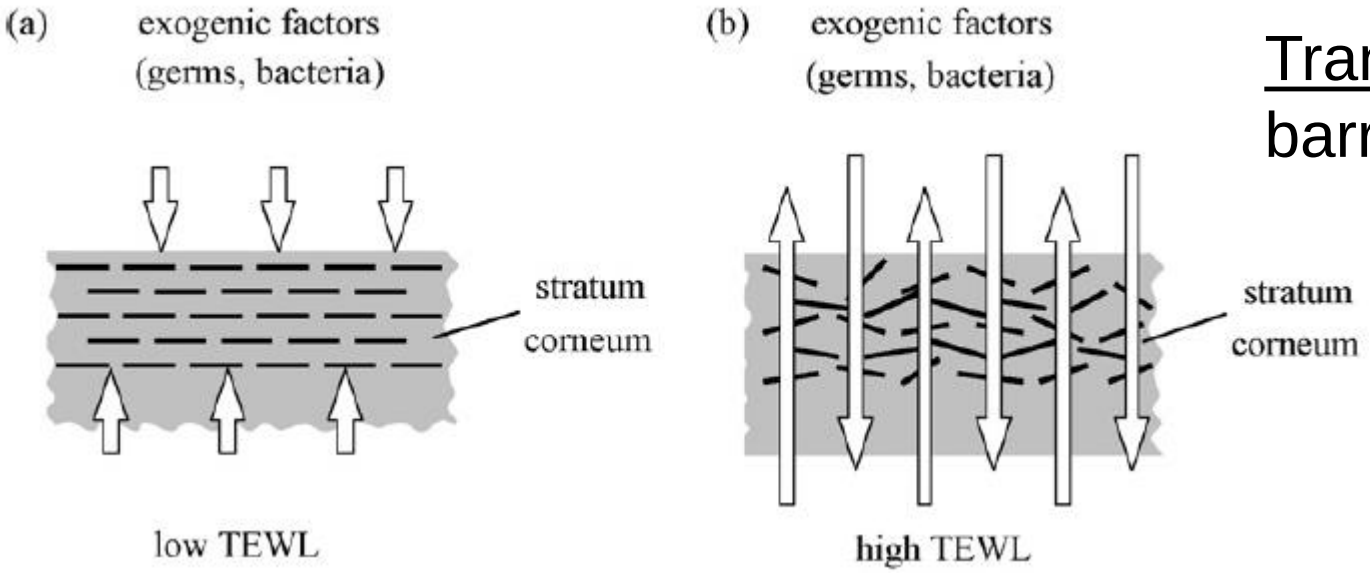
Source: G.K. Johnsen, „Skin Electrical Properties and Physical Aspects of Hydration of Keratinized tissues“, PhD Thesis, University of Oslo, Oslo 2010

Skin hydration (water content)

Hydration is essential for proper function and appearance of the skin [1]

The suggested method today for skin hydration assessment is:

low and single frequency susceptance measurement of stratum corneum



Transepidermal water loss (TEWL) – barrier function of the skin

Source: M. Mündlein, B. Valentin, R. Chabicovsky, J. Nicolics, J. Weremczuk, G. Tarapata et al., „Comparison of Transepidermal Water Loss (TEWL) measurements with two novel sensors based on different sensing principles," Sensors and Actuators A: Physical., Vol. 142(1), March 2008

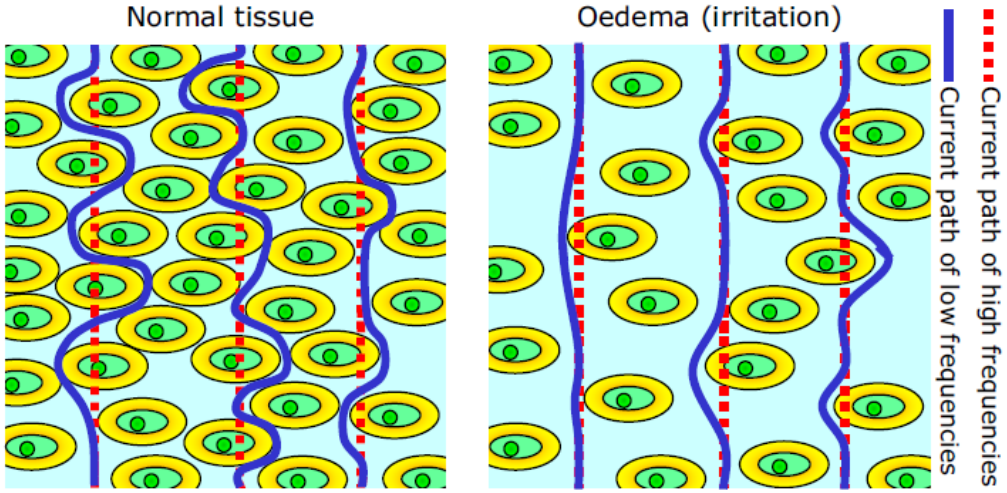
[1] Ø. G. Martinsen, S. Grimnes, „Bioimpedance and Bioelectricity Basics. Third Edition," (Book style), London, Great Britain Academy, 2015, p. 4

Oedema and skin irritation

Oedema – one result of skin irritation:

- accumulation of excessive amount of watery fluid in the extracellular space

Oedema is detectable by using the electrical bioimpedance as:



Source: P. Åberg, „Skin Cancer as Seen by Electrical Bioimpedance“, PhD Thesis, Karolinska Institutet, Stockholm 2004

- For the high frequency,
  the impedance of normal tissue = the impedance of oedema

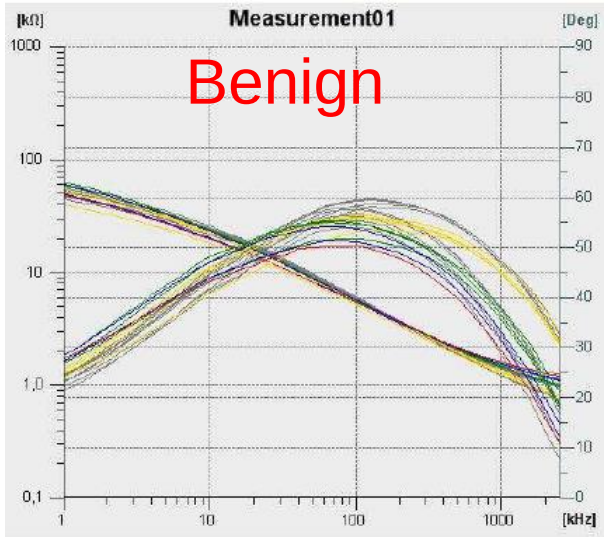
- For the low frequency,
  the impedance of normal tissue > the impedance of oedema

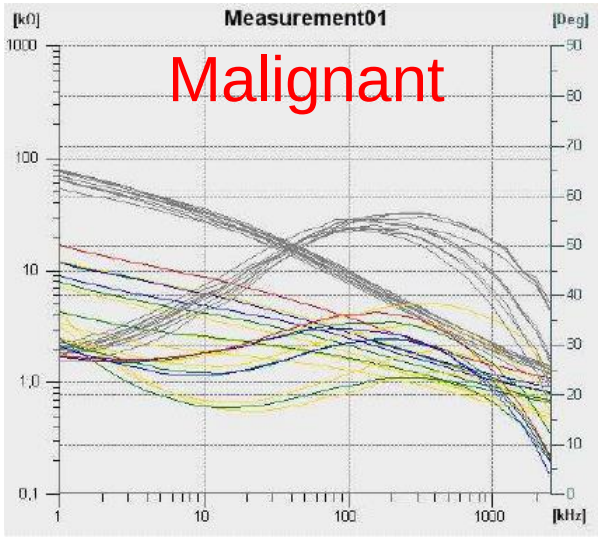
Nevus and skin cancer

Benign (harmless) **nevus** vs. **malignant** (harmful) **melanoma**

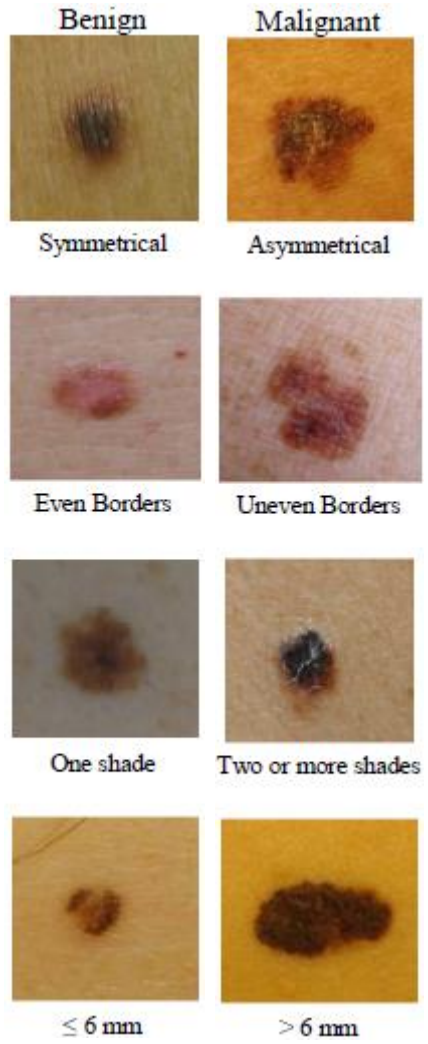
Malignant melanoma affects mainly viable skin

Problem: capacitive properties of stratum corneum





Source: U. Birgersson, „ Electrical Impedance of Human Skin and Tissue Alterations: Mathematical Modeling and Measurements“, PhD Thesis, Karolinska Institutet, Stockholm 2012



Possible solutions:

- selection of suitable frequency and electrode setup
- invasive needles

Wound healing

Three phases of normal wound healing:

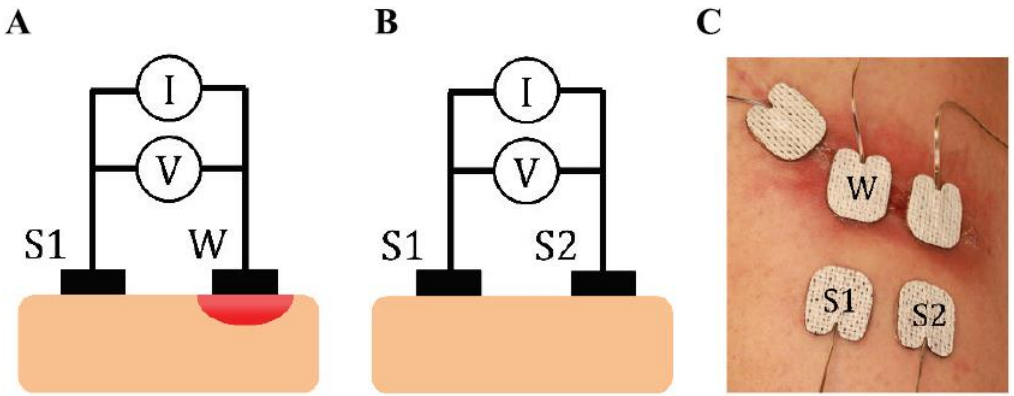
- tissue remodeling
- profileration
- inflammation

Z

In different phases the wounded skin posess different values of measured impedance

The impedance of wound is lower than the impedance of undamaged skin

$$\text{Wound status}\ (\%) = \left\{ \frac{\frac{Z(f_1)_{W,S1}}{Z(f_1)_{S1,S2}} + \frac{Z(f_2)_{W,S1}}{Z(f_2)_{S1,S2}} + \ldots + \frac{Z(f_n)_{W,S1}}{Z(f_n)_{S1,S2}}}{n} \right\} * 100\%$$



Source: A. Kekonen, M. Bergelin, J.-E. Eriksson, A. Vaalasti, H. Ylänen, J. Viik, „Bioimpedance Measurement Based Evaluation of Wound Healing," Physiol. Meas. Vol. 38(7), June 2017

Z_{ratio} at specific frequency

	10Hz	100Hz	1kHz	2.5kHz	6.3kHz	10kHz	25kHz	40kHz	63kHz	100kHz
Day 1	45.2 %	53.5 %	58.3 %	65.3 %	81.8 %	92.7 %	114.4 %	121.8 %	125.2 %	125.1 %
Day 2	47.8 %	53.3 %	69.8 %	86.7 %	103.7 %	110.8 %	123.2 %	126.5 %	127.0 %	124.9 %
Day 3	70.2 %	85.8 %	111.3 %	117.2 %	123.7 %	127.8 %	136.5 %	138.8 %	139.0 %	137.4 %
Day 6	91.5 %	99.5 %	107.6 %	111.1 %	116.0 %	119.5 %	127.8 %	130.5 %	130.8 %	129.4 %

4. Initial results of my measurements of the human skin

Objective of the research

First stage (ongoing):

- To develop a suitable method for evaluating the effect of curative mud on the human skin

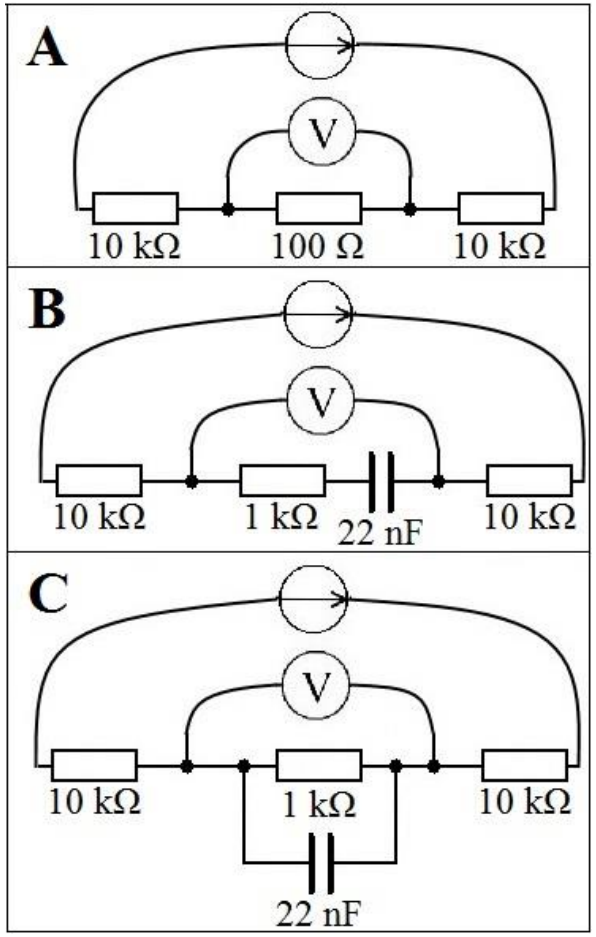
Second stage (planned):

- To implement the developed method on few subject in order to verify its functionality

Third stage (planned):

- To research a group of volunteers in order to study the effect of curative mud on the skin

Verification the of measurement setup

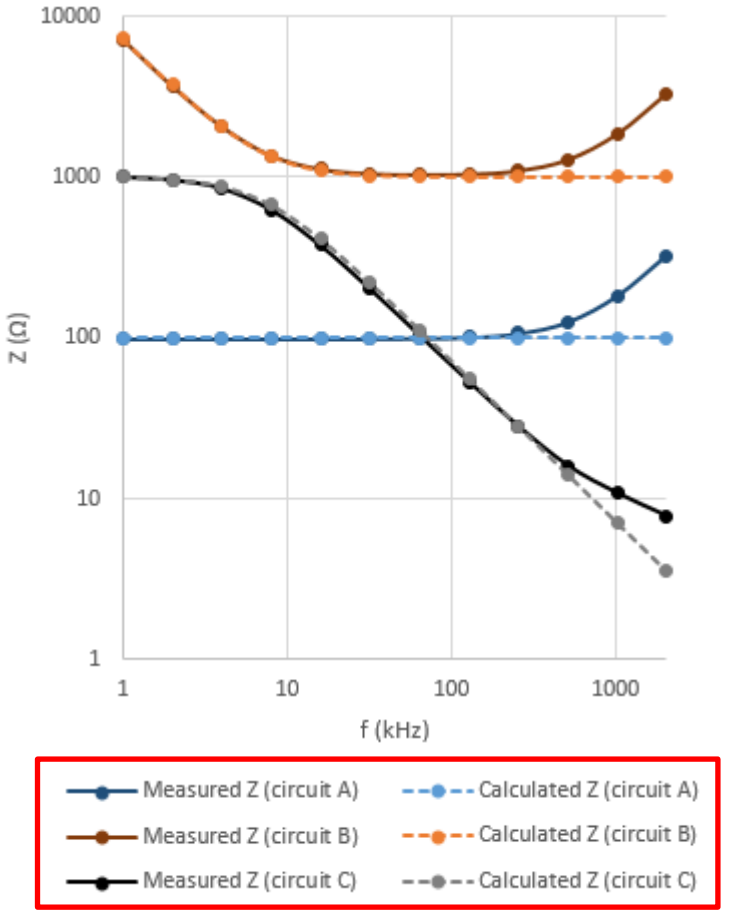


The calculated vs. the measured result

A. Object represented by **single resistive element**

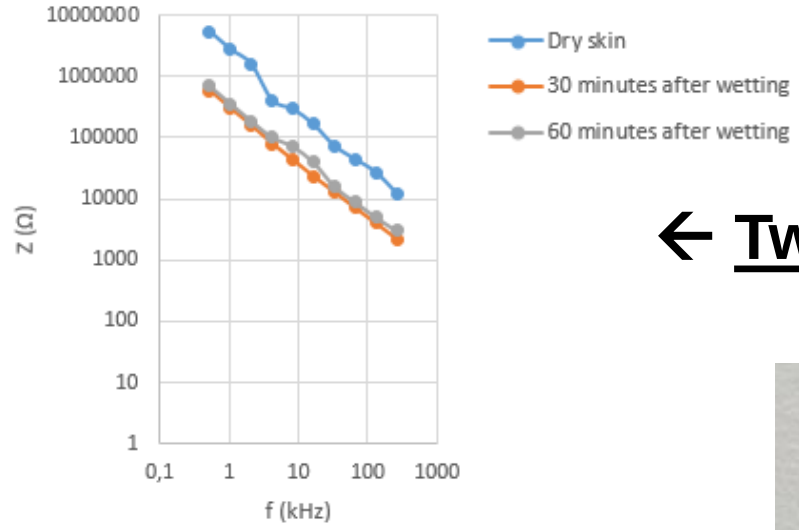
B. Object represented by **series connection of resistive and capacitive element**

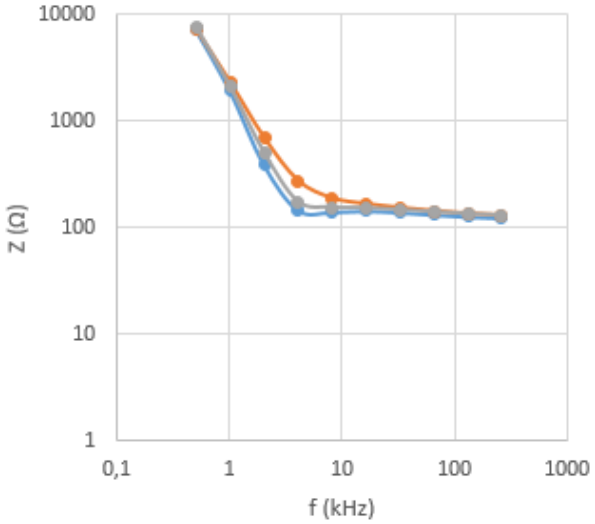
C. Object represented by **parallel connection of resistive and capacitive element**



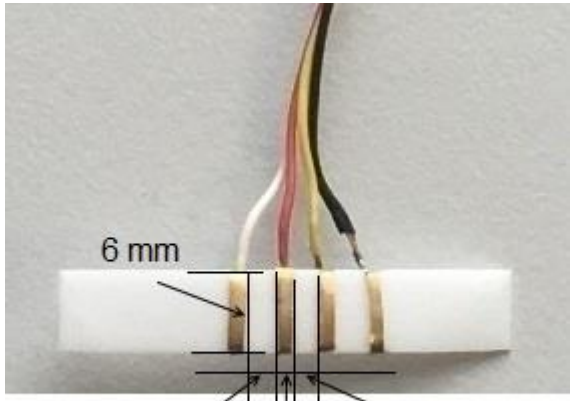
Initial measurement results of the skin

Impedance Z



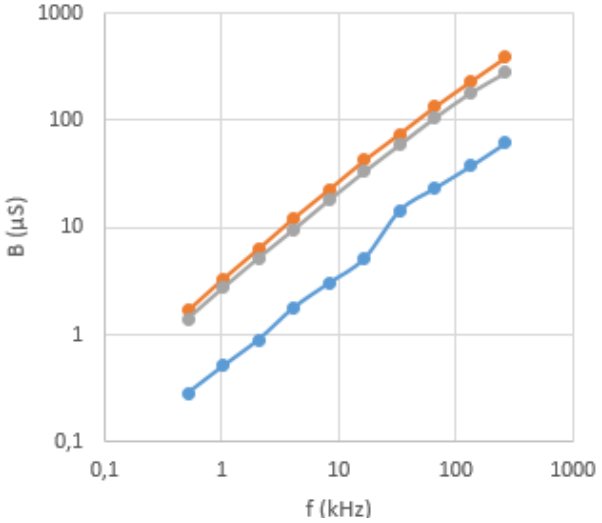


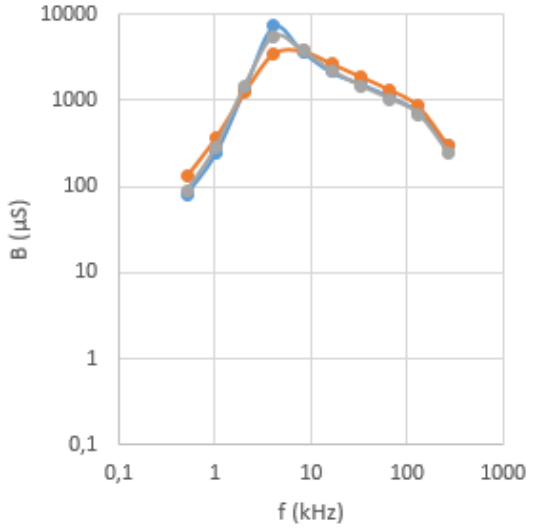
← Two electrode system →



← Four electrode system →

Susceptance B



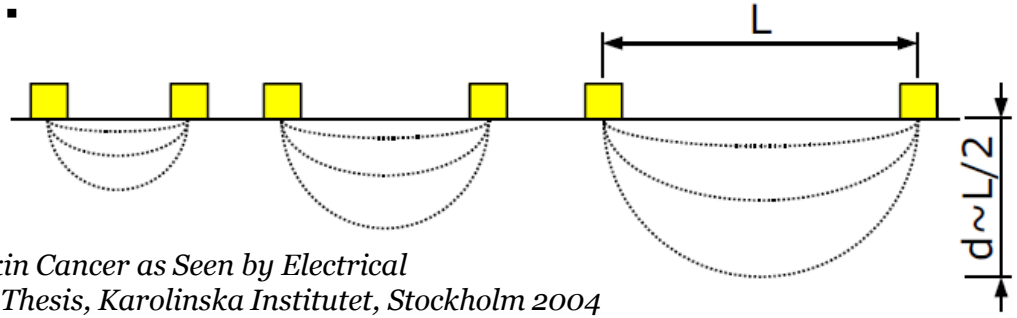


5. Skin and electrical bioimpedance – the appearing uncertainties

What we are measuring?

The measurement depth (is correlated to):

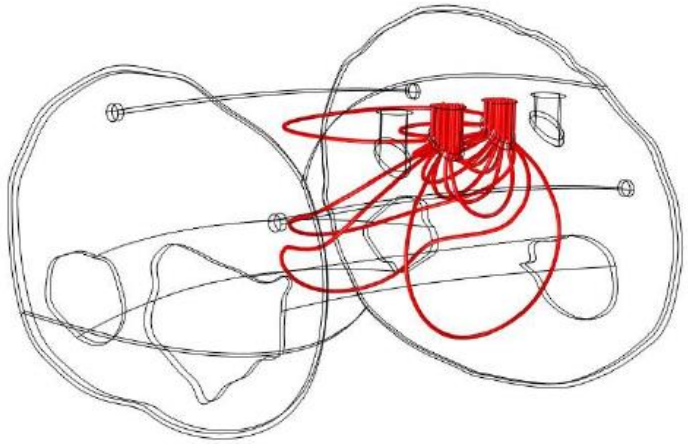
- distance between the electrodes
- physical properties of tissue
- frequency



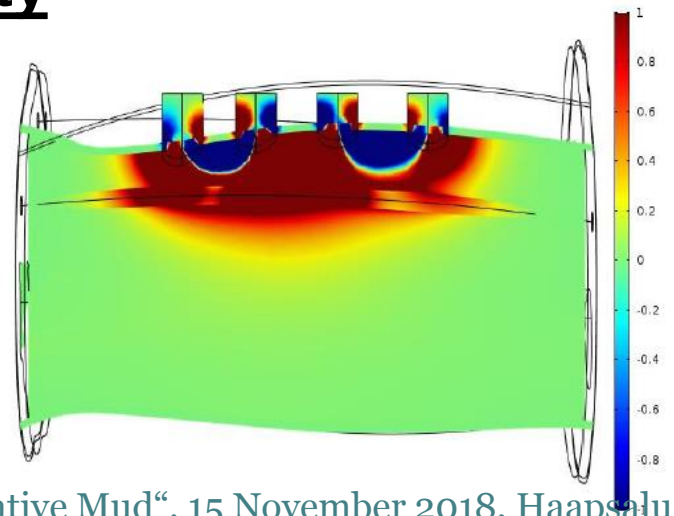
Source: P. Åberg, „Skin Cancer as Seen by Electrical Bioimpedance“, PhD Thesis, Karolinska Institutet, Stockholm 2004

Contribution of the regions of different conductivity

Sensitivity distribution



Source: A. Krotov, „Elektrilise impedantsi mõõtmise simulatsioon 3D inimese käe mudelil,“ Master Thesis, Tallinn University of Technology, Tallinn 2017



The effect of spa therapies on the skin

Two key questions appear

1. **What are the mechanisms of spa therapies?**

Mechanical effects

Thermal effects

Chemical effects

Immunologic effects

Anti-inflammatory effects

Etc.

2. **How do spa therapies contribute to the impedance of the skin?**

Hydration of stratum corneum

Absorbtion of minerals through skin

Increase of sweating

Thank you for attention!

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