Dielectric properties of tissues as a function of age and their relevance in assessment of the exposure of children to electromagnetic fields;

State of knowledge

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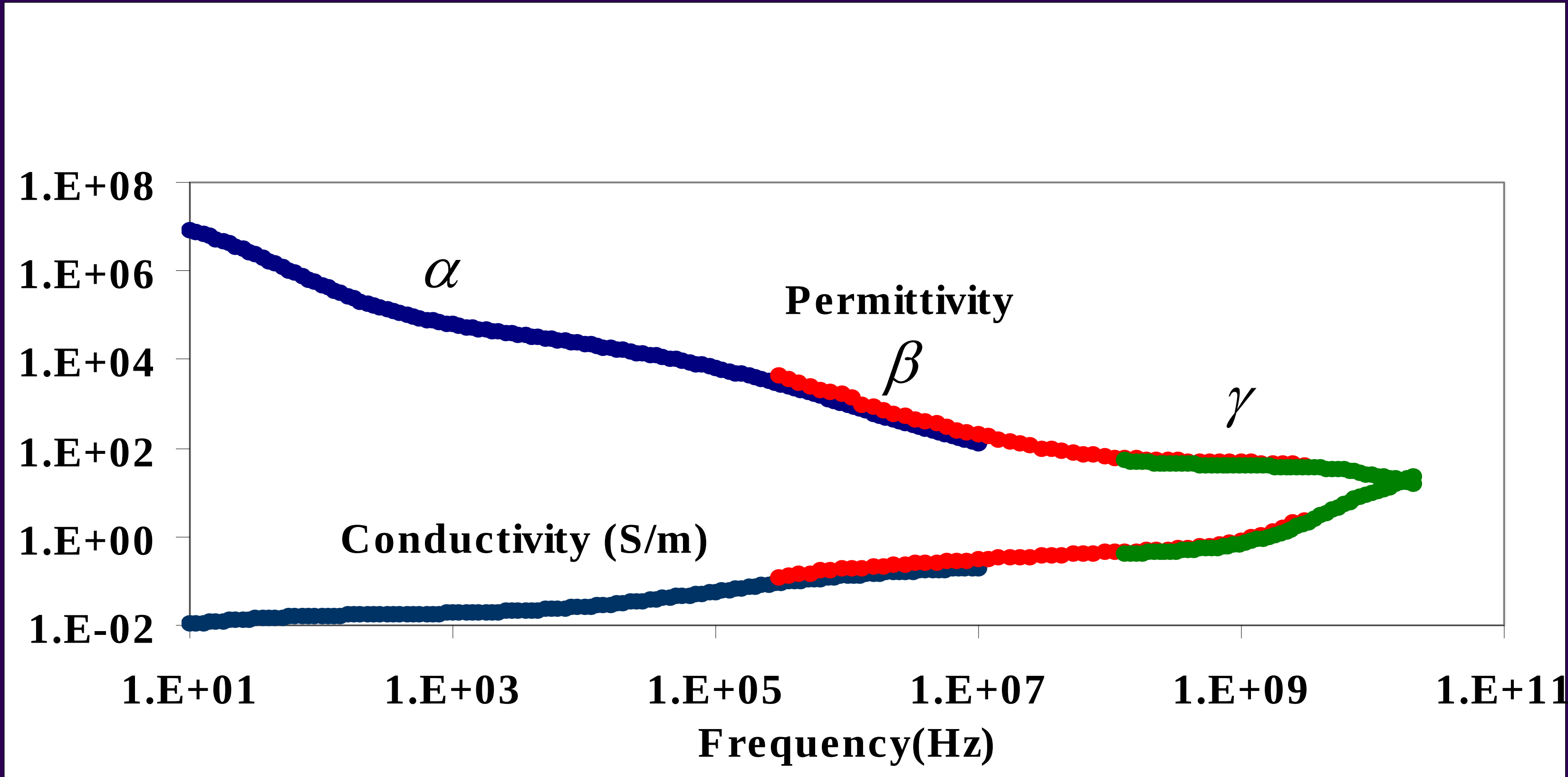
Outline

- Background
- The age related dielectric studies
- Relation to dosimetry

Dielectric Behavior of Tissues



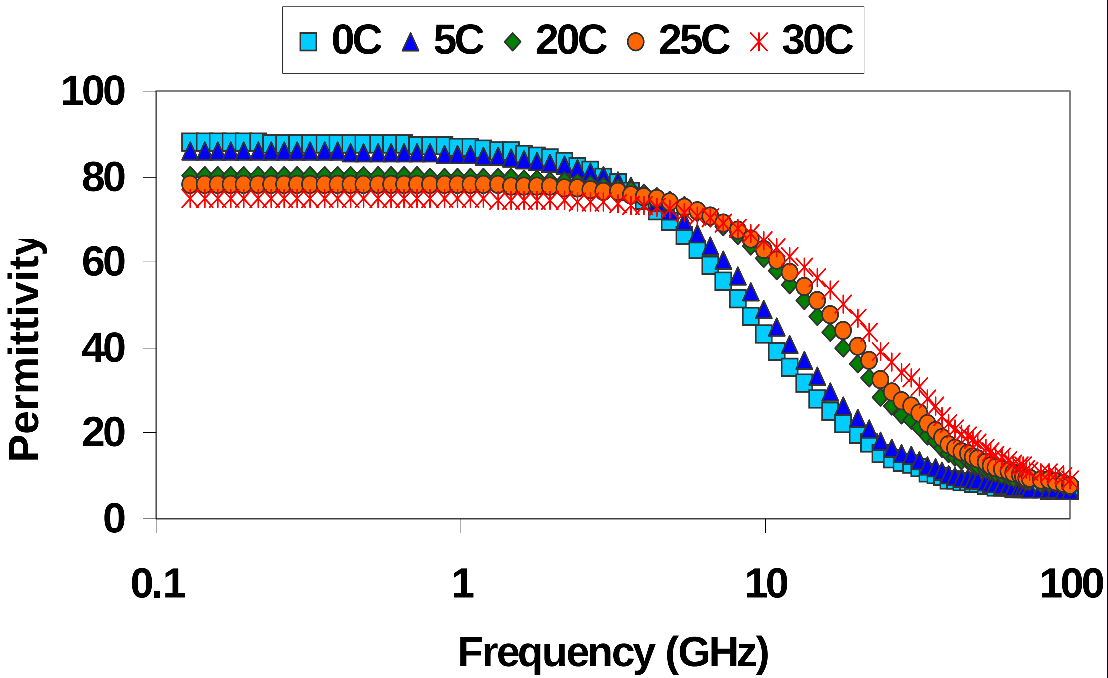
- Intrinsic properties of matter
- Determine the interaction with EMF
- Biological tissues are not uniquely characterised
    - Heterogeneous
    - Sampling and handling
    - Uncertainty

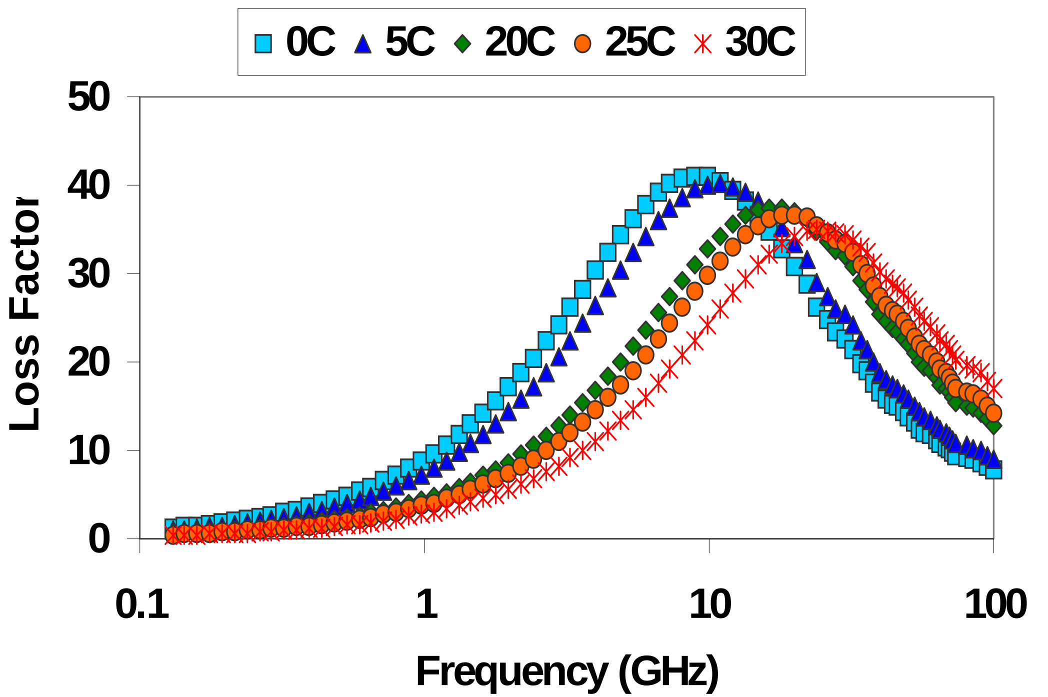
$$\hat{\varepsilon} = \varepsilon_\infty + \sum_n \frac{\Delta\varepsilon_n}{1+(j\omega\tau_n)^{(1-\alpha_n)}} + \frac{\sigma_i}{j\omega\varepsilon_0}$$

(Cole-Cole Equation)

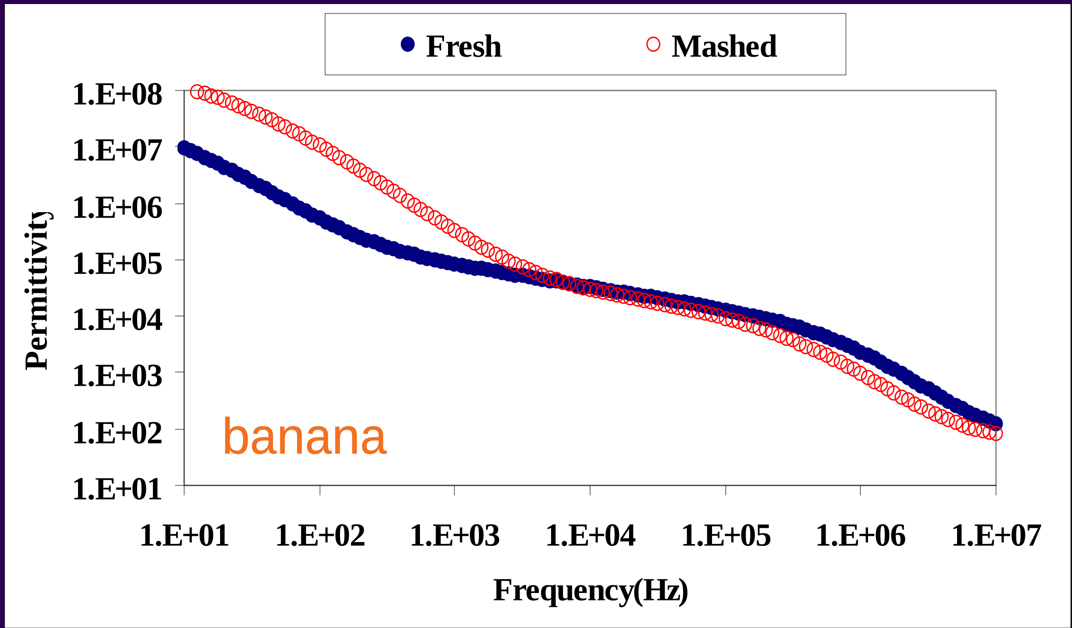
Systematic Change in The Dielectric Behaviour

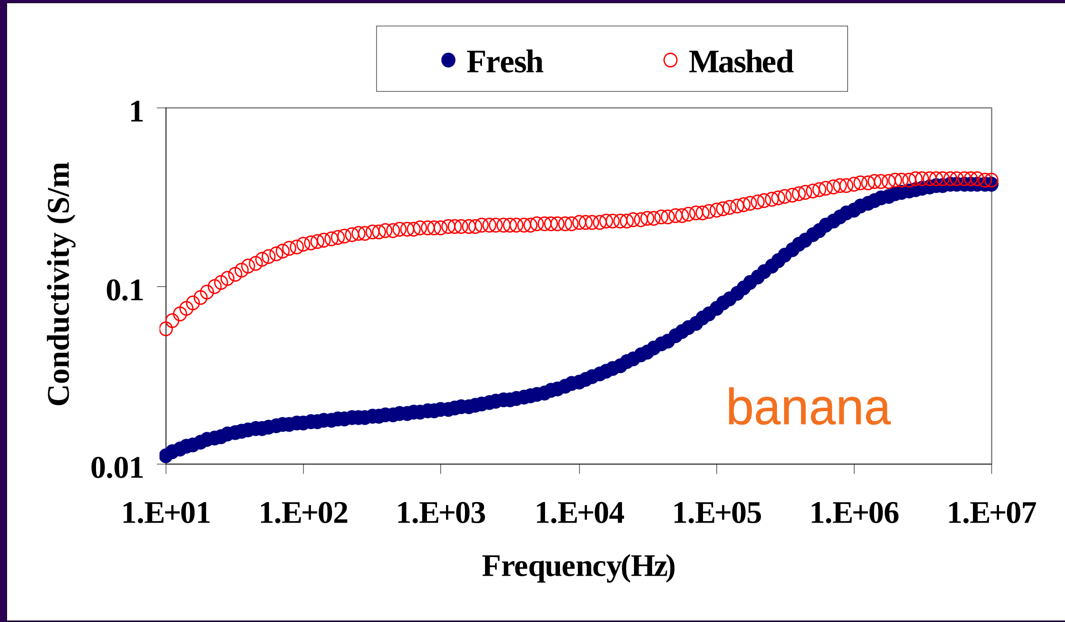
- Temperature
- Intactness of cell membrane
- Direction of *E* field with respect to the fibrous materials
- Water content

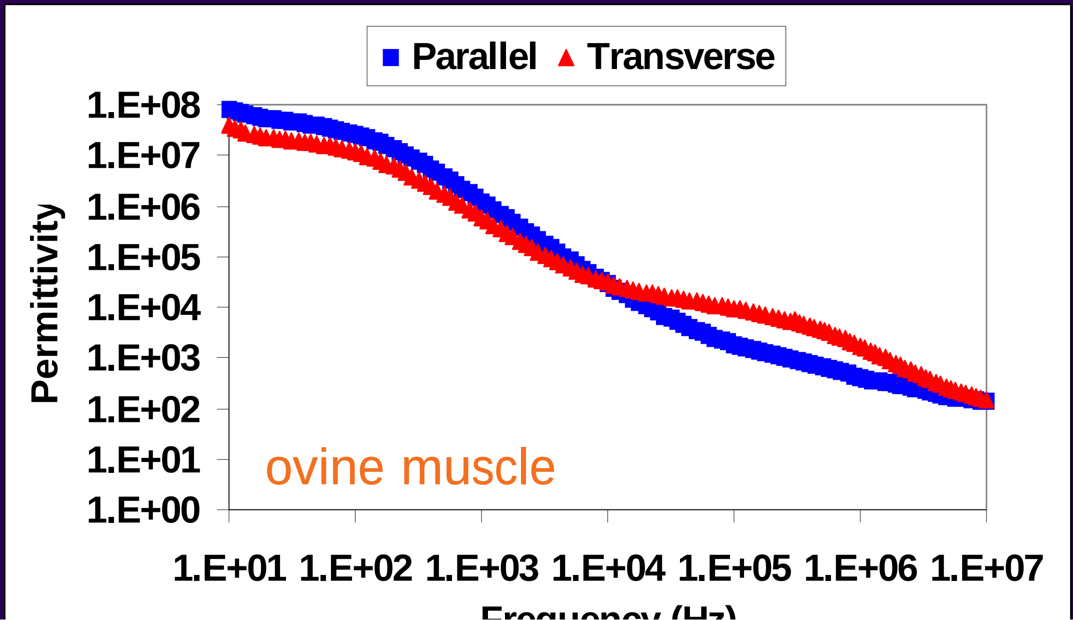


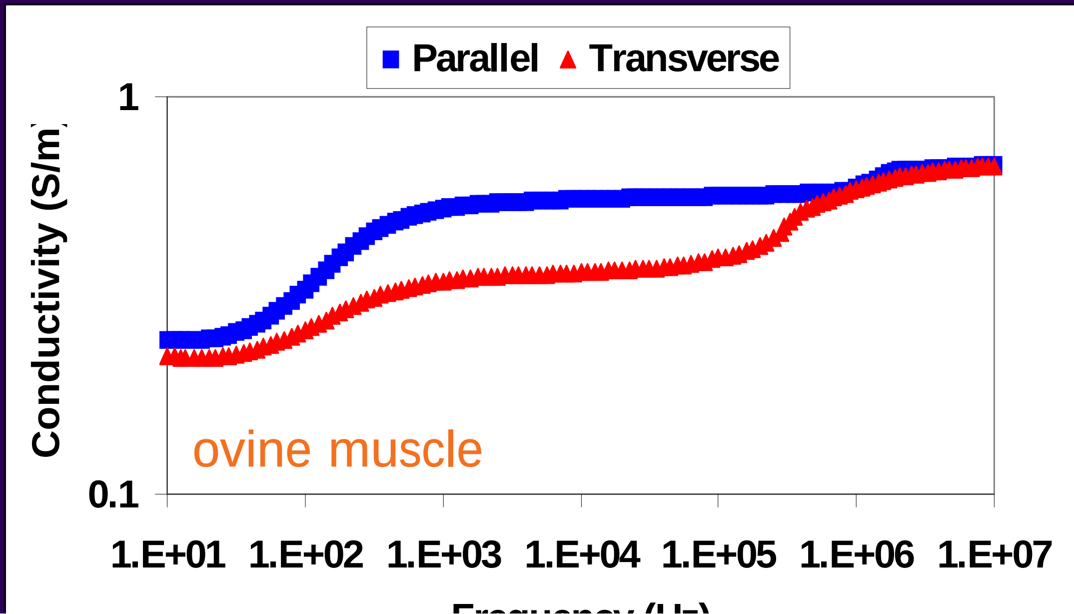


Systematic Change in The Dielectric Behaviour









Applications of Dielectric Data in Dosimetry

- **Different dispersions give information about the status of the tissue under the influence of the external electric field**
  - Experimental assessment of human exposure from electromagnetic sources
  - Dielectric properties of various tissues needed to determine (SAR) in models of animals and human

$$SAR = \frac{\sigma}{\rho} E_{rms}$$

State of Knowledge
1996 Dielectric Database

- Gabriel et al. 1996 assessed the state of knowledge in terms of the dielectric properties of tissues over ten frequency decades

  (Gabriel C, Gabriel S and Corthout E 1996a The dielectric properties of biological tissues: I. Literature survey Phys.Med.Biol. 41 2231-2249)

- They carried out an experimental study on a large number of biological tissues using 3 different measurement techniques spanning the frequency range 10Hz - 20GHz

  (Gabriel S, Lau R W and Gabriel C 1996b The dielectric properties of biological tissues: II. Measurements in the frequency range of 10Hz to 20GHz Phys.Med.Biol. 41 2251-2269)

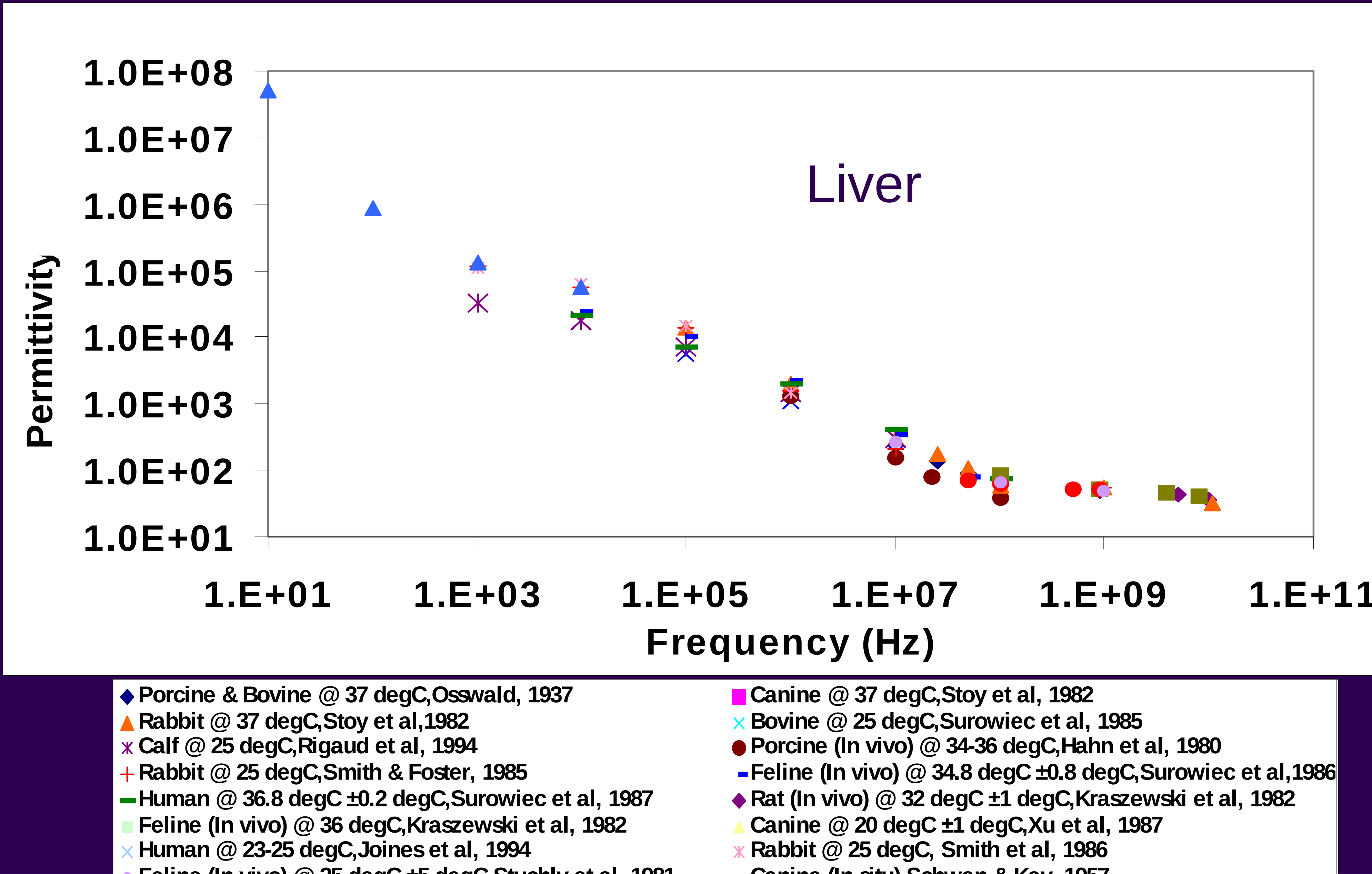
- Finally, Gabriel et al 1996 used their experimental data, complemented by the data surveyed from the literature, to develop a parametric model to describe the variation of dielectric properties of tissues as a function of frequency

  (Gabriel S, Lau R W and Gabriel C 1996c The dielectric properties of biological tissues: III. Parametric models for the dielectric spectrum of tissues Phys.Med.Biol. 41 2271-2293)

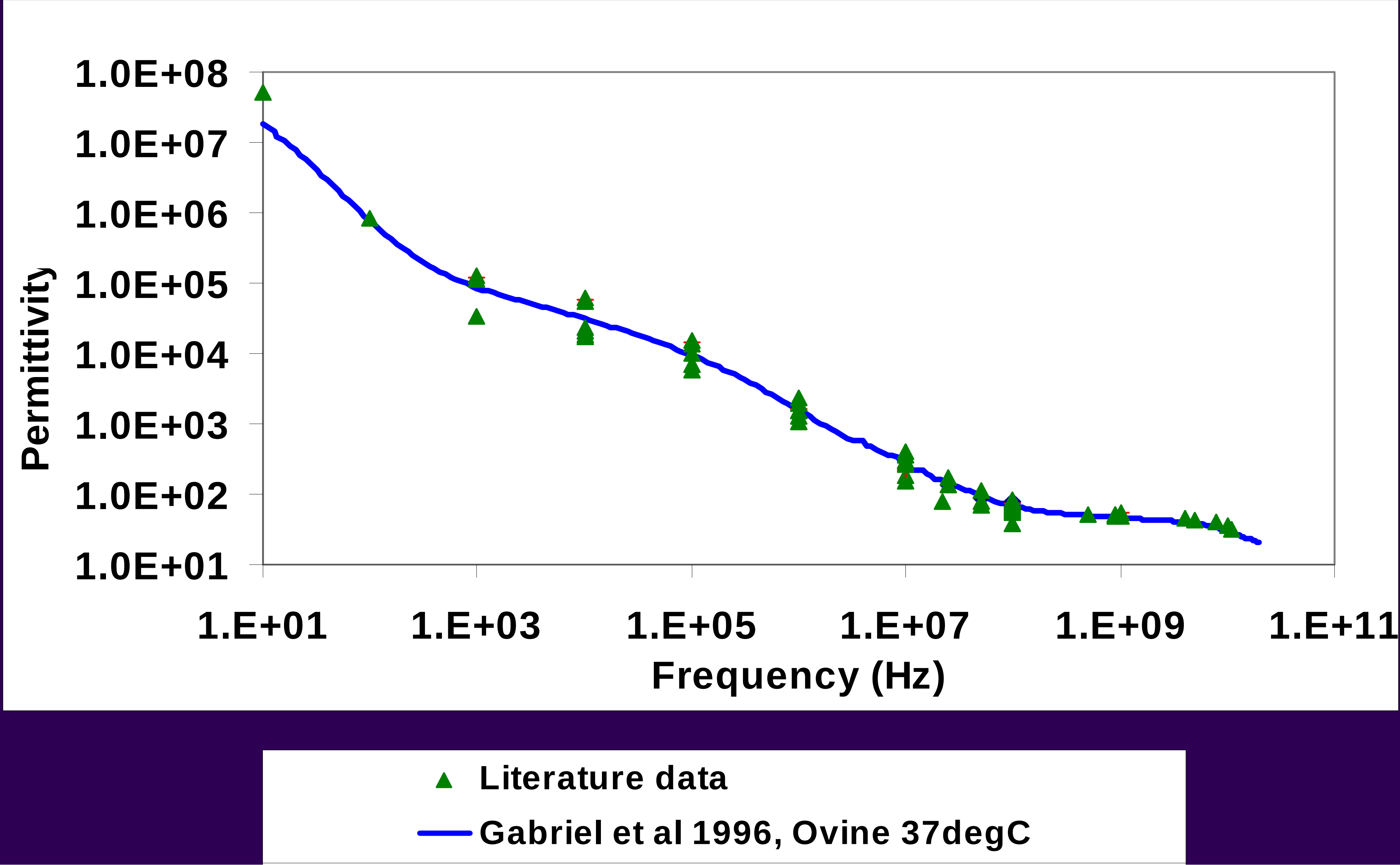
- The main source of tissue dielectric data in the last decade, extensively used by scientific community specially in dosimetric studies

1996 Database;

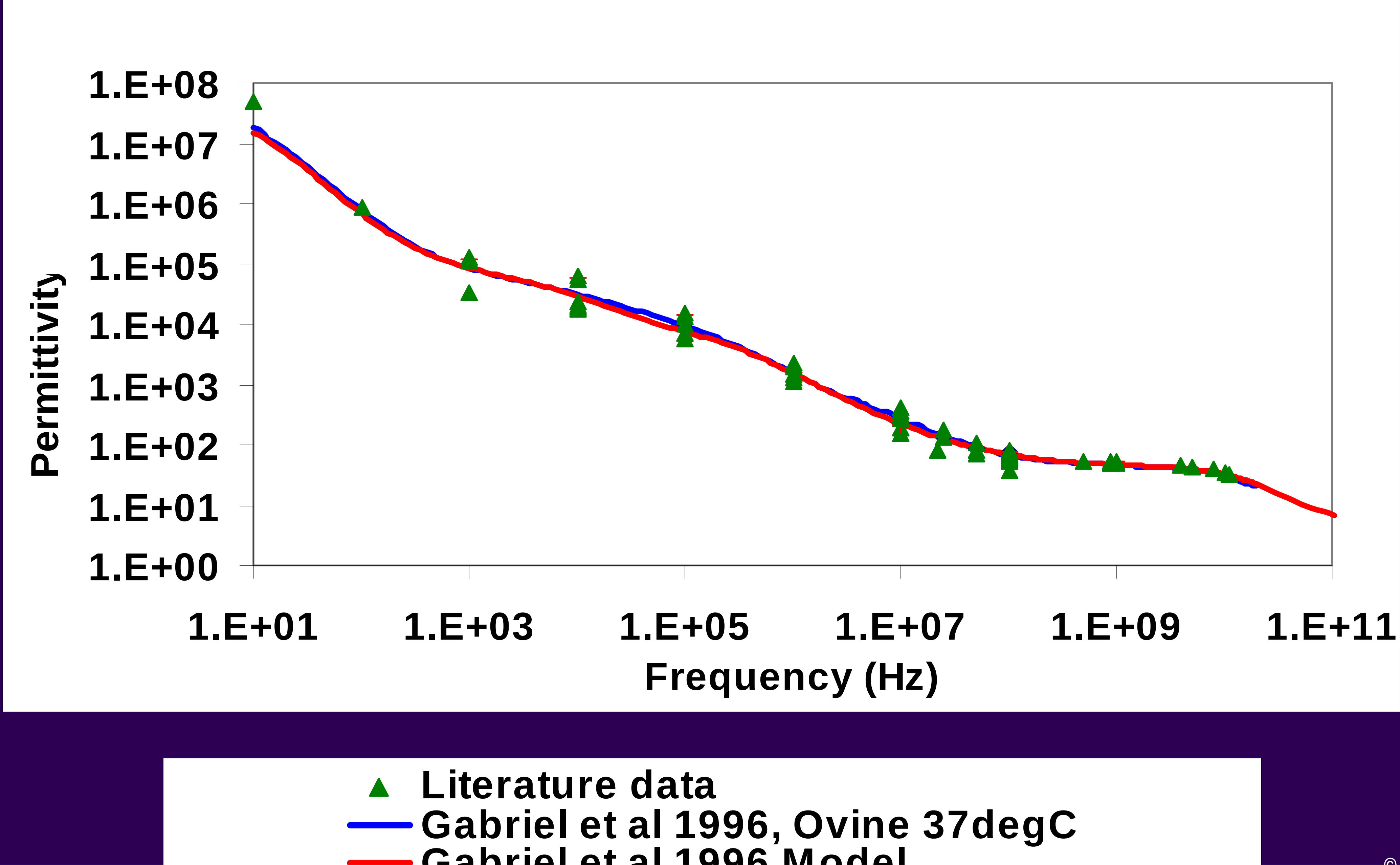
Literature Review



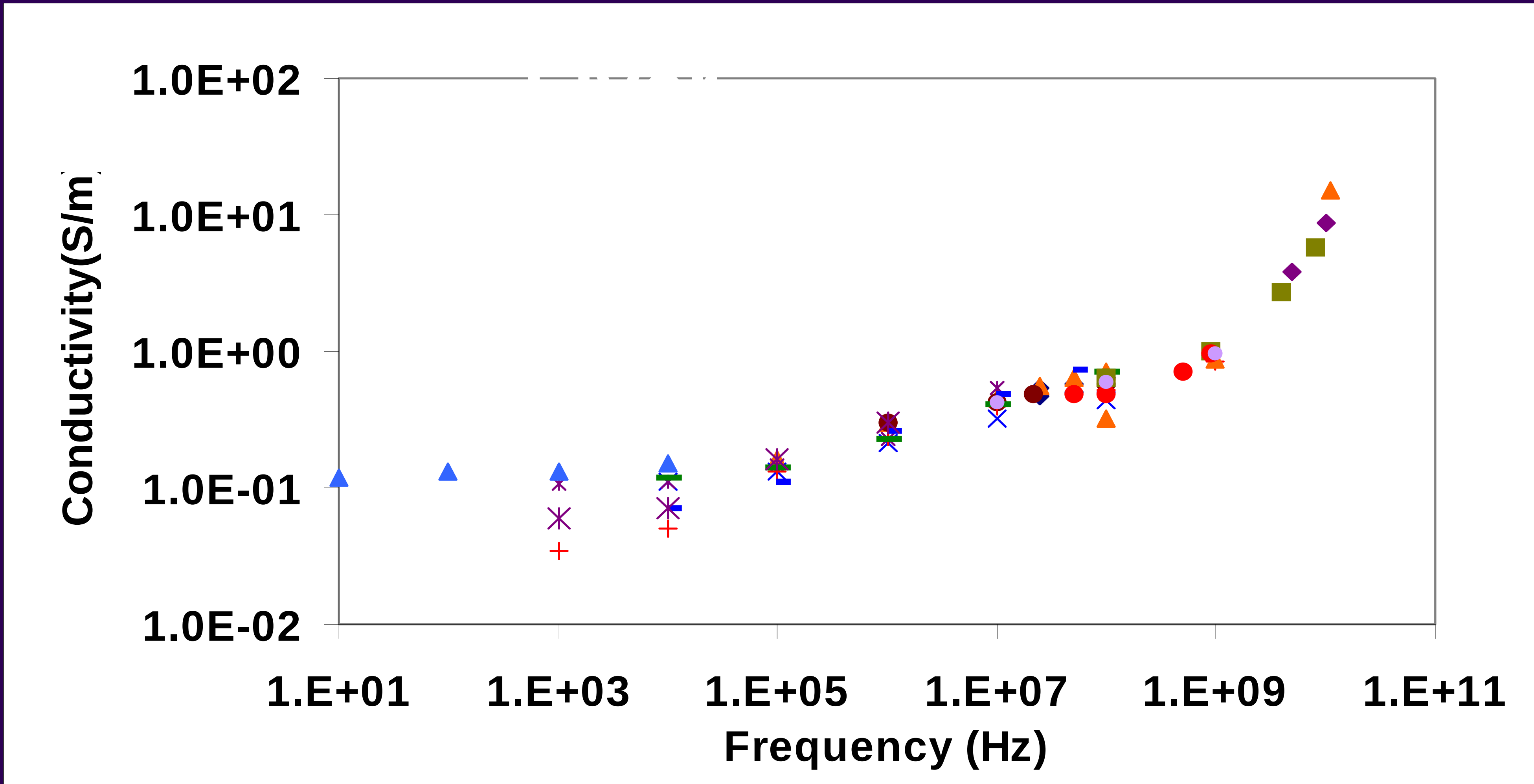
1996 Database;
Experimental Measurements



1996 Database;
4 Term Cole-Cole Model

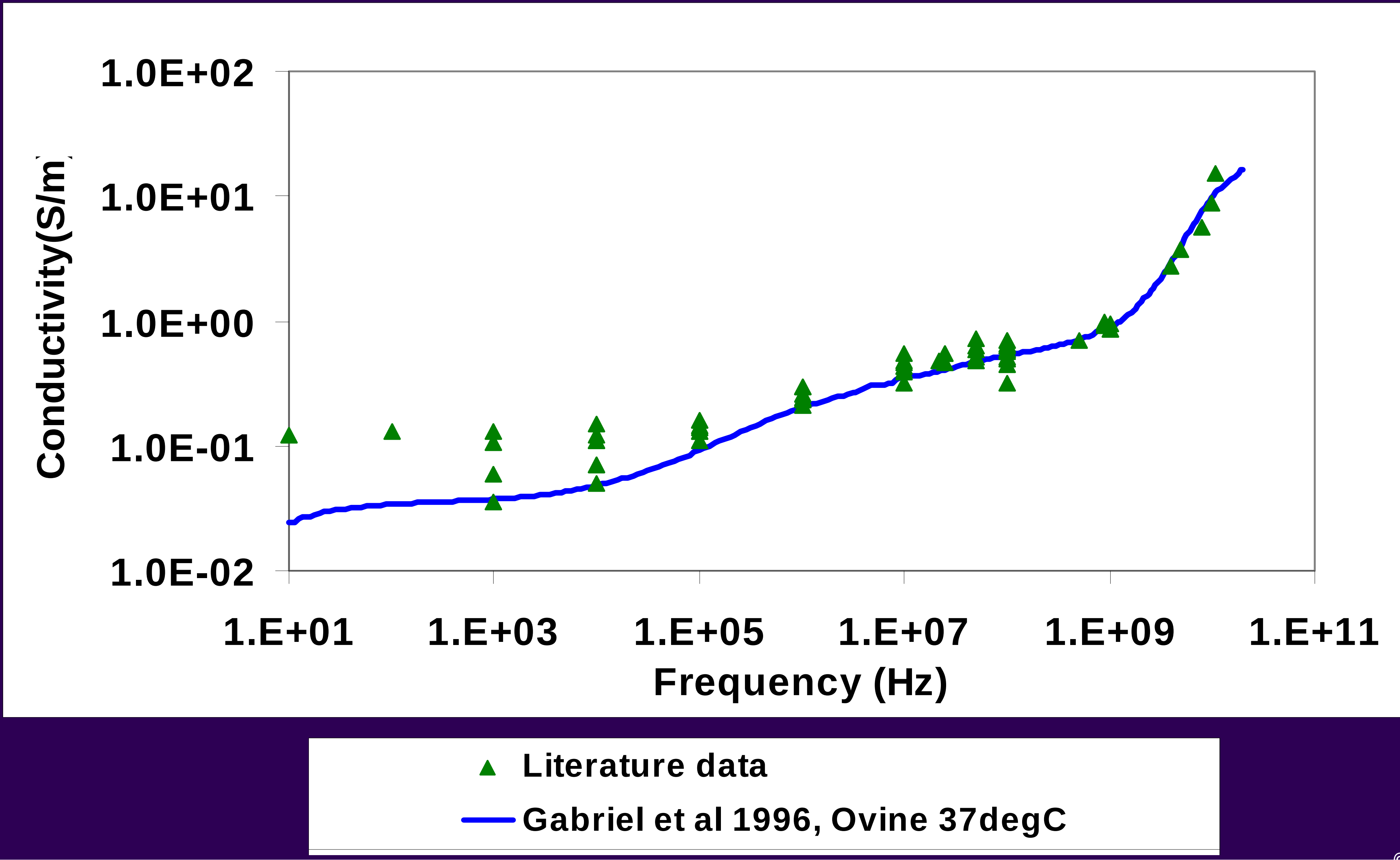


1996 Database; Literature Review

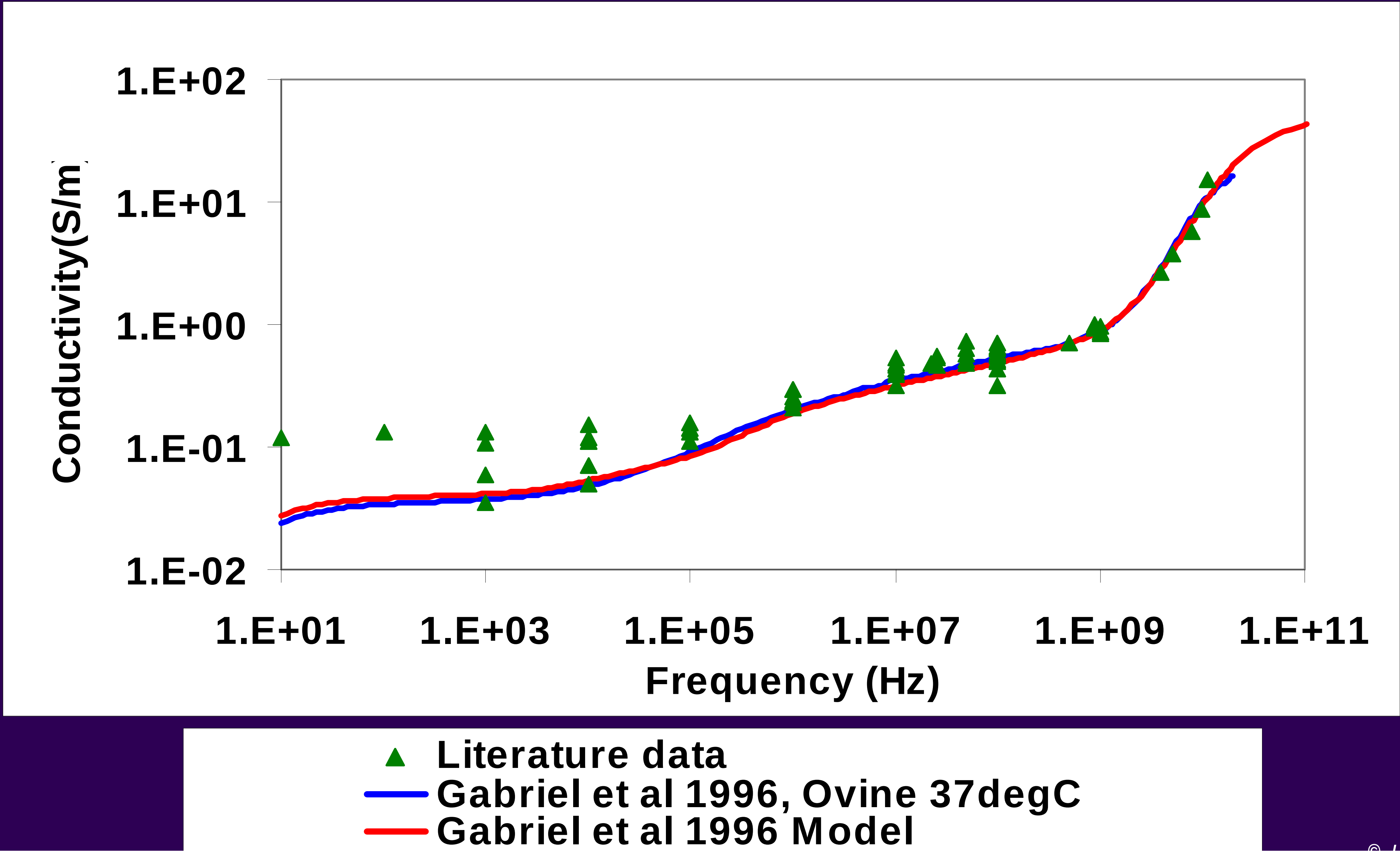


- Porcine & Bovine @ 37 degC,Osswald, 1937
- Rabbit @ 37 degC,Stoy et al,1982
- Calf @ 25 degC,Rigaud et al, 1994
- Rabbit @ 25 degC,Smith & Foster, 1985
- Human @ 36.8 degC ±0.2 degC,Surowiec et al, 1987
- Feline (In vivo) @ 36 degC,Kraszewski et al, 1982
- Human @ 23-25 degC,Joines et al, 1994
- Canine @ 37 degC,Stoy et al, 1982
- Bovine @ 25 degC,Surowiec et al, 1985
- Porcine (In vivo) @ 34-36 degC,Hahn et al, 1980
- Feline (In vivo) @ 34.8 degC ±0.8 degC,Surowiec et al,1986
- Rat (In vivo) @ 32 degC ±1 degC,Kraszewski et al, 1982
- Canine @ 20 degC ±1 degC,Xu et al, 1987
- Rabbit @ 25 degC, Smith et al, 1986

1996 Database; Experimental Measurements



1996 Database;
4 Term Cole-Cole Model

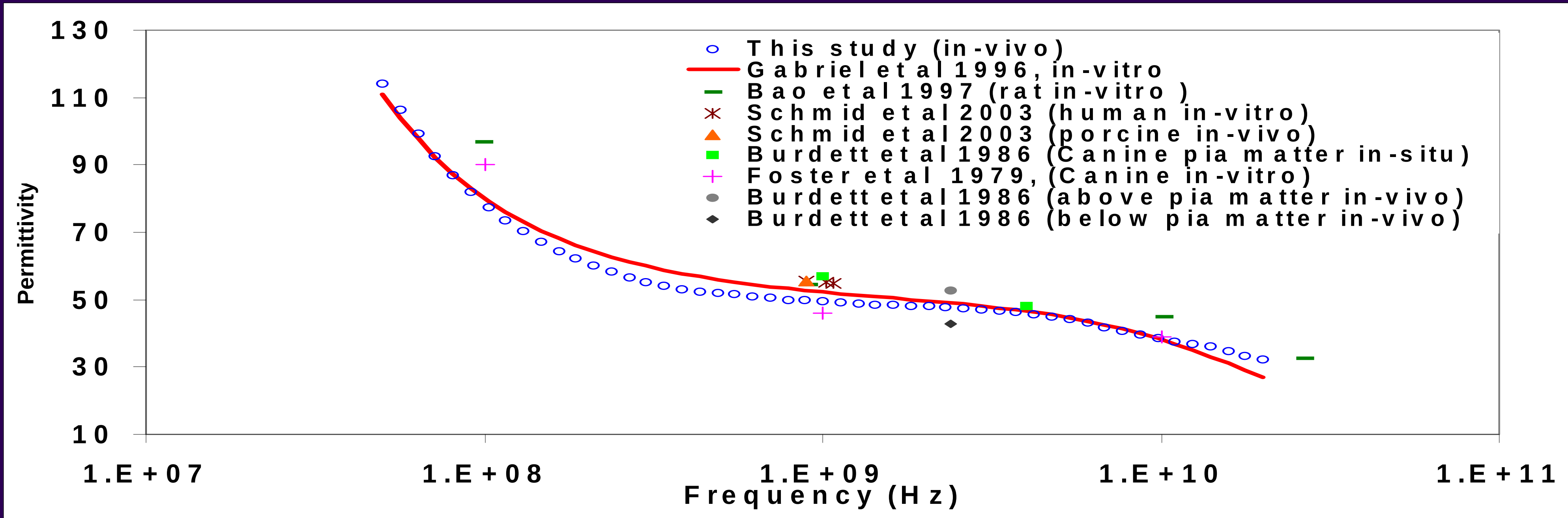


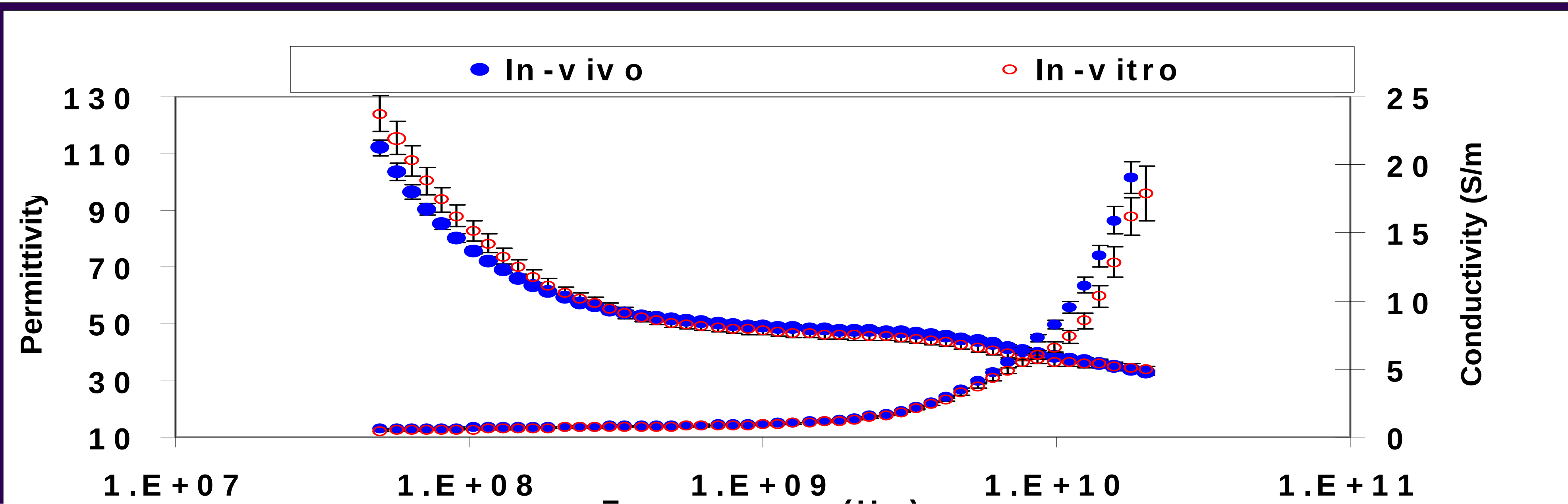
Post 1996 Database

- A decade on, fresh dielectric study carried out as part of Mobile Telecommunication Health Research Program (MTHR).
- A literature review of all relevant papers published in the past decade (after 1996, 43 studies pertaining to different frequency regions , tissue-types, purposes*).*
- Obtaining, analysing and making available extensive, novel, experimental data acquired from measurement in-vivo.
- The recent study has consolidated and added to the knowledge in several important respects.
  - **58 tissues**
  - **21 pigs in total**
  - **3 surgical positions**
  - **At least 6 animals for each tissue**
  - **At least 6 measurements per animal**

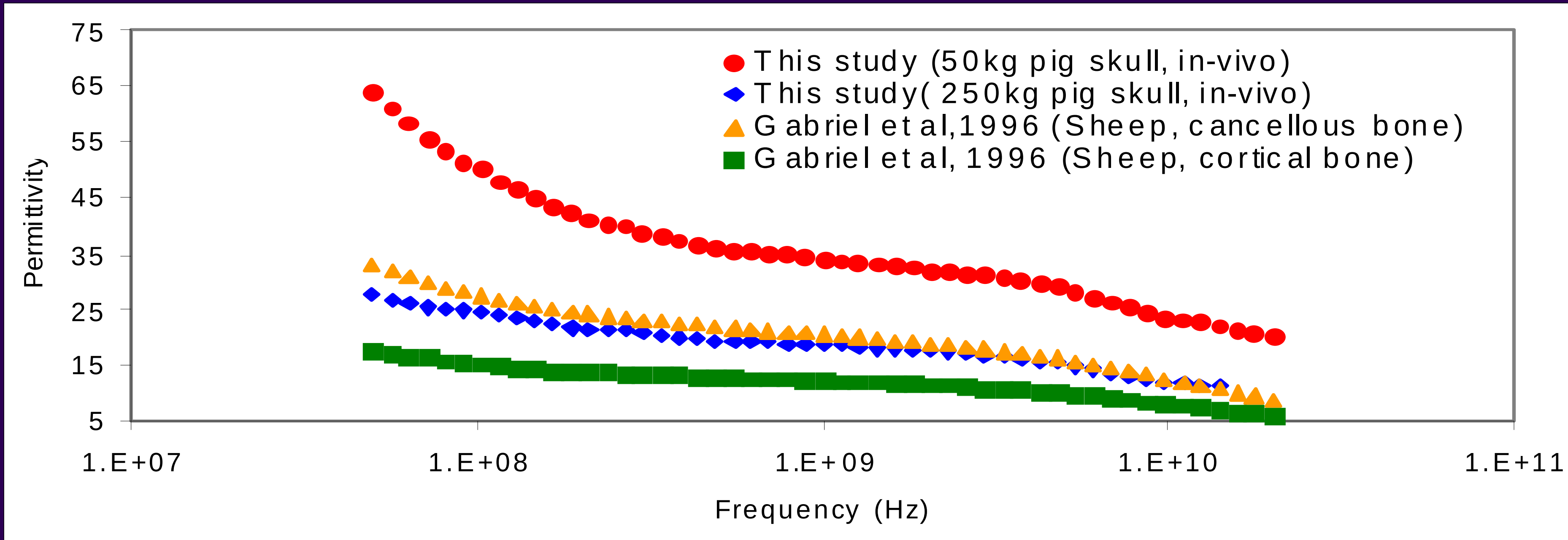
All the measurements on porcine tissues were carried out by DSTL in their premises

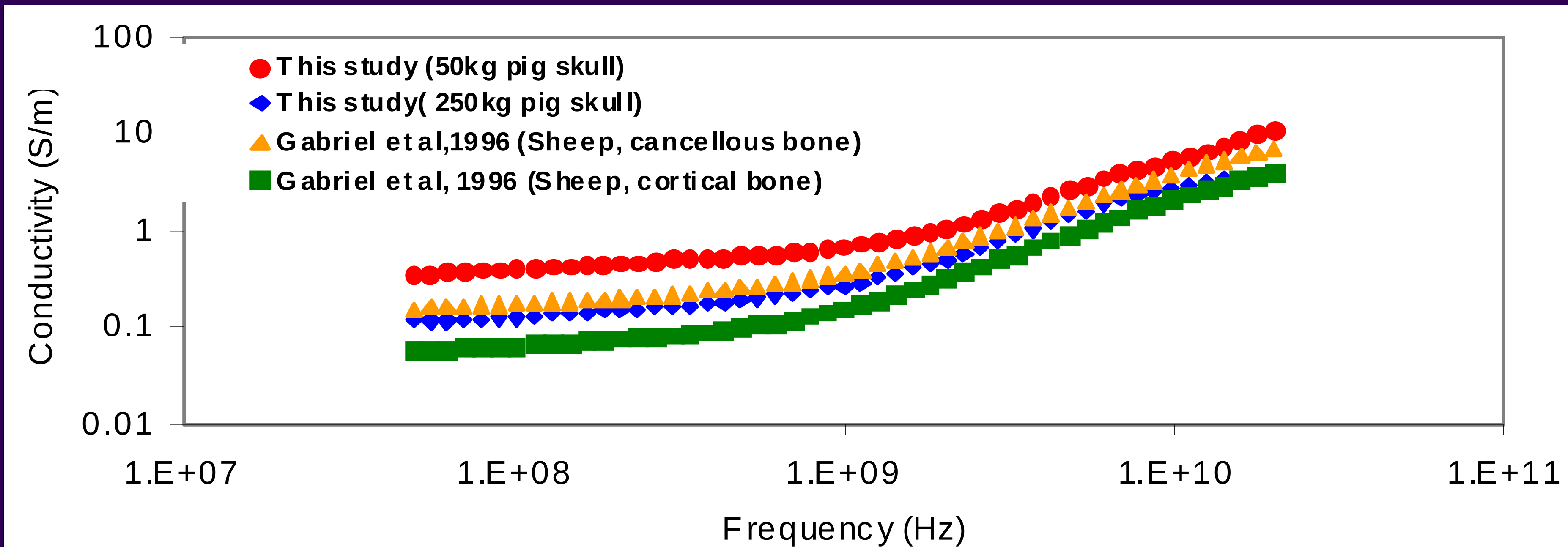
Results: Grey Matter



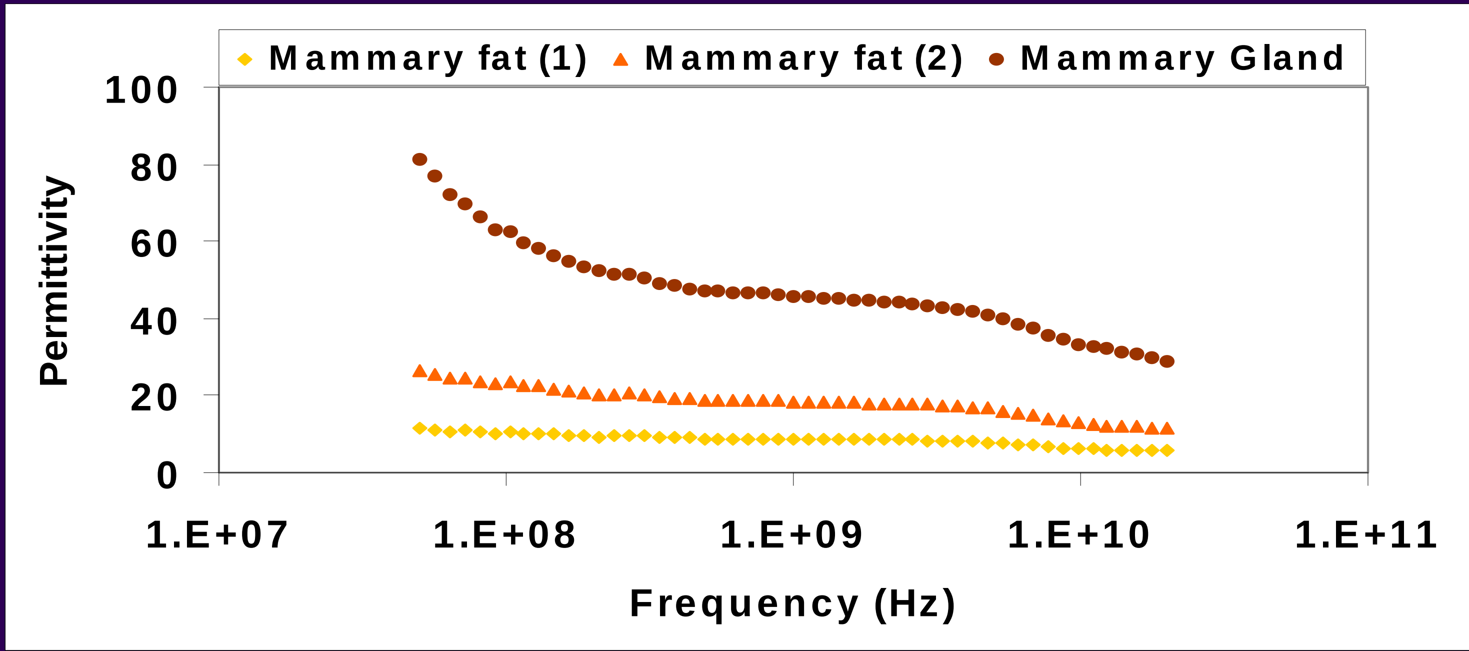


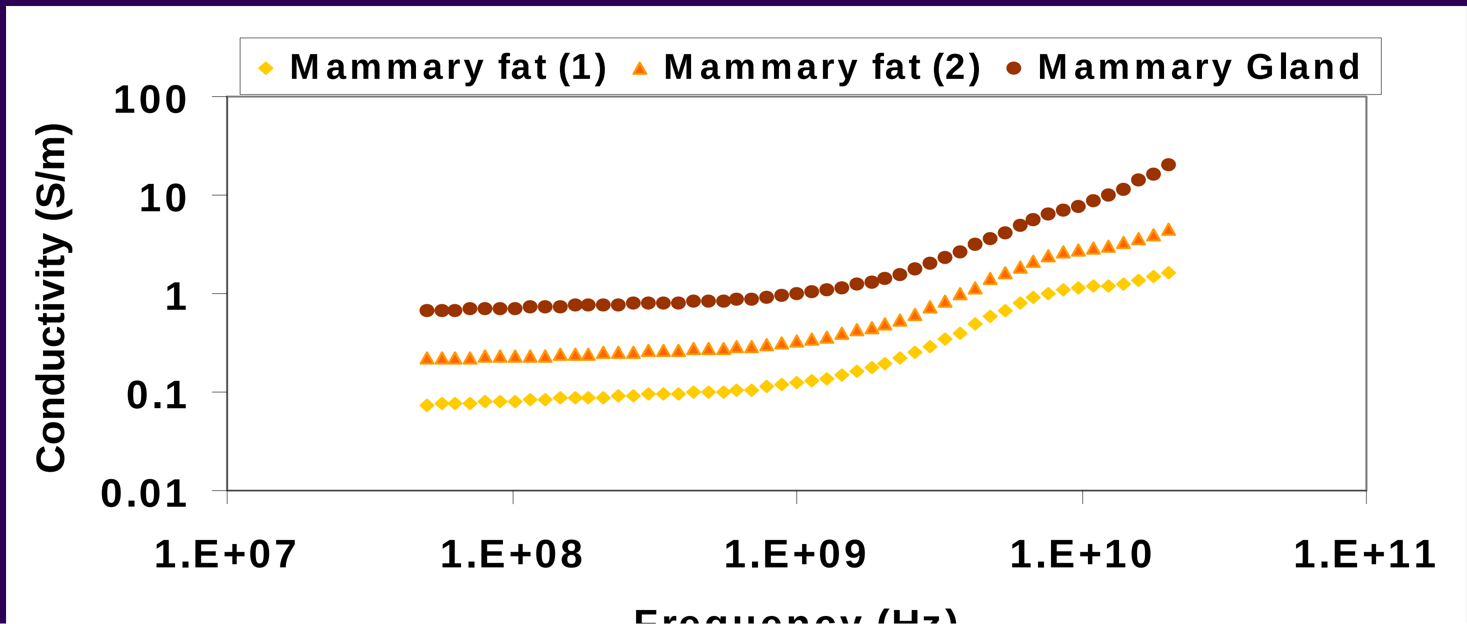
Results: Bone





Another Interesting Outcome





Uncertainty Analysis

- Systematic statistical and comparative analyses on large amount of experimental data
- Identification and quantification of the main sources of experimental error
- Development of a procedure to estimate the total uncertainty in dielectric data

Gabriel C and Peyman A 2006 Dielectric measurement: error analysis and assessment of uncertainty Phys. Med. Biol. 51 (2006) 6033–6046

Summary of New Dielectric Data

- The results of recent dielectric studies are comparable to the 1996 data base for most of the tissues (brain and abdominal tissues)

- In the case of skeletal tissues, the large numbers of independent dielectric measurements on both skull and long bone of different pigs show generally higher values than those reported in the Gabriel et al 1996 data base.

- These high values could be due to the differences in the species and the age of the animals used in this study and others.

- The recent study shows that the differences between the *in-vivo* and *in-vitro* measured dielectric properties of tissues are not systematic at microwave frequencies

- New dielectric data are now available for tissues such as: lymph node, mammary glands, Diaphragm, Uterine Horn, Thymus gland, Salivary glands, Urine

Dielectric Properties of Tissues; Variation With Age

Health Protection Agency

Children might be more vulnerable

Differences between the dielectric parameters of biological tissue in children and adults

(Independent Expert Group on Mobile Phones report, 2000,UK)

2001: Rodents, High frequency study 200 MHz - 20 GHz

- **Newborn, 10, 20, 30, 50, and 70 days old rats**
- **Brain, muscle, skull, skin, salivary glands, tongue and eyes**

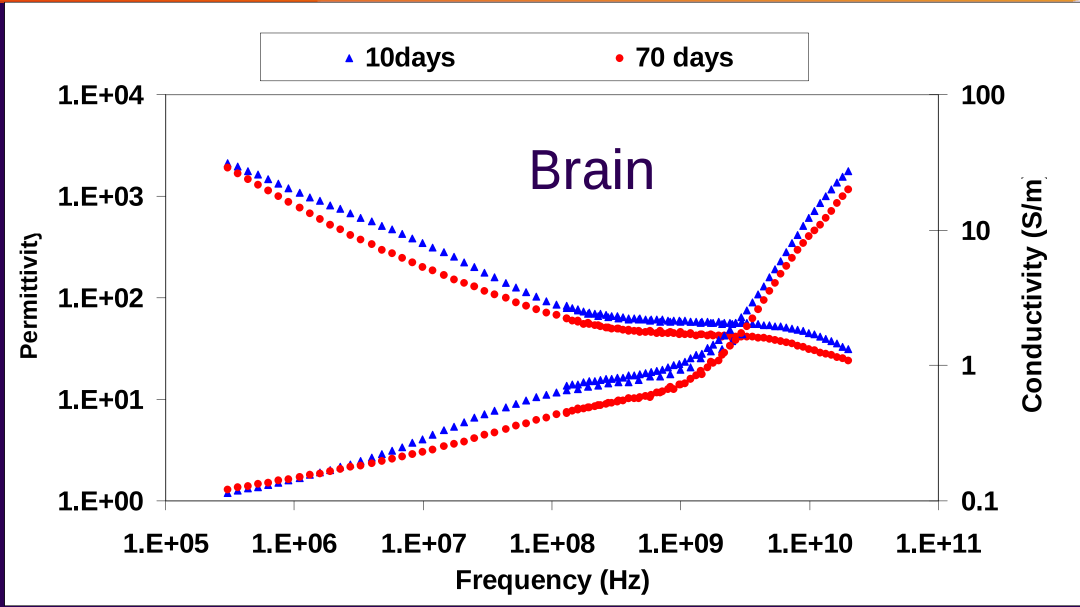
2003: Rodents, Intermediate frequency 300 kHz - 1 GHz

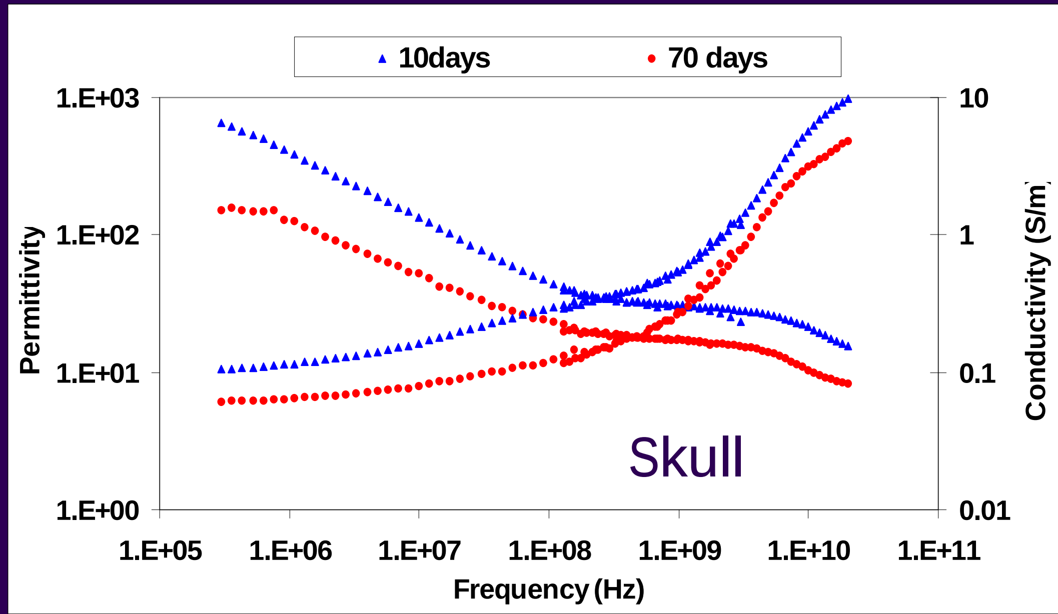
- **10, 20, 30, 50, and 70 days old rats**

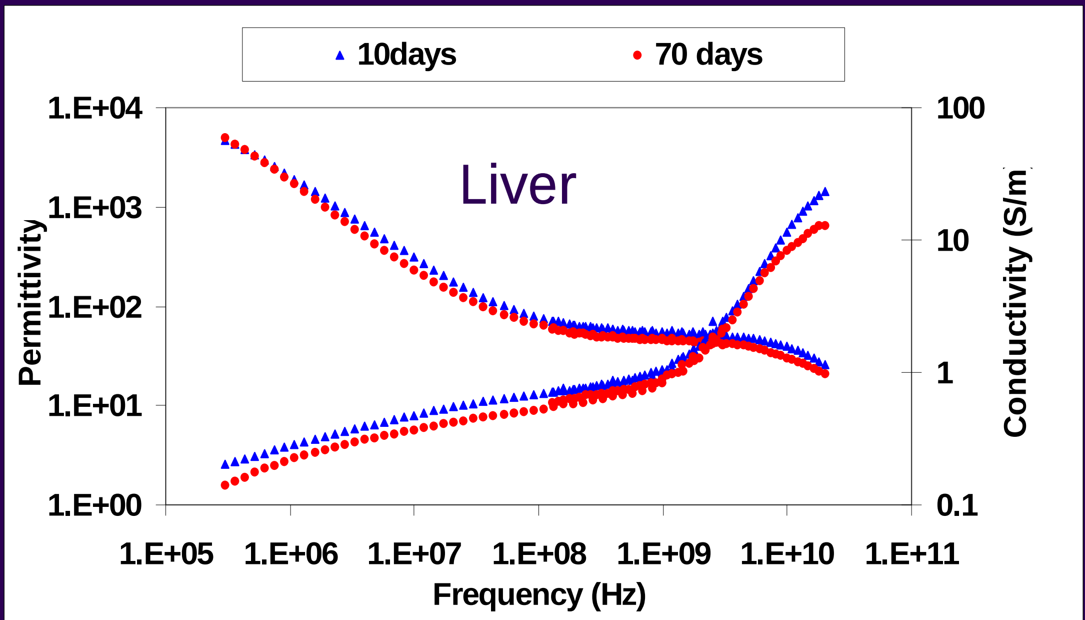
2003: Porcine, MTHR study, High Frequency 50MHz-20GHz

- **10kg, 50kg and 250 kg pigs, 17 tissues**

Results of Rodent Study







	%decrease in permittivity		% decrease in conductivity	
	900MHz	*1800MHz*	*900MHz*	*1800MHz*
Brain	7.9	8.2	16.3	13.5
Skull	31.0	31.2	42.5	32.9
Skin	11.9	11.7	20.5	10.7

Changes in dielectric data of different tissues from 30 to 70 days in rat

Peyman A, Rezazadeh AA and Gabriel C, 2001, "Changes in the dielectric properties of rat tissue as a function of age at

Results of Porcine Study

Health Protection Agency

Systematic age-related effect observed

- White matter
- Dura
- Spinal cord
- Bone (cortical)
- Skull
- Intervertebral disc
- Intervertebral disc centre
- Bone marrow
- Fat
- Skin

No age-related effect

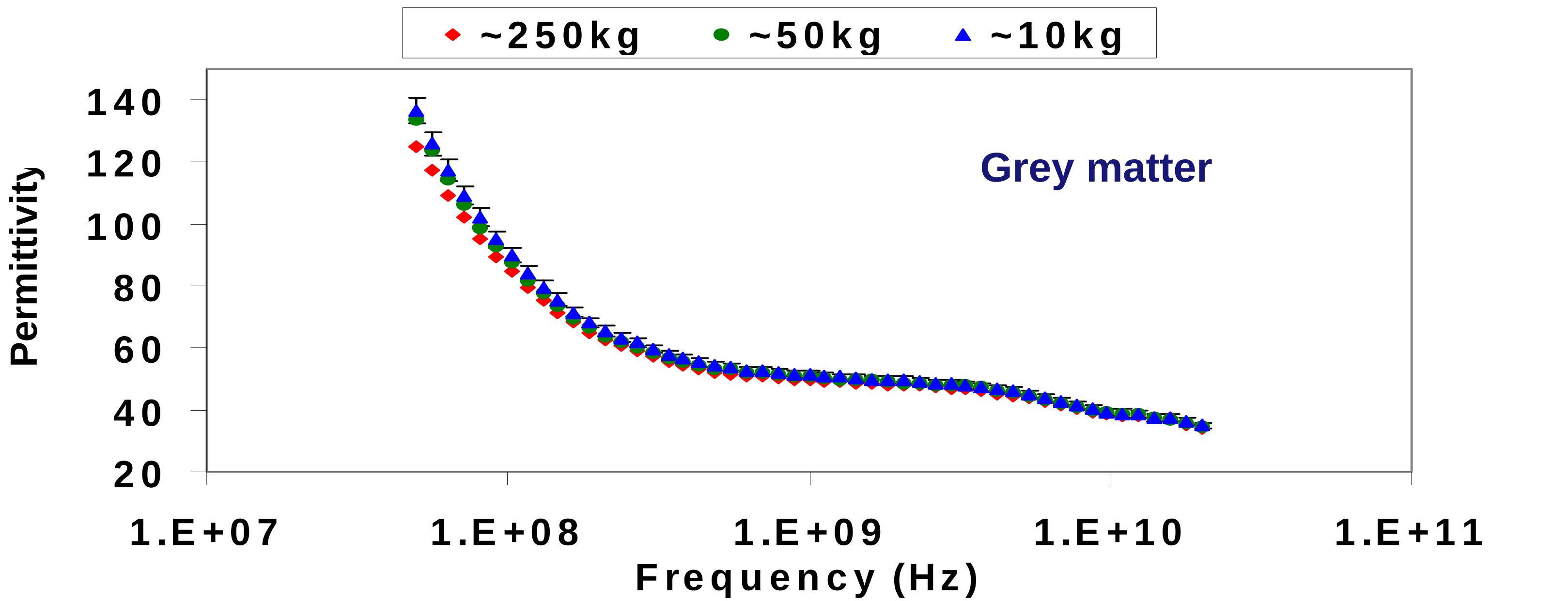
- Grey Matter
- Tongue
- Cornea
- Mammary fat

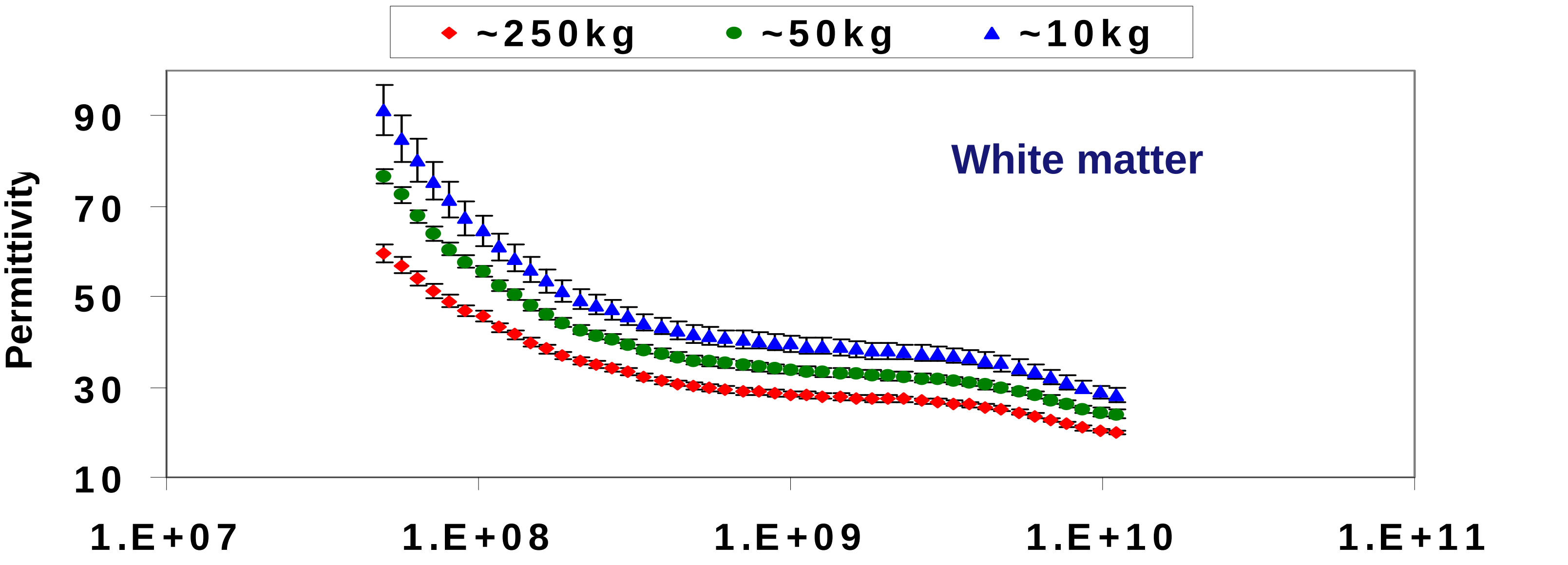
No difference between *in-vivo* and *in-vitro* at microwave frequencies

Peyman A, Holden S J and Gabriel C, 2007, Dielectric Properties of Porcine Cerebrospinal Tissues at Microwave Frequencies; In-vivo, In-vitro and Systematic Variation With Age, Phys. Med. Biol. 52 (2007) 2229-2245

Peyman A, Holden S and Gabriel C, 2009 Dielectric Properties of Porcine Skeletal Tissues at Microwave Frequencies; In-

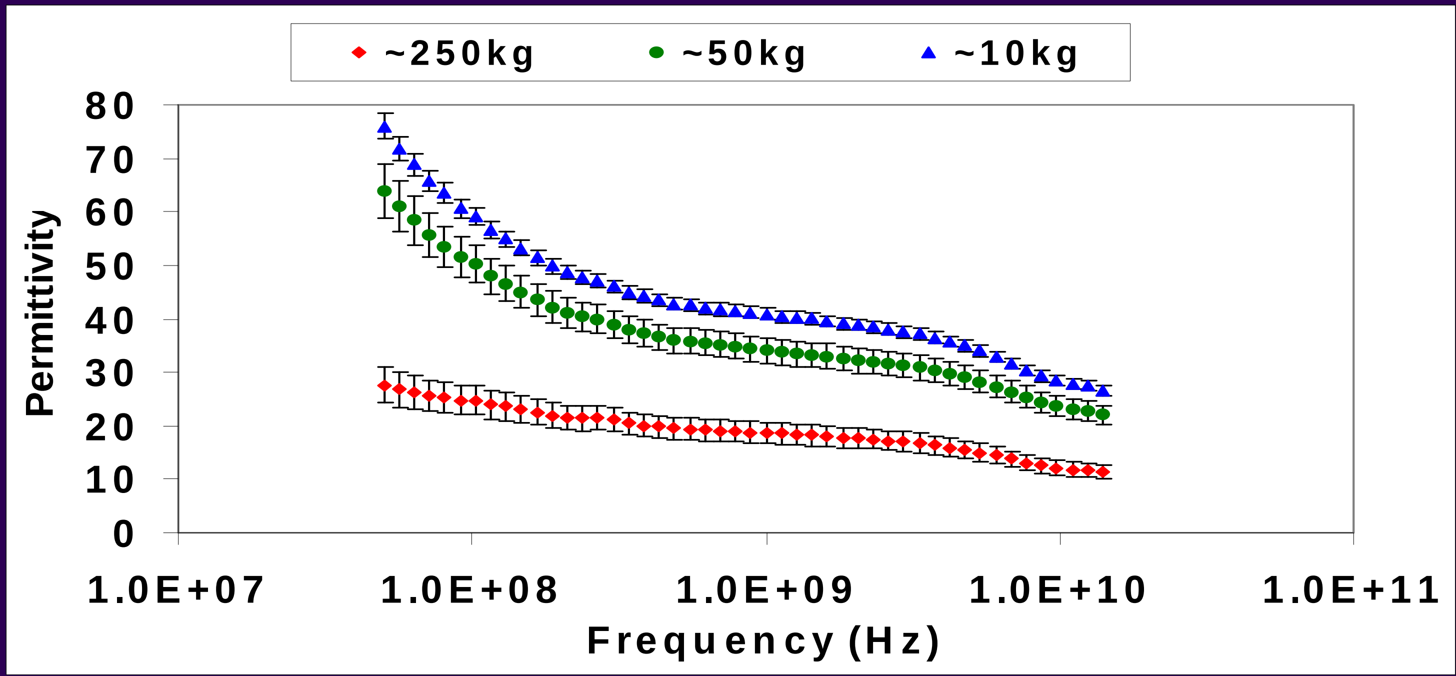
Results: Brain Tissues

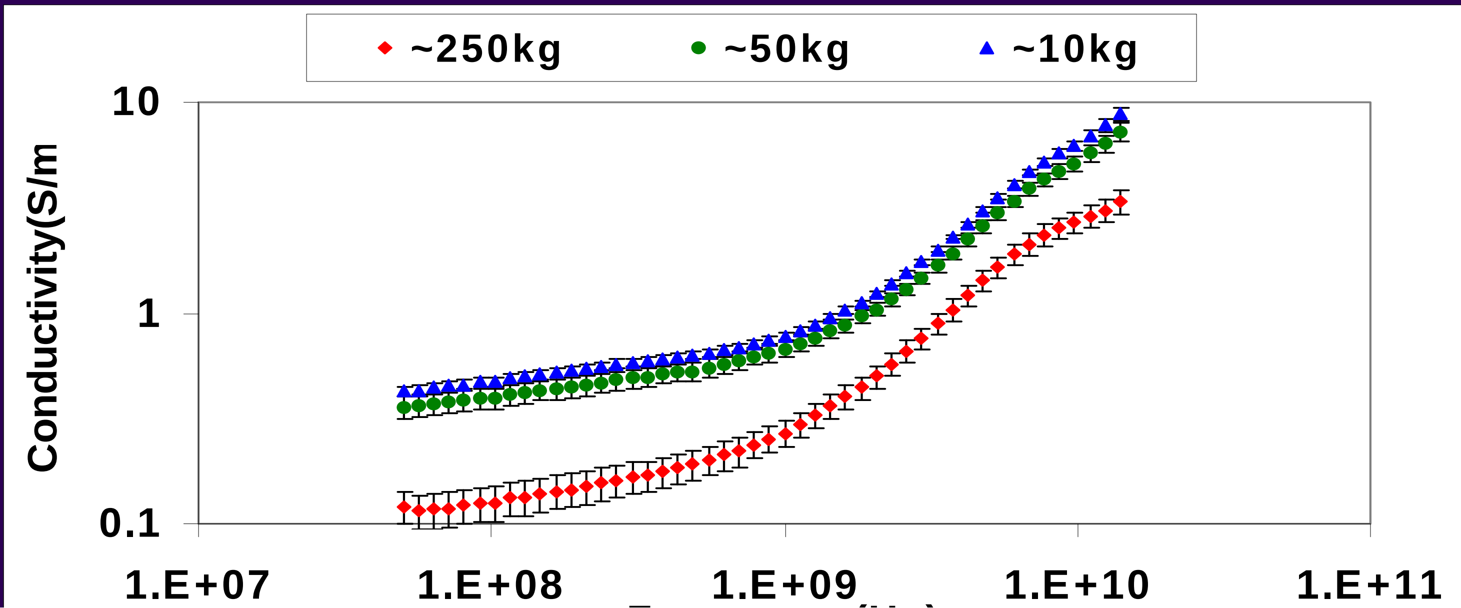




The differences between the two extremes are of the order, or in excess, of three times the measurement uncertainty

Results: Skull

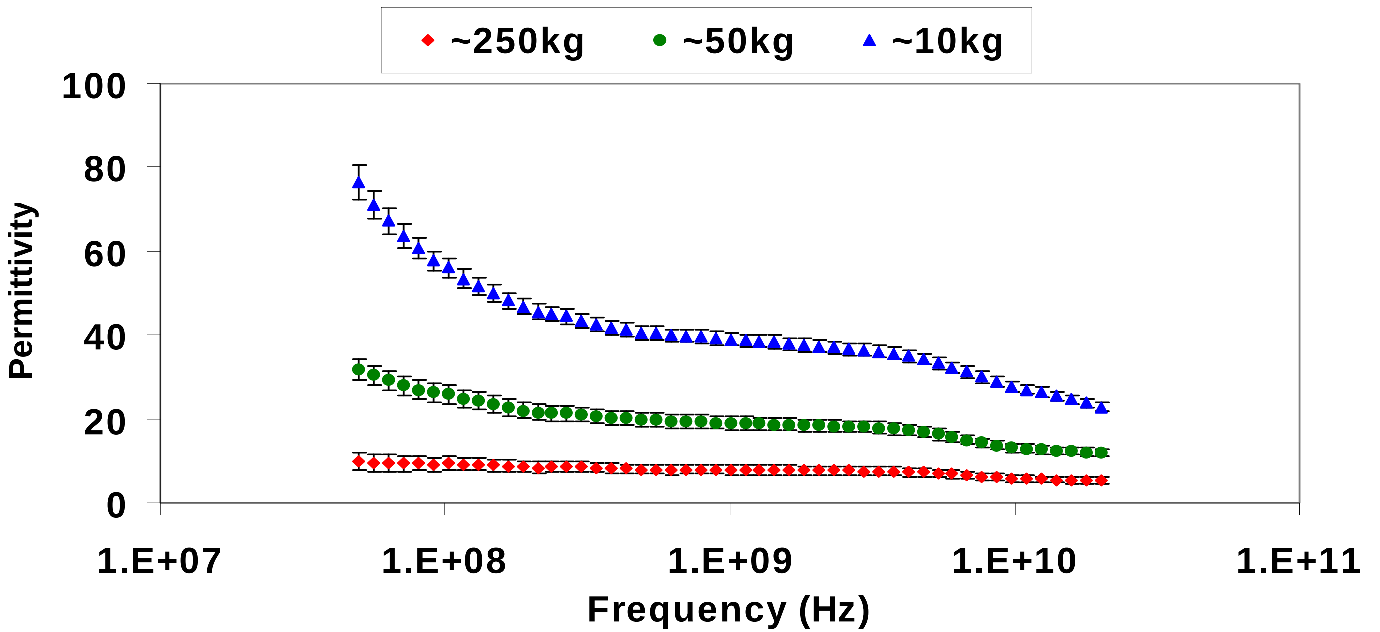


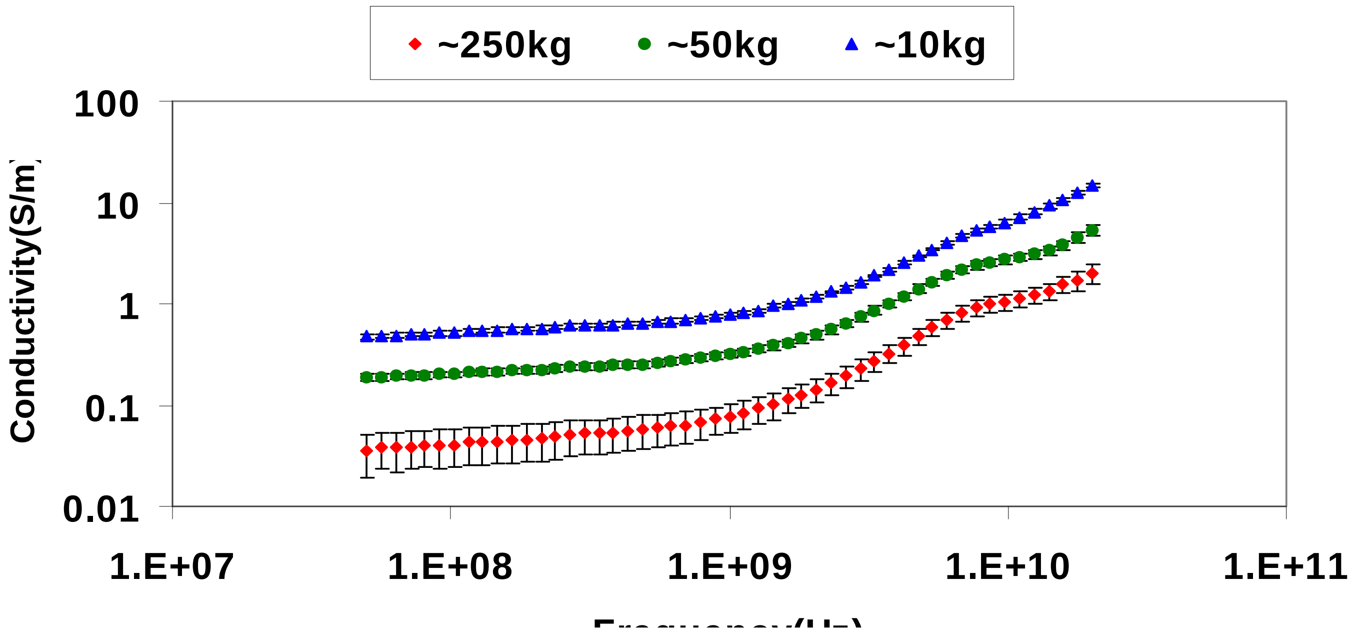


At 900MHz:

%decrease in permittivity and conductivity values when animal aged from 10kg to 250kg are 54.3 and 65.9% respectively

Results: Bone marrow





At 900MHz:

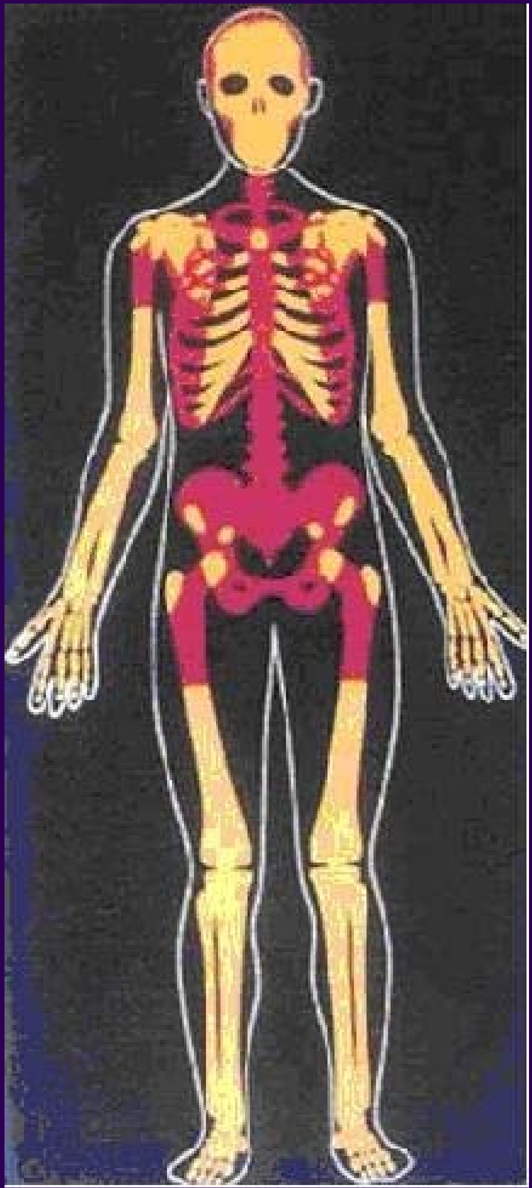
%decrease in permittivity and conductivity values when animal aged from 10kg to 250kg are 79.8% and 90.2% respectively

Why?

- For white matter and spinal cord
  - Increased myelination
  - High lipid and low water content of myelin.
  - Decreased water content as a function of age
  - MRI scans of infant brains differ from scans in later childhood primarily because of the much higher water content and a much lower myelin deposition in infant brains (Peterson and Ment 2001).

- For bone tissues
  - Variations in the amount of water due to changes in the degree of mineralisation of the calcified bone matrix.
  - During mineralisation of the osteoid, water is gradually replaced by calcium apatite, which fills the volume previously occupied by water,

Bone Marrow



In the young animals the marrow is mostly red and as the animal grows older, the marrow acquires a higher fat content and hence a yellow colour.

In the adult most bones contain yellow marrow and red marrow is limited to the spongy bone in the skull, ribs, sternum, clavicles, vertebrae and pelvis.

Normal adult bone marrow contains an age-related proportion of fat cells (This can be up to 60% fat in rib and vertebra and over 80% in femur).

The red bone marrow has higher water content compare to yellow bone marrow, which contains fat cells, therefore accounts for higher dielectric values in younger animals.

(Allen *et al.* 1995 and Data from Custer RP, Ahlfeldt FE. *J Lab Clin Med* 1933 17 960–963)

Cole–Cole parameters for the dielectric properties of porcine tissues as a function of age at microwave Frequencies

Peyman A and Gabriel C, Phys. Med. Biol. 55 (2010) N1–N7

Sensitivity of SAR to Variation in Dielectric Properties

- Can the extent of the finding be sufficient to affect the SAR values?

- To the best of our knowledge three studies have so far used dielectric properties as a function of age in their dosimetric calculations.

  – Alfadh et al 2003 and Gabriel 2005 (Far field exposure, plane waves, rat models)

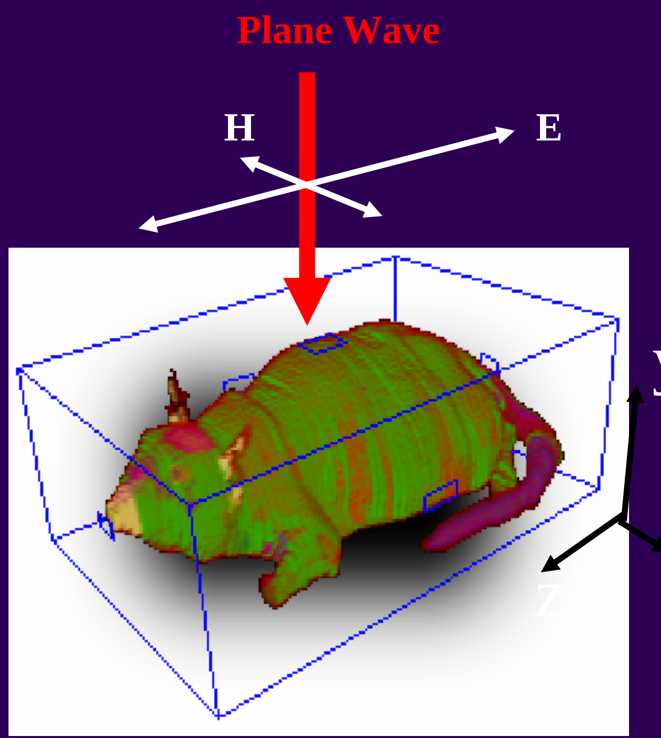
  – Peyman et al 2009 (Near field exposure of children to walkie-talkie devices)

  – Christ et al 2010 (Near field exposure to handsets at 900 MHz and 1800 MHz)

Sensitivity of SAR to Variation in Dielectric Properties
(Far Field Exposure)

- Model: Rat - Size equivalent to 10, 30 and 70 days old, FDTD
- Frequency 27, 160, 400, 900 and 2000 MHz
- 34 Tissue-types (9 of them had variation with age)

- Changing the tissue dielectric properties:
  - Affects the localised SAR but no clear pattern could be established
  - Affects the coupling with the body and the interaction of tissues with the electromagnetic fields.
  - Dielectric properties of skin is an important factor in the coupling efficiency and hence the intensity of the exposure
  - It is important to isolate the effect of changing tissue properties from all size and exposure parameters effects



Alfadh Y, Chiau CC, Wang Z, Chen X, Peyman A and Gabriel C, 2003, Numerical dosimetry on 10, 30 and 70 days old rat models exposed to a wide range of frequencies and dielectric properties, ST-9 BEMS 25th Annual Meeting Maui, Hawaii, USA

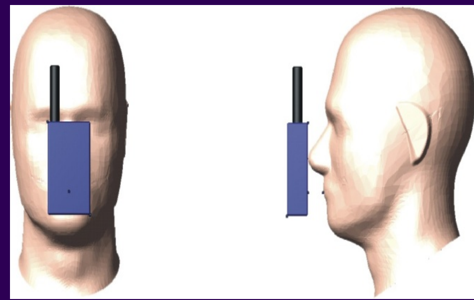
Gabriel C 2005 Review: Dielectric Properties of Tissues: Variation with Age , Bioelectromagnetics Supplement 7:S12-S18

Sensitivity of SAR to Variation in Dielectric Properties
(Near Field Exposure, Walkie-Talkie devices)

Health Protection Agency

Ghent University, Belgium

- Frequency: 446MHz, effective radiated power (ERP):250 mW
- Phantoms represent Adult, 3 and 7 years old child
- Dielectric properties of10 kg pig (1-4 year old), 50 kg pig (11-13 years old) and 250 kg pigs (adults) were used.
- Variation on SAR_{10gr} are less than 10% for the investigated configuration
- The variation of the tissue properties are not really reflected in a variation of SAR_{10gr}
    - Averaging of the SAR dilutes the effect of the change in the SAR_{10gr}
    - Head tissues do not contribute equally in the averaging volume
    - Not all tissues in the averaging volume have the same variation of the dielectric properties with age, in this case only skin contributed to the variation within the 10gr cube.



Peyman A, Gabriel C, Grant EH, Vermeeren G and Martens L, 2009, Variation of the dielectric properties of tissues with age:

Sensitivity of SAR to Variation in Dielectric Properties
(Near Field Exposure, Handset 900 and1800MHz)
IT'IS, Zurich

Health Protection Agency

- **3 anatomical head models: Visible Human (VH), 3 and 7 year old children (3YC, 7YC)**
- **16 tissue types @ 900MHz & 1800MHz, dielectric properties of 10kg, 50kg and 250 kg pigs were used.**
- **Generic dual band phone (900MHz and 1800MHz) with internal antenna**
- **SAR variations due to the age dependent changes within ±30%**
- **The hypothesis that the dielectric parameters results in larger exposure of young mobile users could not be confirmed**
- **May be due to the fact that highest age dependent variations occur in tissues with low**

Age Dependent Tissue-Specific Exposure

- Age dependencies of dielectric tissue properties do not lead to systematic changes of the peak spatial SAR. This is valid for all the configurations analyzed here (phone models, positions, etc)

- The exposure of the bone marrow of children can exceed that of adults by about a factor of ten. This is due to the strong decrease in electric conductivity of this tissue with age

Christ A, Gosselin MC, Christopoulou M, Kühn S and Kuster N 2010 Age-dependent tissue-specific exposure of cell phone users Phys. Med. Biol. 55 1767

More Recent and Ongoing Studies

- Increase interest in simulating the exposure of pregnant women and their in-utero foetuses.
- In the absence of dielectric properties for pregnancy-specific tissues, substitutes are used
  - muscle (or blood) data for placenta
  - cerebrospinal fluid (CSF) for amniotic fluid.
- Dielectric properties of human placenta, umbilical cord and amniotic fluid
  - study completed and results are published

Peyman A, Gabriel C, Benedickter H R and Fröhlich J 2011 Dielectric properties of human placenta, umbilical cord and amniotic fluid Phys. Med. Biol. 56 (2011) N93-N98.

Dielectric properties of pregnancy associated tissues; Highlights of results:

- Dielectric properties of placenta are higher than muscle and slightly lower than blood; generally closer to blood than muscle
- The measured dielectric properties of umbilical cord, were higher than those of placenta mainly due to the presence a thick and whitish high water content substance called Wharton's jelly which cannot be found on any other part of human body.
- Strong temperature dependance of dielectric properties of amniotic fluid
- Amniotic fluid has higher permittivity and lower conductivity compared to those of CSF

More detailed analysis of the results will be presented at BEMS 2011, Halifax

Ongoing Study

- Dielectric properties of rat foetus as a function of gestation age final analysis of experimental data
  - Data collection is completed
  - *Results will be presented at BEMS 2011, Halifax*

Summary

- Numerical modelling tools have been improved over the last 20 years, from coarse geometrical models to very high resolution models based on real human imaging data.

- Measurements of dielectric properties of tissues are also moving towards more in-detail information, expanding the number of tissues defined in the models and taking into consideration the variation of data with age.

- It is the matter of reassurance that the studies so far did not show any significant differences in the calculated SAR values due to higher conductivity values for younger tissues.

- However, in some cases, for instance single tissue exposure such as bone marrow, the differences can not be neglected.