# SAR-distribution in human beings exposed to RF radiation with regard to small structures and thermo-physiological parameters

**G. Schmid[1], R. Überbacher[1], T. Samaras[2],**
**P.R. Mazal[3], A. Jappel[4], W.-D. Baumgartner[4], M. Tschabitscher[5]**

[1] ARC Seibersdorf research GmbH, A-2444 Seibersdorf, Austria
[2] Aristotle University of Thessaloniki, GR-54124 Thessaloniki, Greece
[3] Department of Clinical Pathology, Medical University Vienna, A-1090 Vienna, Austria
[4] Department of Otolaryngology, Medical University Vienna, A-1090 Vienna, Austria
[5] Center for Anatomy and Cell Biology, Medical University of Vienna, A-1090 Vienna, Austria

# Background:

- Available numerical head models do not, if at all, acurately represent small anatomical structures (e.g. inner ear, pineal gland, eyes, skin)

  ⇒ RF-power absorption in these organs unknown so far

  ⇒ Question of RF-induced temperature elevations in these organs under realistic thermophysiological assumptions

  ⇒ Impact of spatial SAR-averaging mass (10g in most current standards)

  ⇒ Impact of temporal SAR-averaging (6 min. in most current standards)

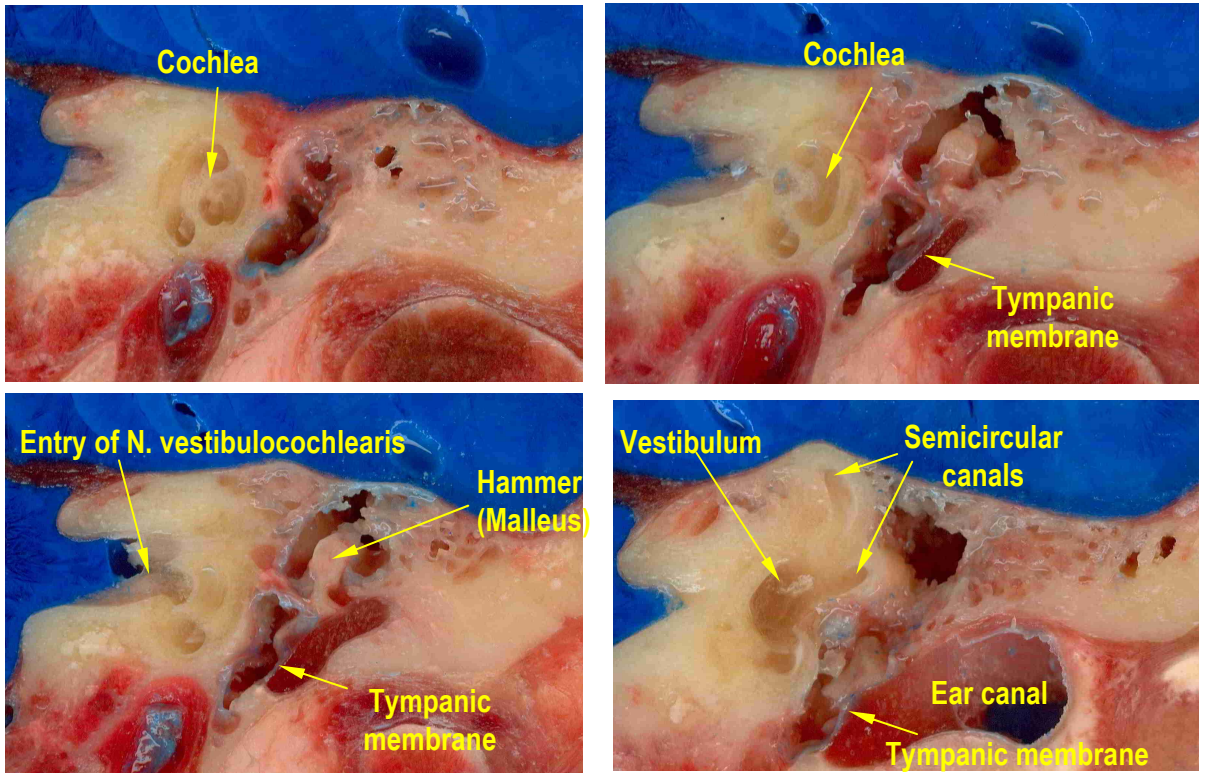
# Project Outline:

- Development of high resolution (0.1 mm x 0.1 mm x 0.1 mm) numerical models of target regions (inner ear, pineal gland, eye) based on real human tissue samples
- „Implantation“ of these HR organ models into an available head model
- Measurements of dielectric as well as thermal tissue properties, where literature data is lacking (pineal gland, peri-/endolymph liquid)
- FDTD-based computations of RF absorption with generic source models representing typical transmit devices operated close to the head (400 MHz, 900 MHz, 1850 MHz)
- FDTD-based thermodynamic computations in order to estimate RF-induced temperature elevations under realistic thermophysiological conditions

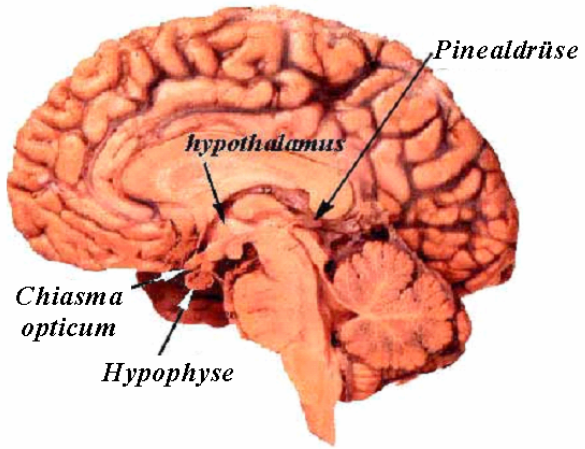
# 1. Development of righ resolution organ models:

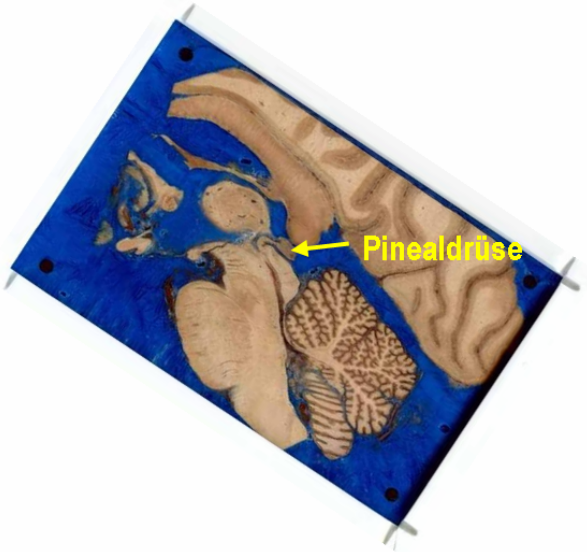
- ***Slice generation (0.1 mm steps) by frozen section technique*** *(tissue from a male adult)*

***Middle Ear and Inner Ear***

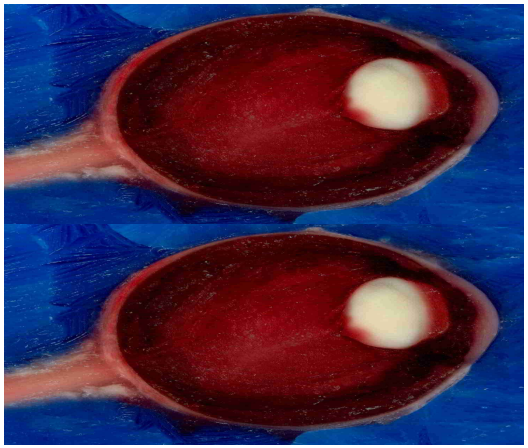


## Pineal gland



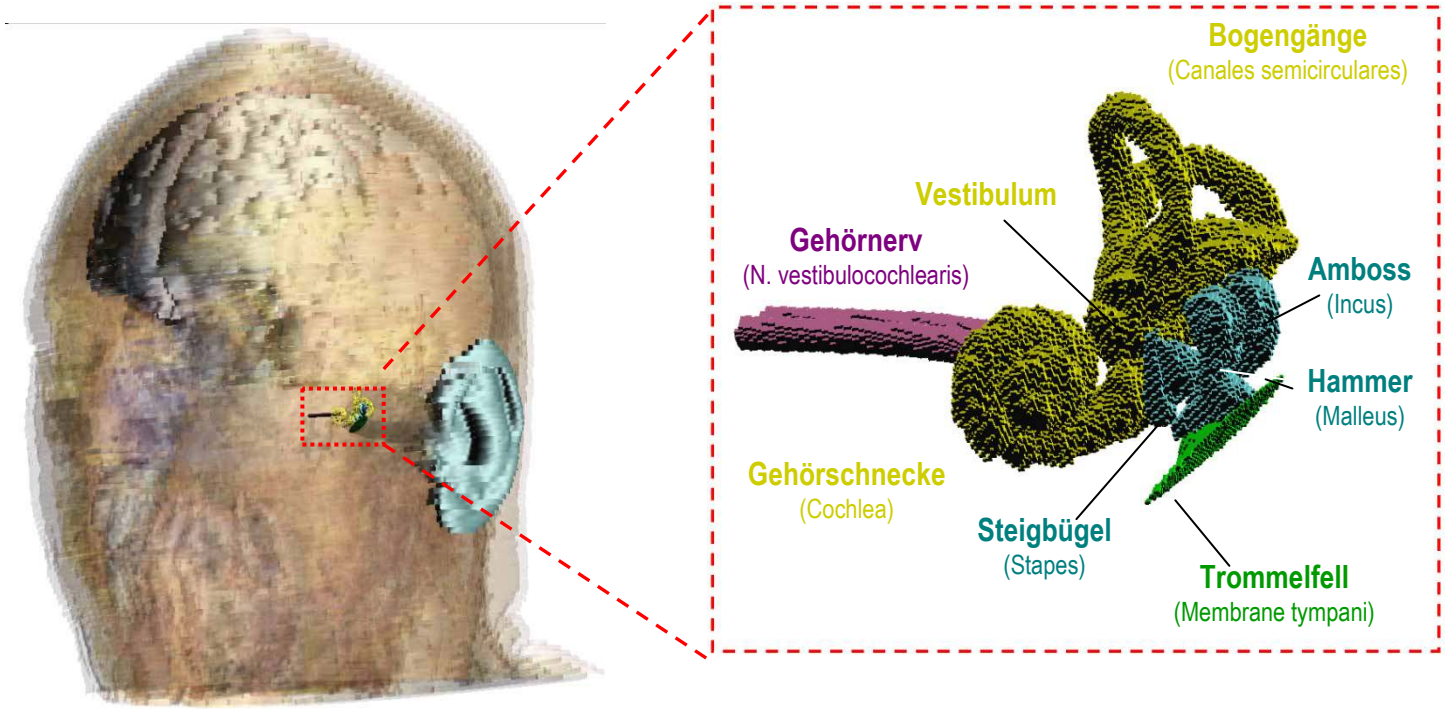

## Eye



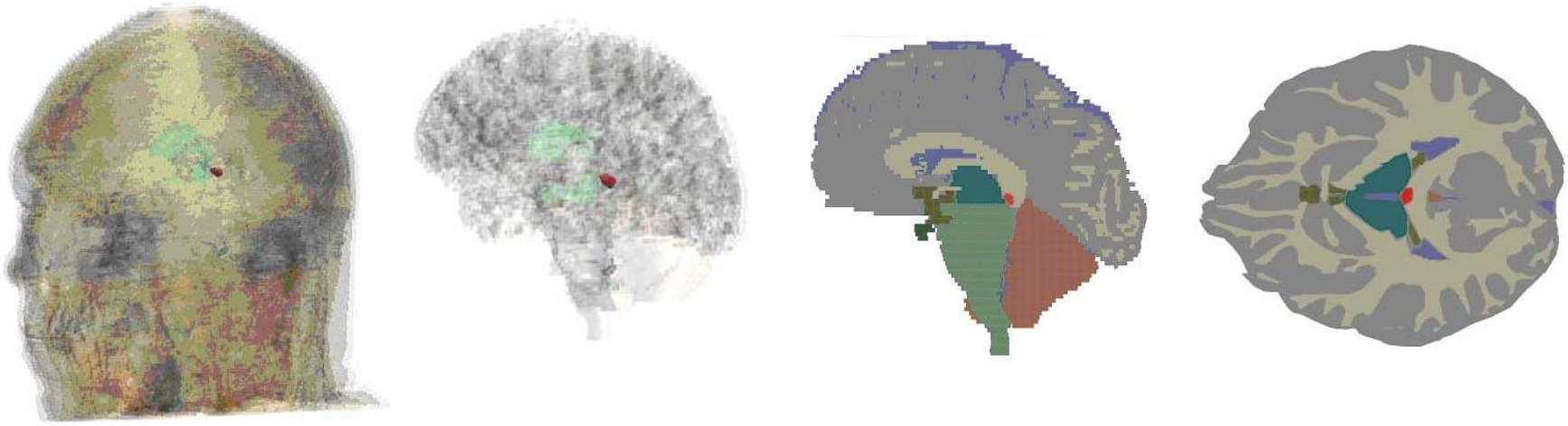
- ***Segmentation of slices (0.1 mm x 0.1 mm):*** *carried out by IT'IS Foundation*

# 2. „Implantation“ into available head model:

## *Middle Ear and Inner Ear*

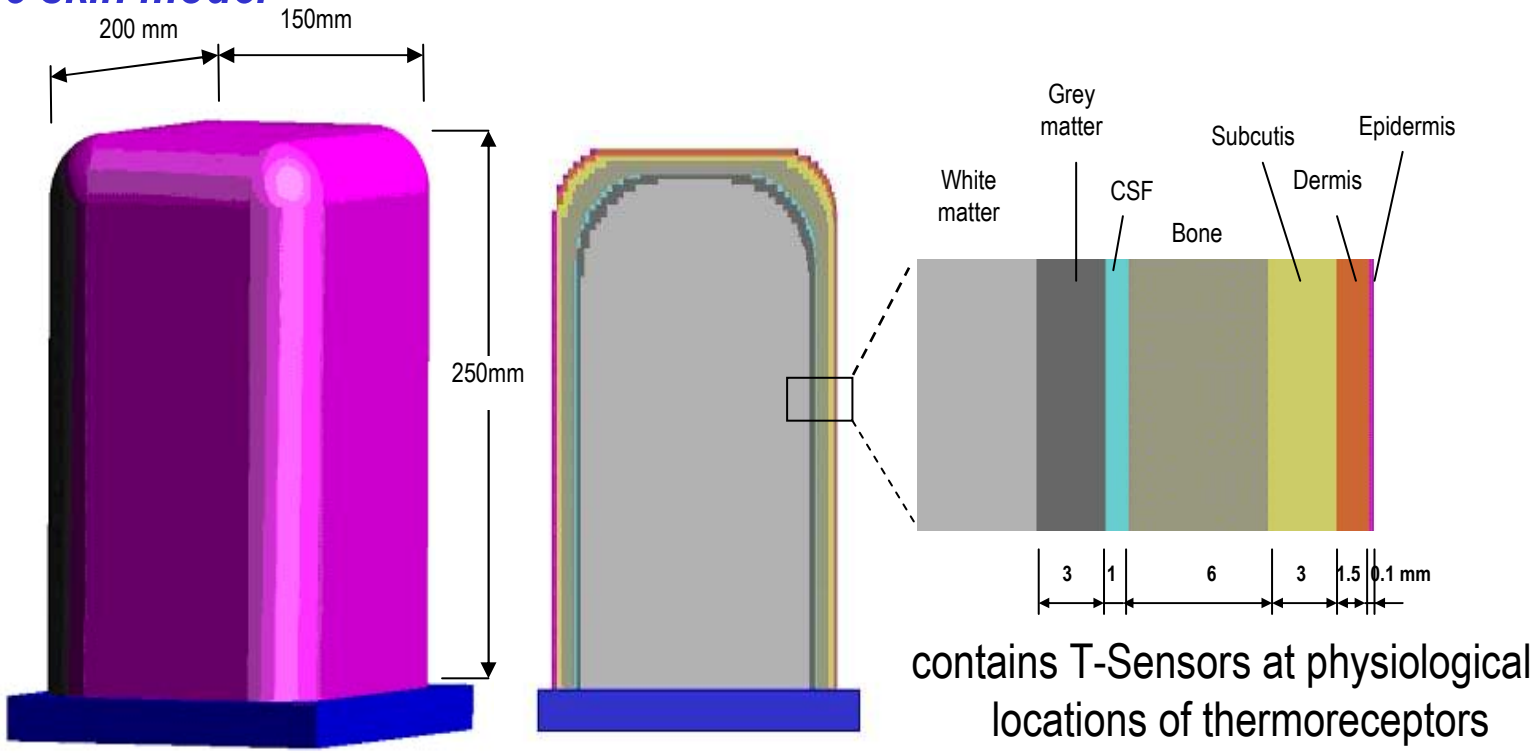


## Pineal gland



## Eye

## Generic skin model

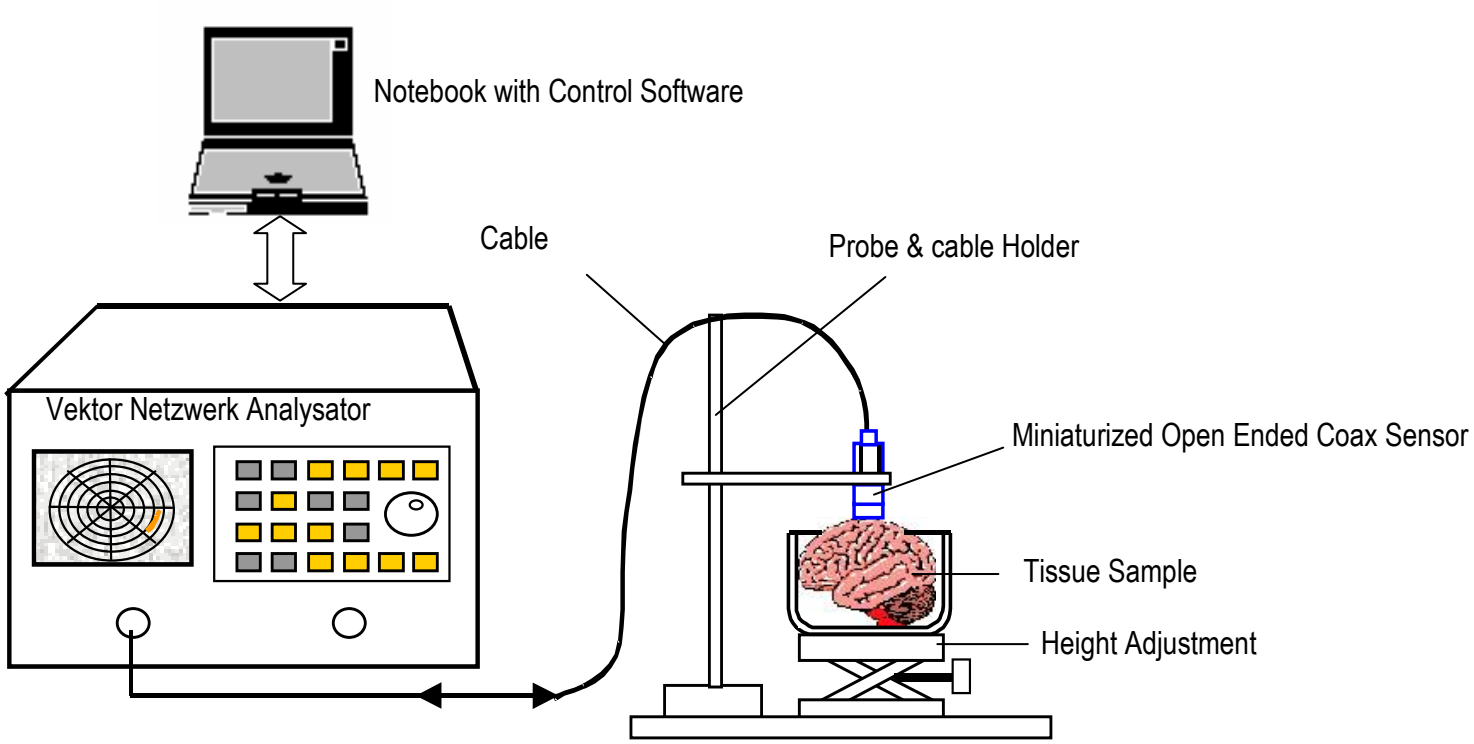



contains T-Sensors at physiological locations of thermoreceptors
(Hendler et al. 1963)

⇒ ***to investigate separately temperature elevations by RF-absorption, by isolation and by case heating (due to power dissipation inside the phone)***

# 3. Measurements of tissue properties:

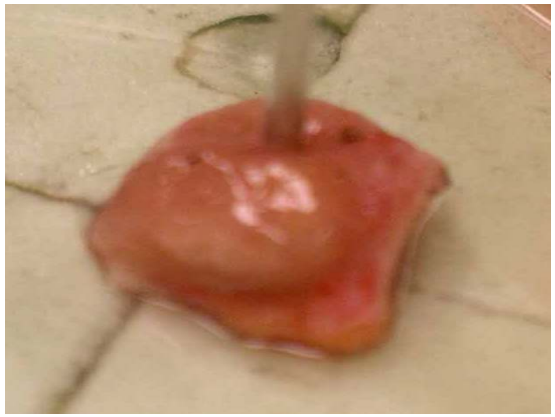
## *Dielectric Properties ( 1 mm diameter Open Ended Coax Sensor)*

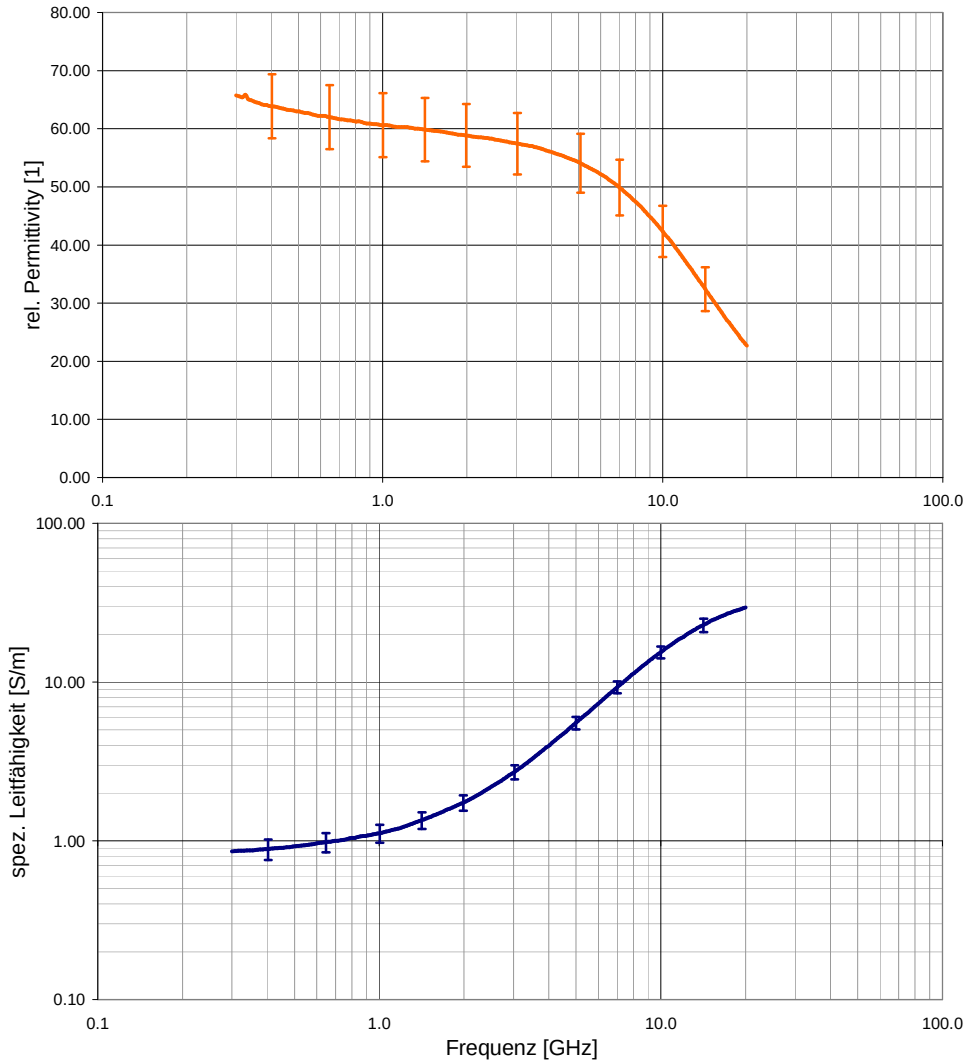


## *Pineal Gland:*

**20 glands ≤ 20 hours post mortem, excised during autopsy**

(approved by ethics commission)

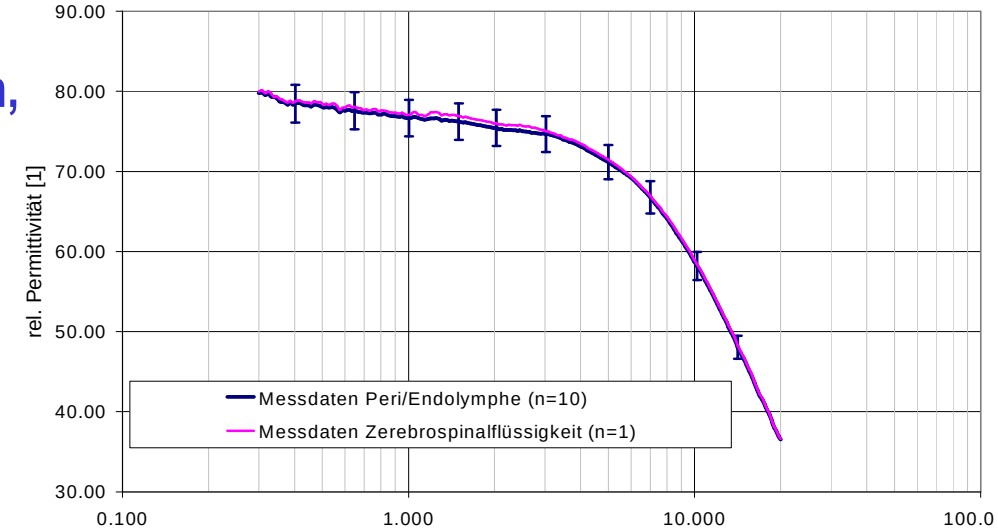


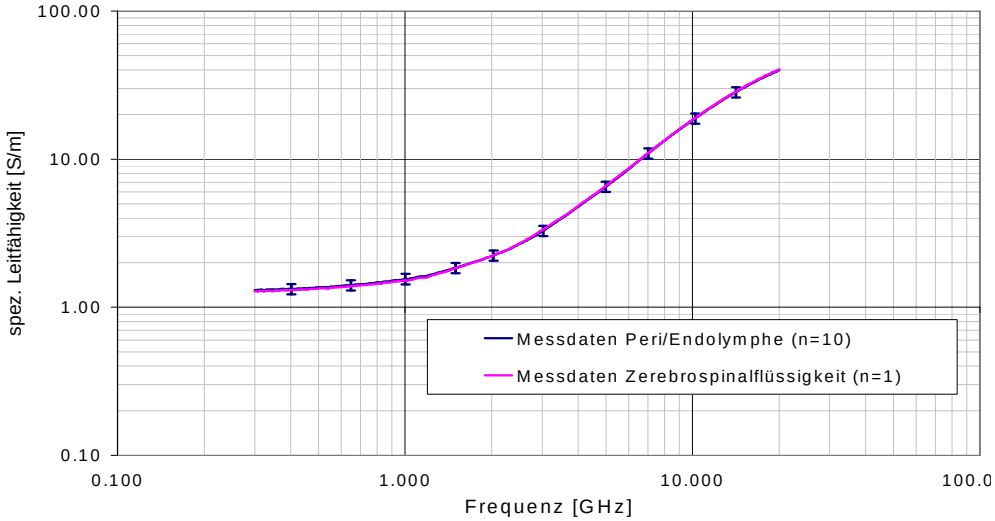


## *Perilymphe / Endolymphe:*

**10 samples ≤ 20 hours post mortem, excised during autopsy**

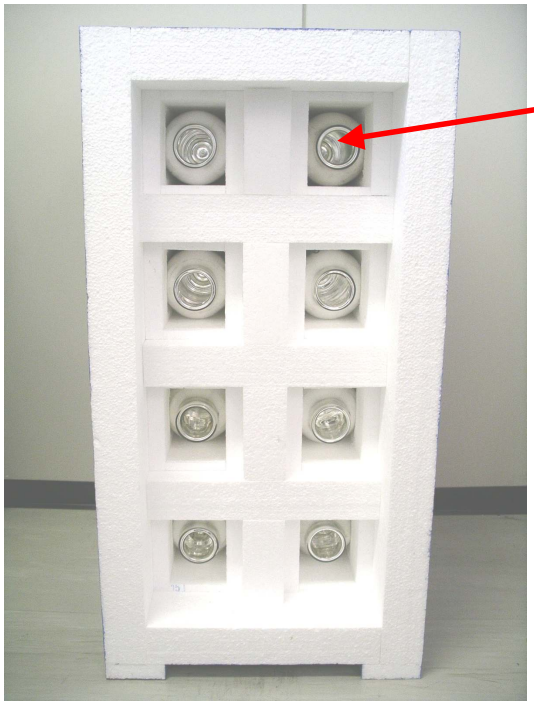
(approved by ethics commission)



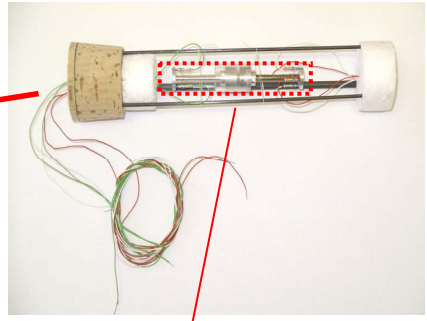




⇒ *practically the same as CSF*

# *Thermal Properties ( miniaturized calorimeter for sample mass less than 1 g)*



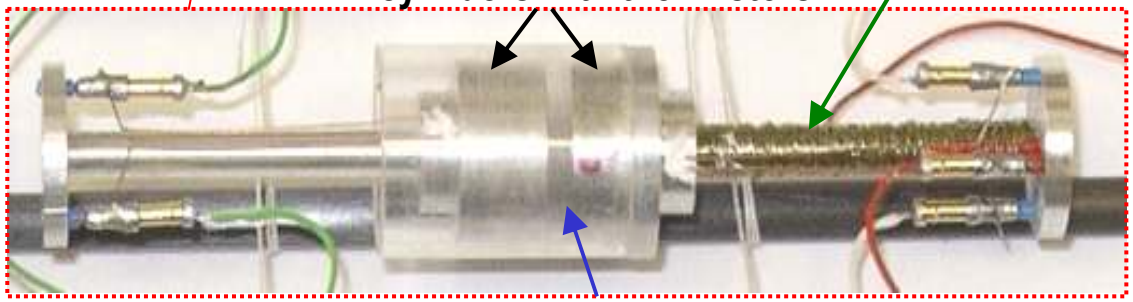
8-chamber calorimeter



single channel

**heat source**
(copper wire coil)

**Al – cylinders with thermistors**



**Sample**

After calibration (water), thermal conductivty ***k*** and specific heat ***c*** can be derived from time course of temperature change and steady state temperature, respectively.

## *Obtained thermal properties of Pineal Gland and Brain tissue:*

## ≤ 20 hours post mortem, excised during autopsy

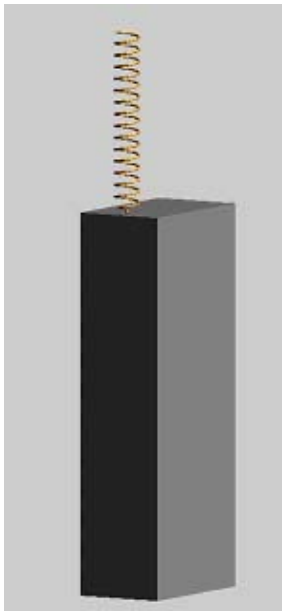
(approved by ethics commission)

| | Mass density ρ [kg/m$^3$] | Specific heat c [J/(kg.K)] | Therm. Conductivity k [W/(m.K)] |
|---|---|---|---|
| Pineal gland | 1,11 | 4000 | 0,60 |
| Grey matter | 1,03 | 3900 | 0,60 |
| White matter | 1,02 | 3700 | 0,50 |

# 4. Considered Exposure Scenarios:

## *RF-Sources: Generic Box-Phones at 400 MHz, 900 MHz, 1850 MHz*

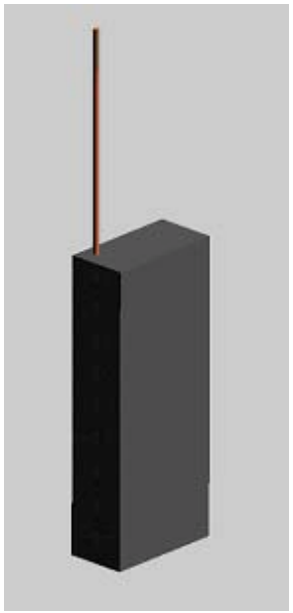
***400 MHz***



***Helix antenna***

*Case: 130 x 50 x 30 mm$^3$*

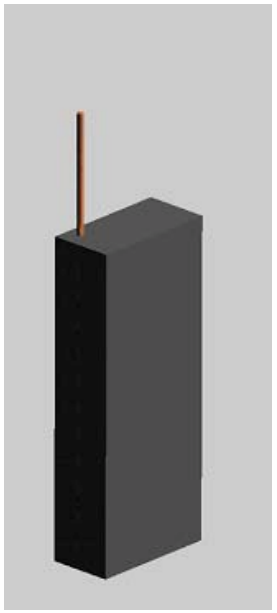
***900 MHz***



***λ/4 Monopole antenna***

*Case: 100 x 40 x 20 mm$^3$*

***1850 MHz***

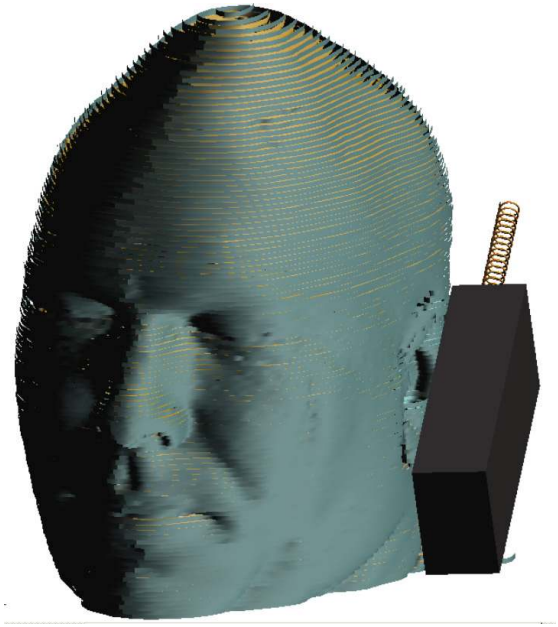


***λ/4 Monopole antenna***

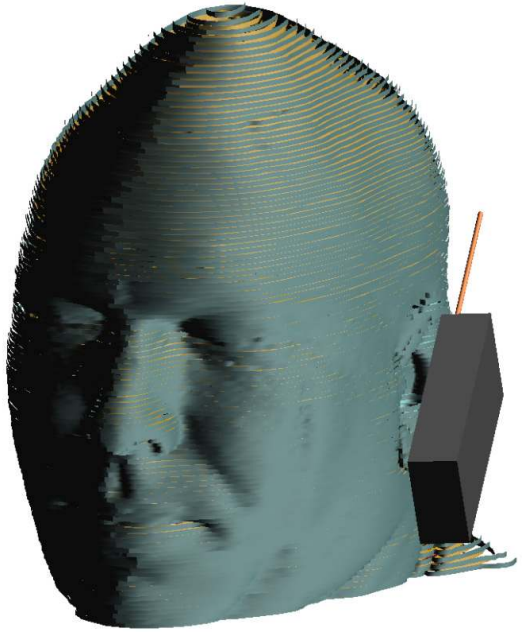
*Case: 100 x 40 x 20 mm$^3$*

# Side Exposure („Tilt“):

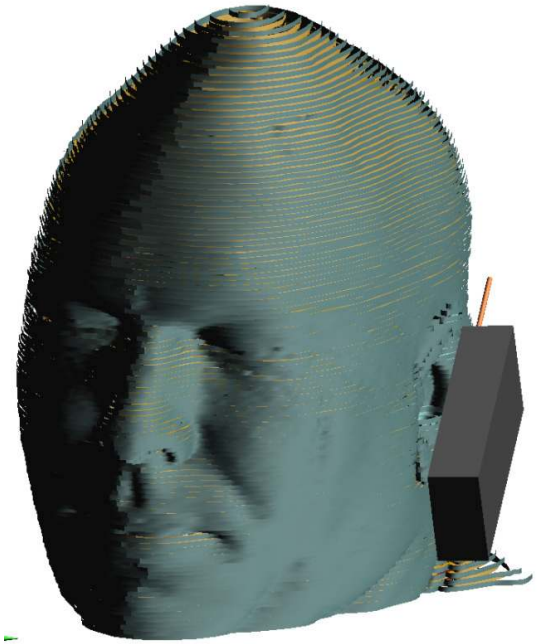
400 MHz



900 MHz

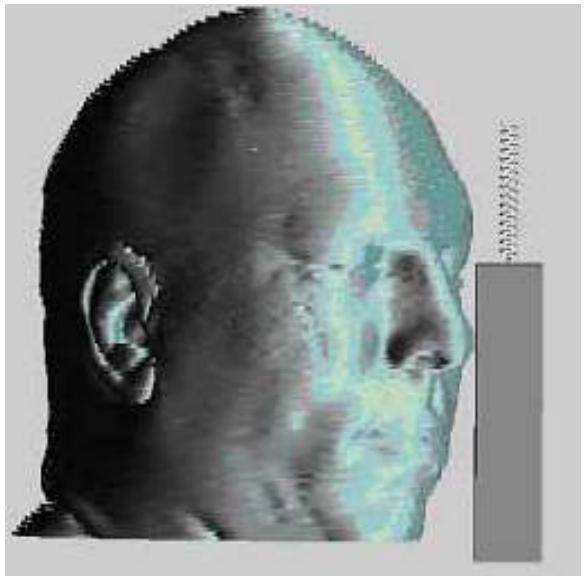


1850 MHz

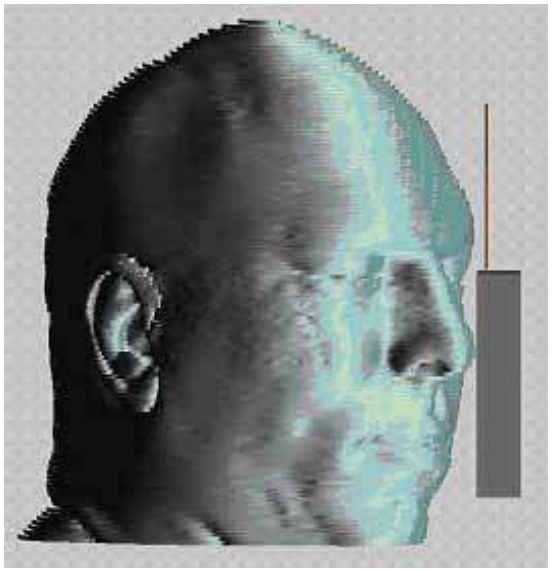


# Front Exposure (Eye):

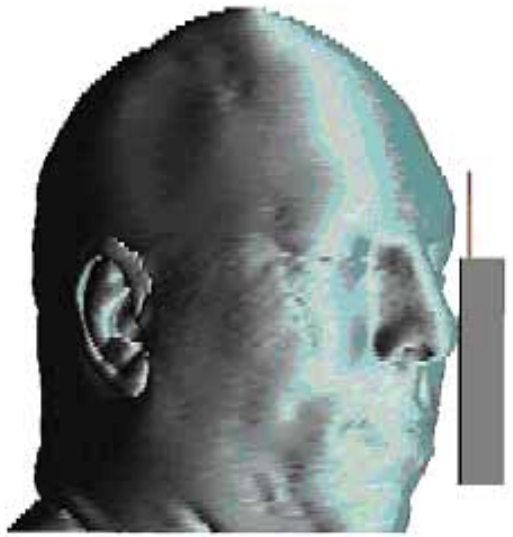
400 MHz



900 MHz



1850 MHz



# 5. Computational Tools used:

## *SEMCAD X Simulation Platform (FDTD)*

- **EM Solver**
- **Thermal Solver (Pennes' *Bioheat Transfer Equation*)**

$$\rho c \frac{\partial T}{\partial t} = \nabla k \cdot \nabla T + (\rho c)_b w_b (T_a - T) + q_m$$

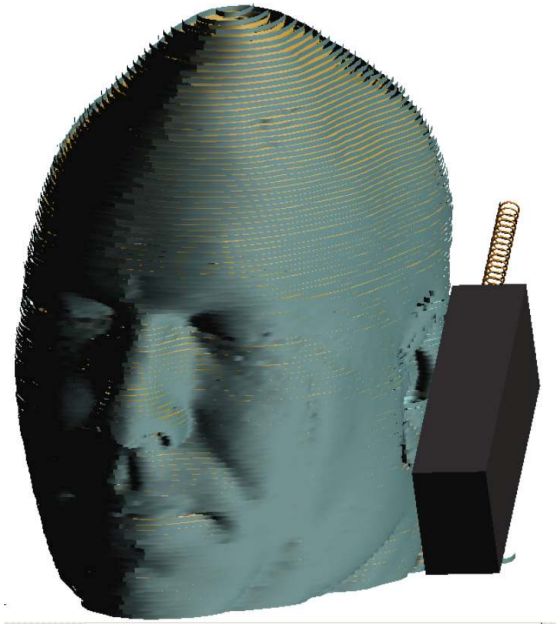
ρ… mass density (kg/m$^3$)
c …specific heat (J/kg.K)
k …thermal conductivity (W/m.K),
w …blood flow rate (m$^3$/s)/m$^3$)
q …meatbolic heat production (W/m$^3$)

Indices: a…arterial
b…blood
m…metabolic

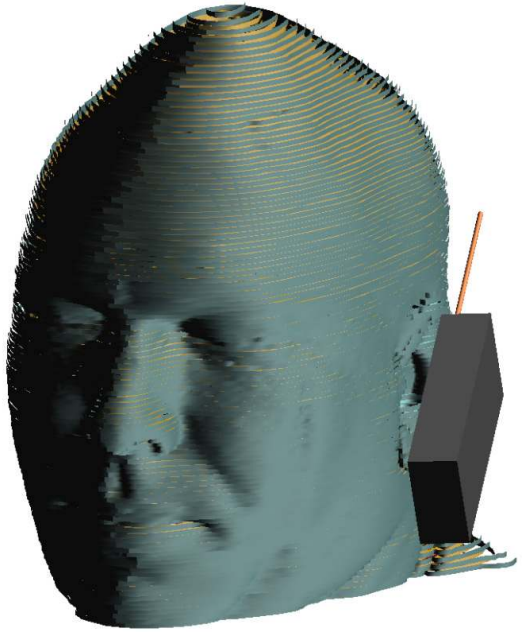
# 6. Results:

## *Side Exposure („Tilt“):*

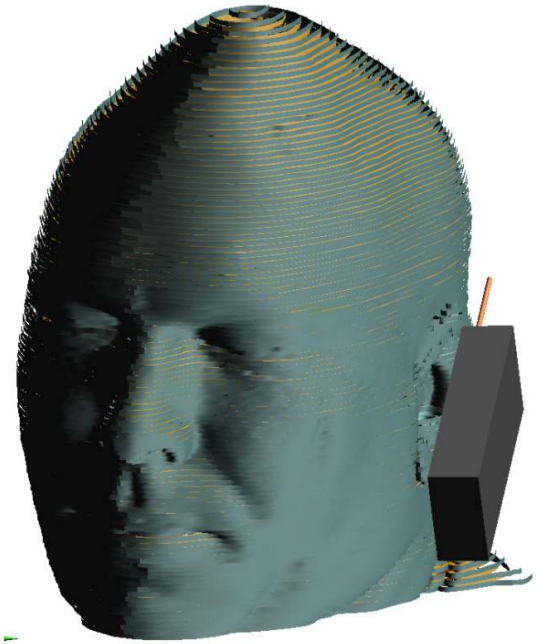
*400 MHz*



*900 MHz*

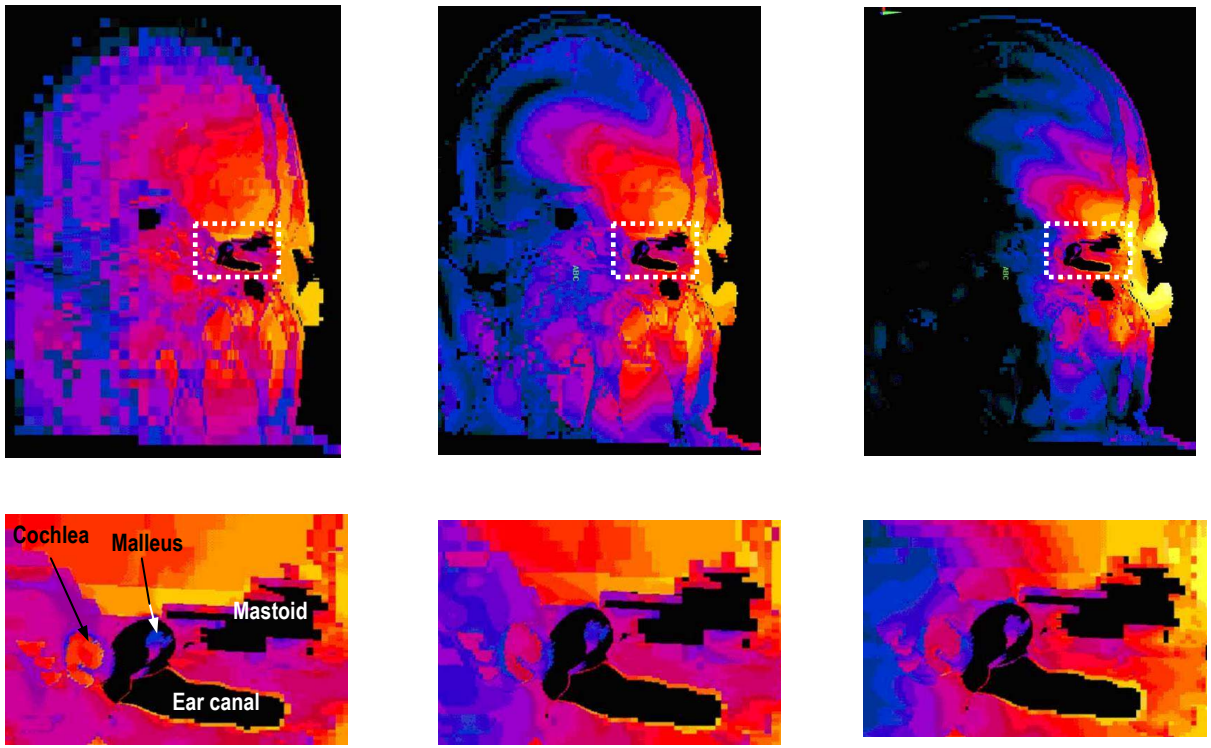


*1850 MHz*



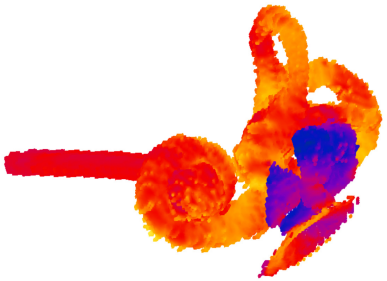
## *Side Exposure:* SAR- Distribution (normalized to 1 W)

400 MHz | 900 MHz | 1850 MHz



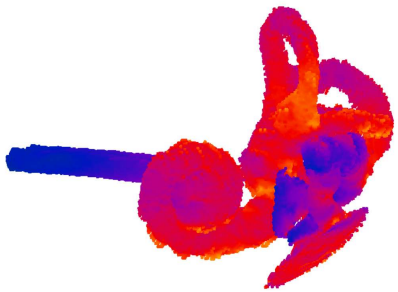
## *Side Exposure:* SAR on Middle/Inner Ear Organs (normalized to 1 W)

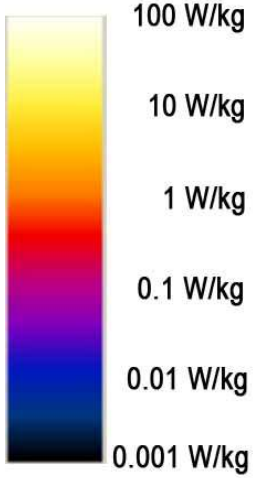
400 MHz



900 MHz

1850 MHz



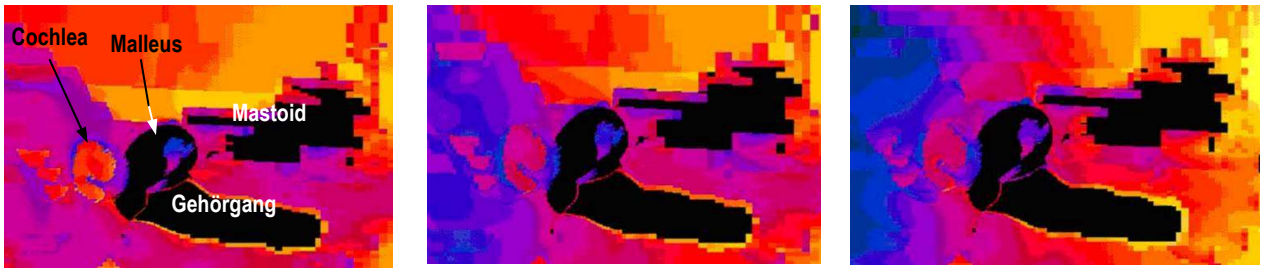


# *Side Exposure:*

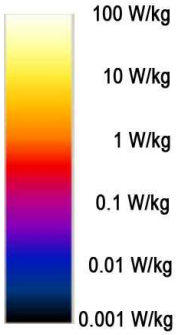
## SAR vs. Temperature Distribution

400 MHz | 900 MHz | 1850 MHz

SAR

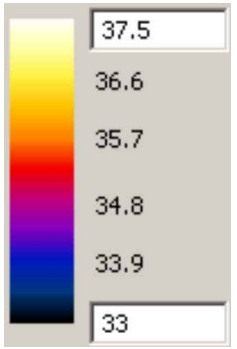



**SAR-Scale**




Temperature

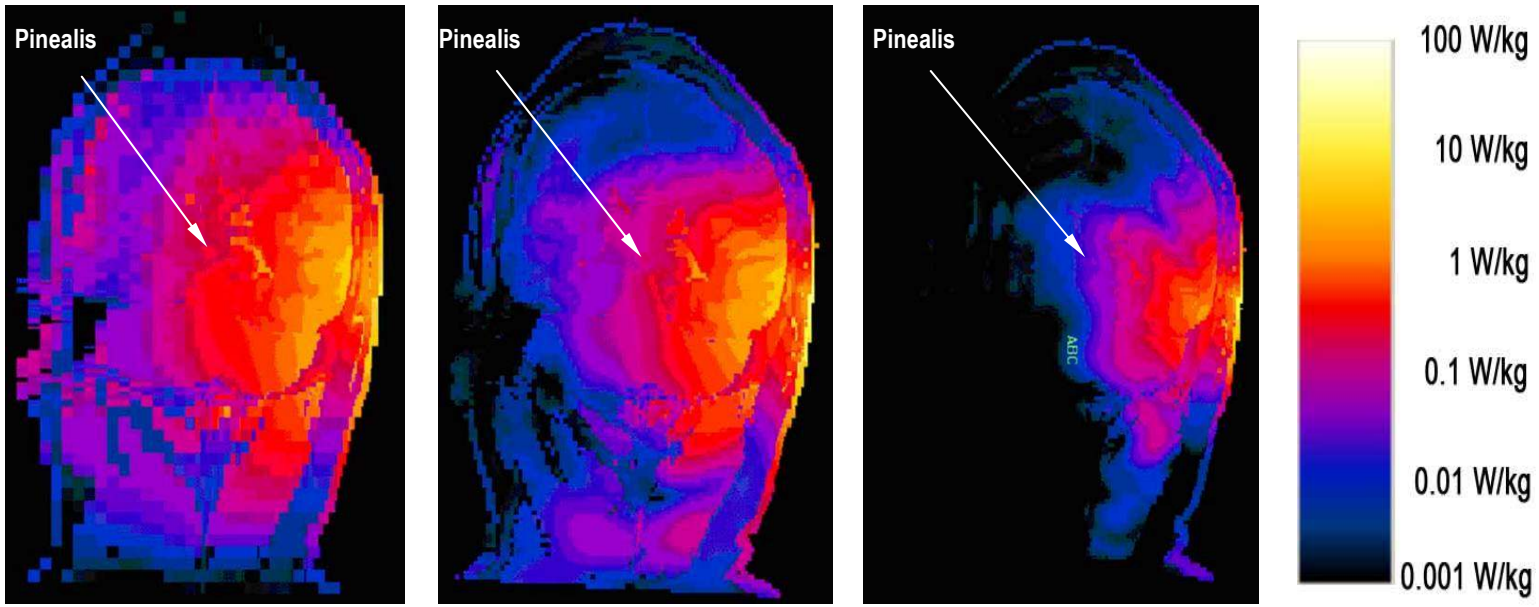
**Temperature scale in °C**



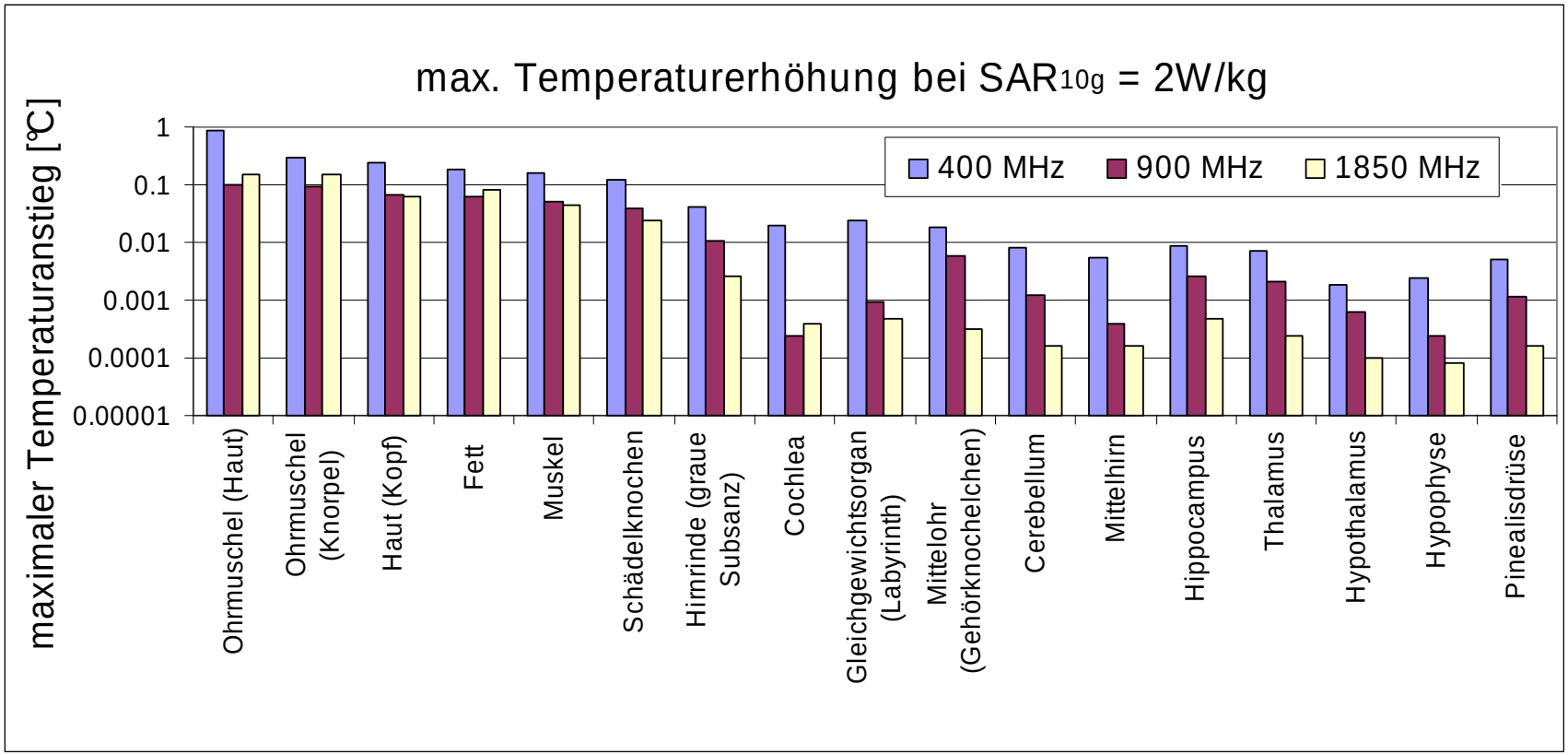

⇒ SAR-“Hot Spots“ **do not cause** relevant Temperature-“Hot Spots“

## *Side Exposure:* SAR in the Pineal Gland (normalized to 1 W)

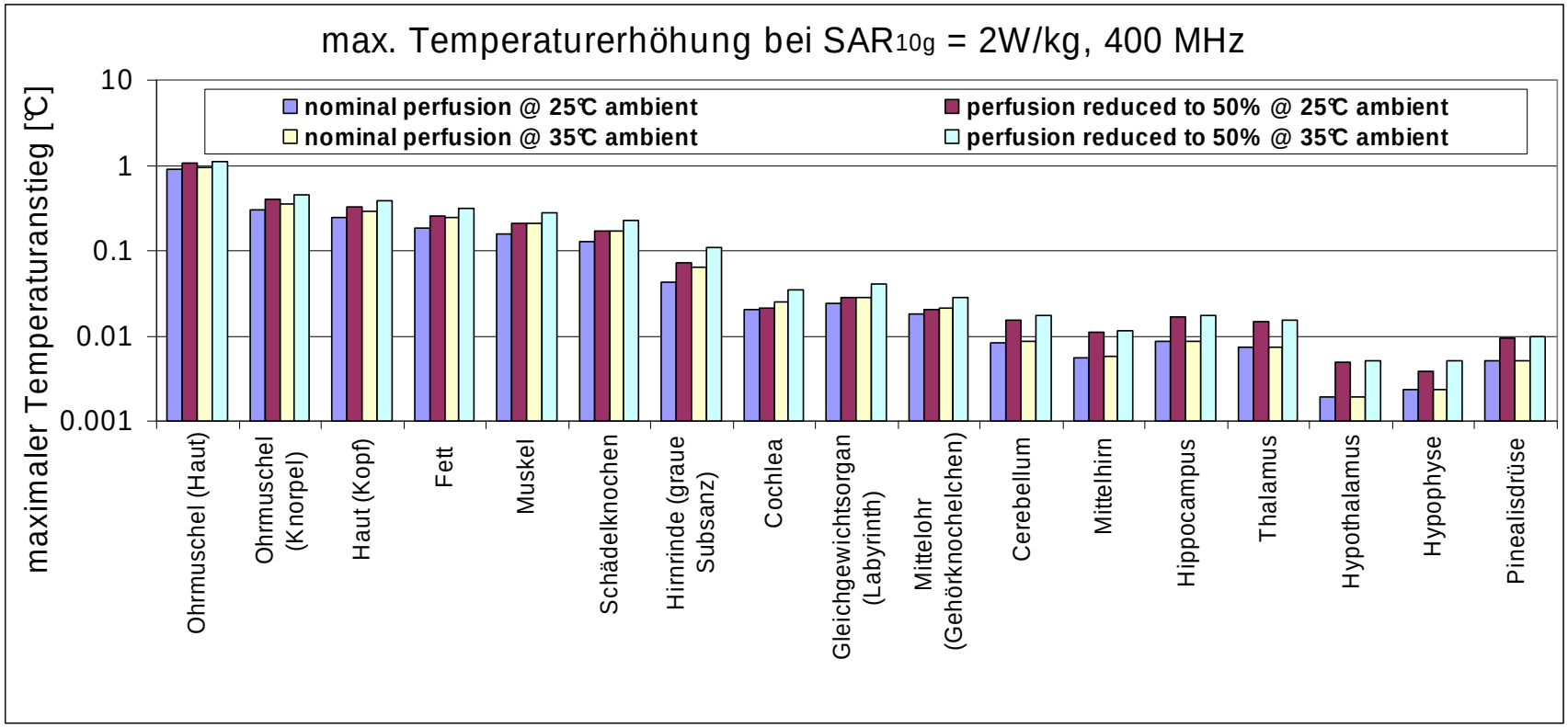
400 MHz | 900 MHz | 1850 MHz



# *Side Exposure:* Maximum temperature elevations at ICNIRP-SAR Limit



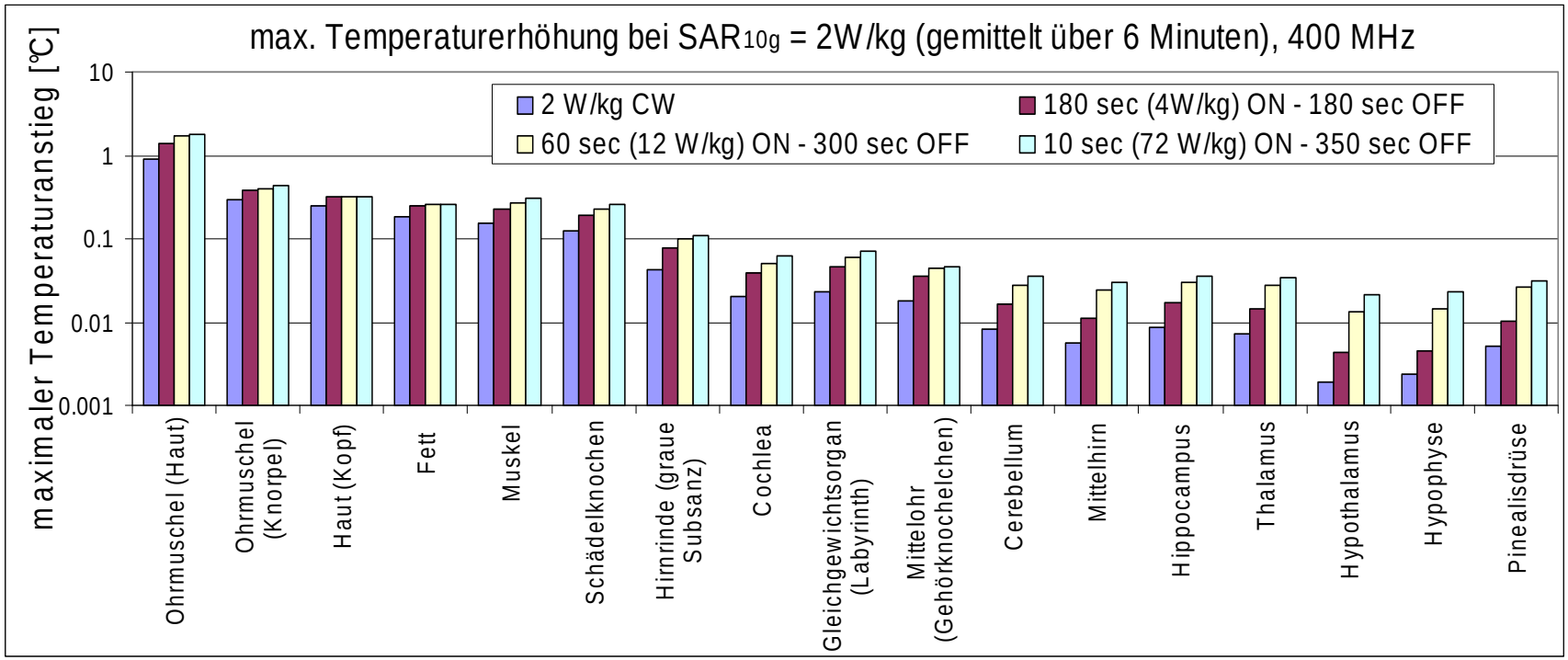
# *Side Exposure:* Influence of perfusion and ambient temperature (400 MHz)




⇒ Perfusion most relevant for inner tissues (no direct heat exchange with ambience)

## *Side Exposure:* Influence of (Worst Case) pulsed exposure (400 MHz)

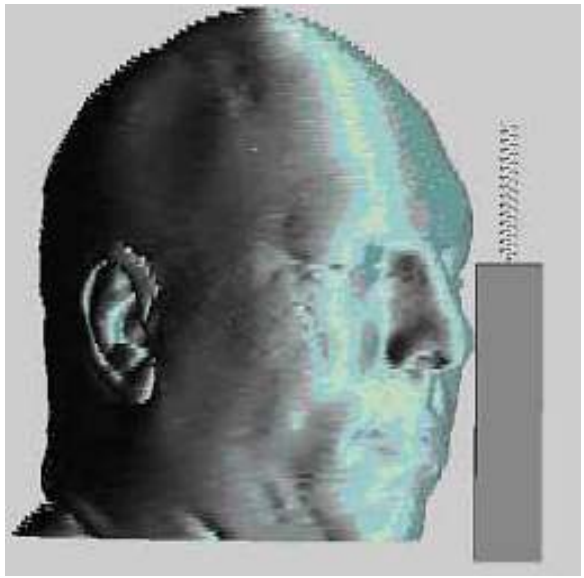
(not representative for current handheld communication devices)



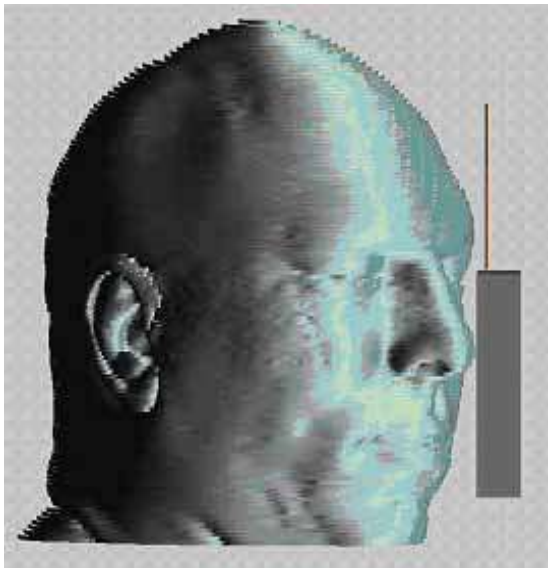

⇒ Deeper tissues (relatively) more affected than superficial tissues

# Front Exposure (Eye):

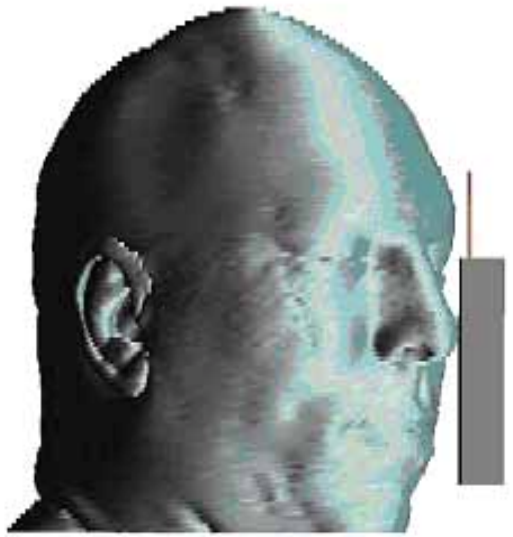
400 MHz



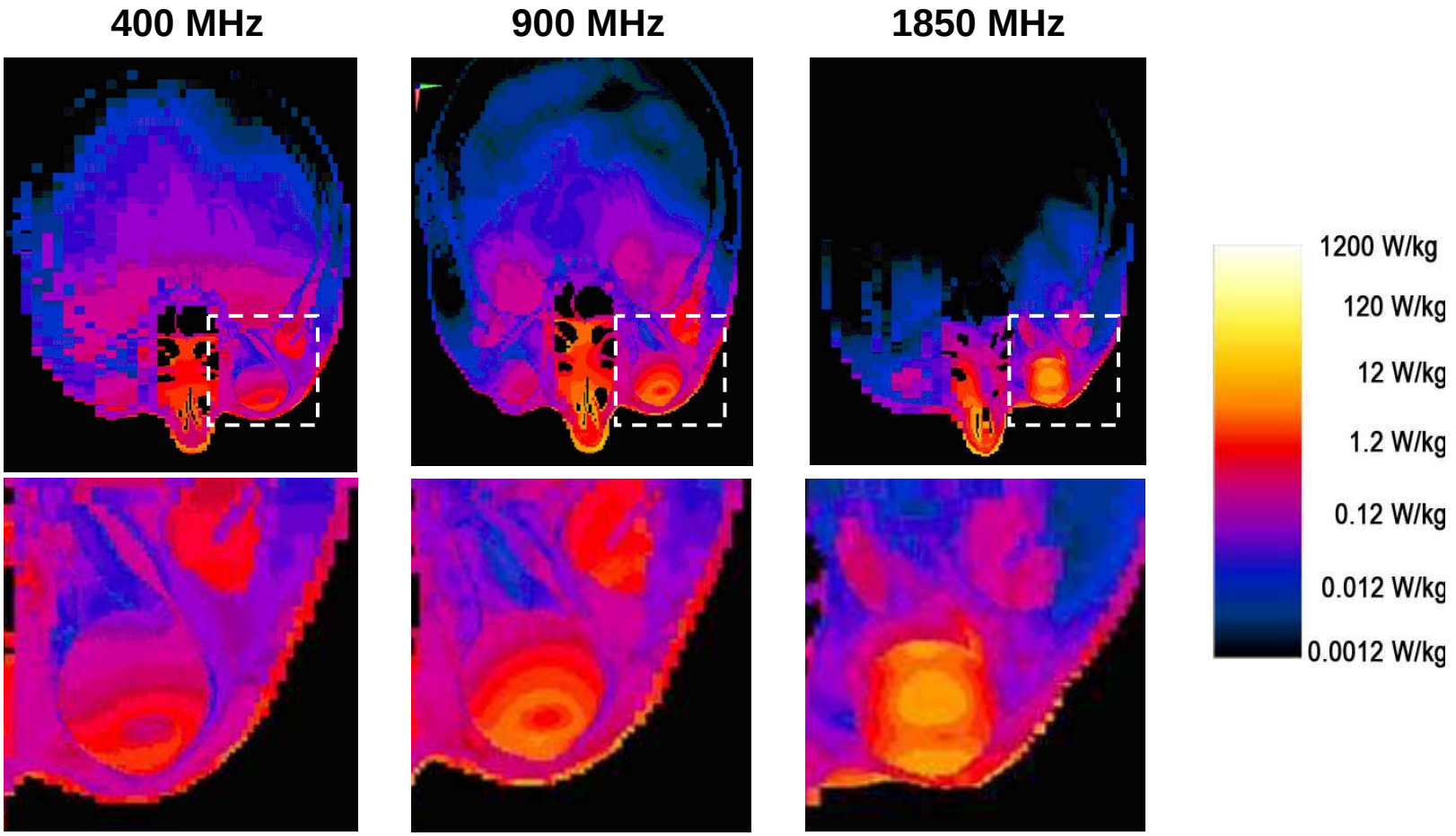
900 MHz



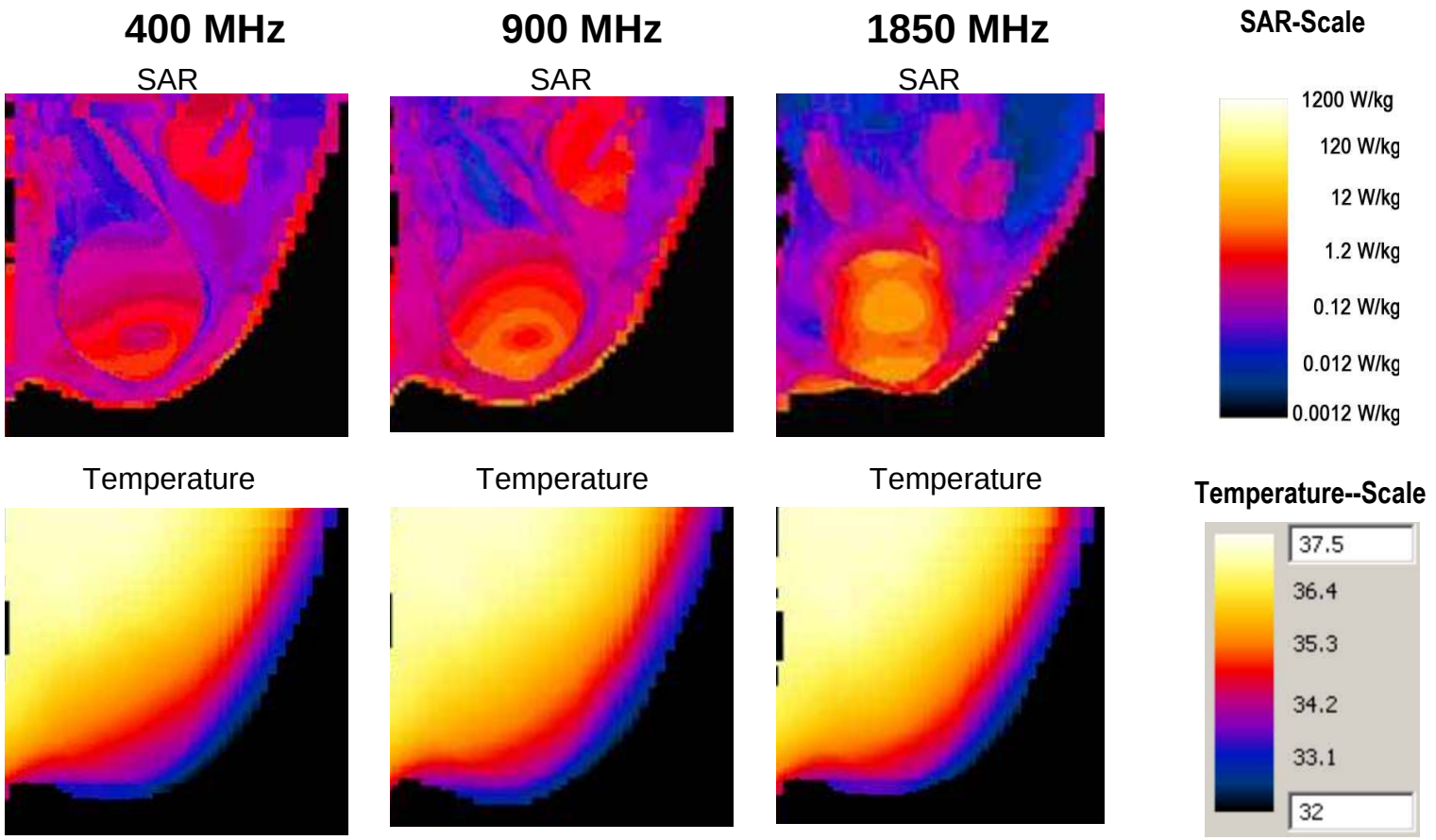
1850 MHz



# *Front Exposure:* SAR- Distribution (normalized to 1 W)

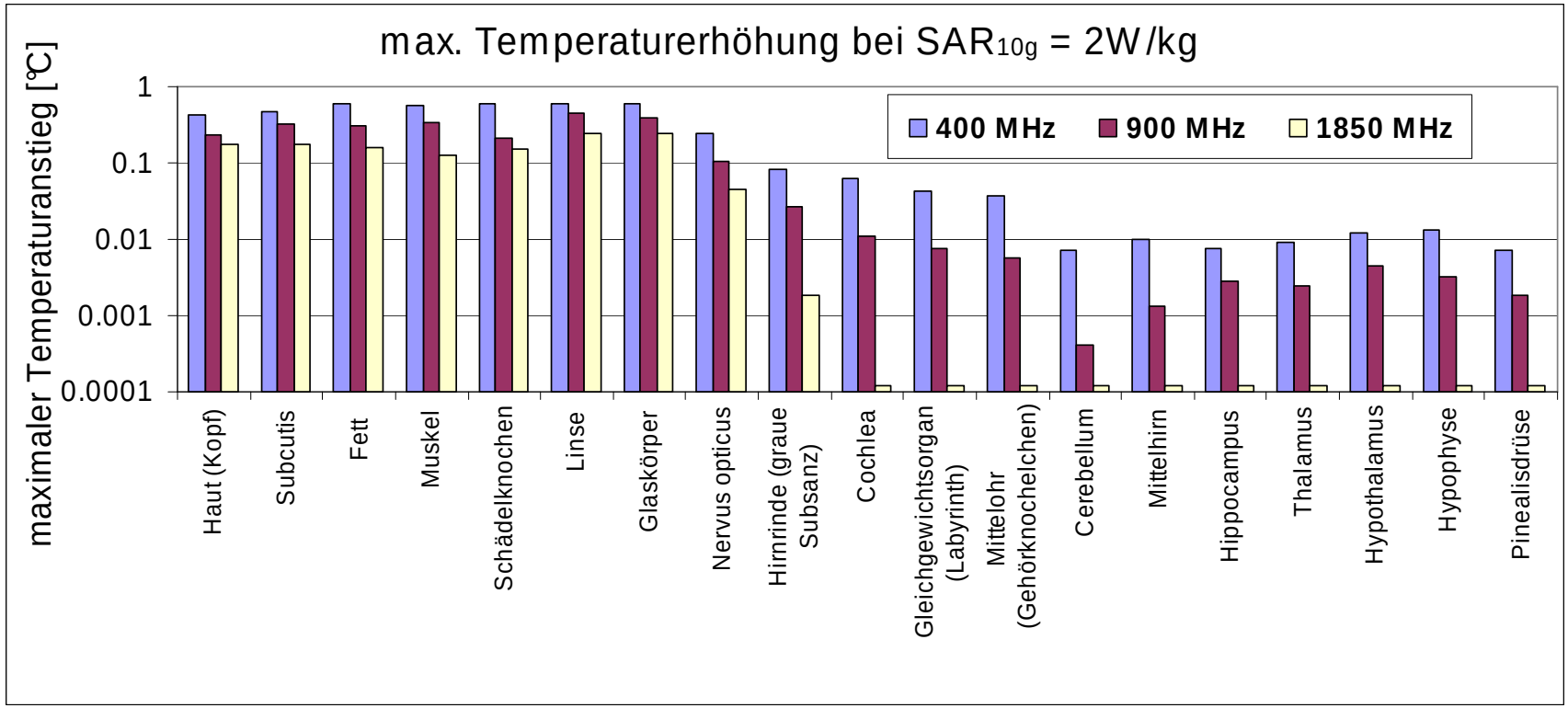


# *Front Exposure:* SAR- vs. Temperature-Distribution

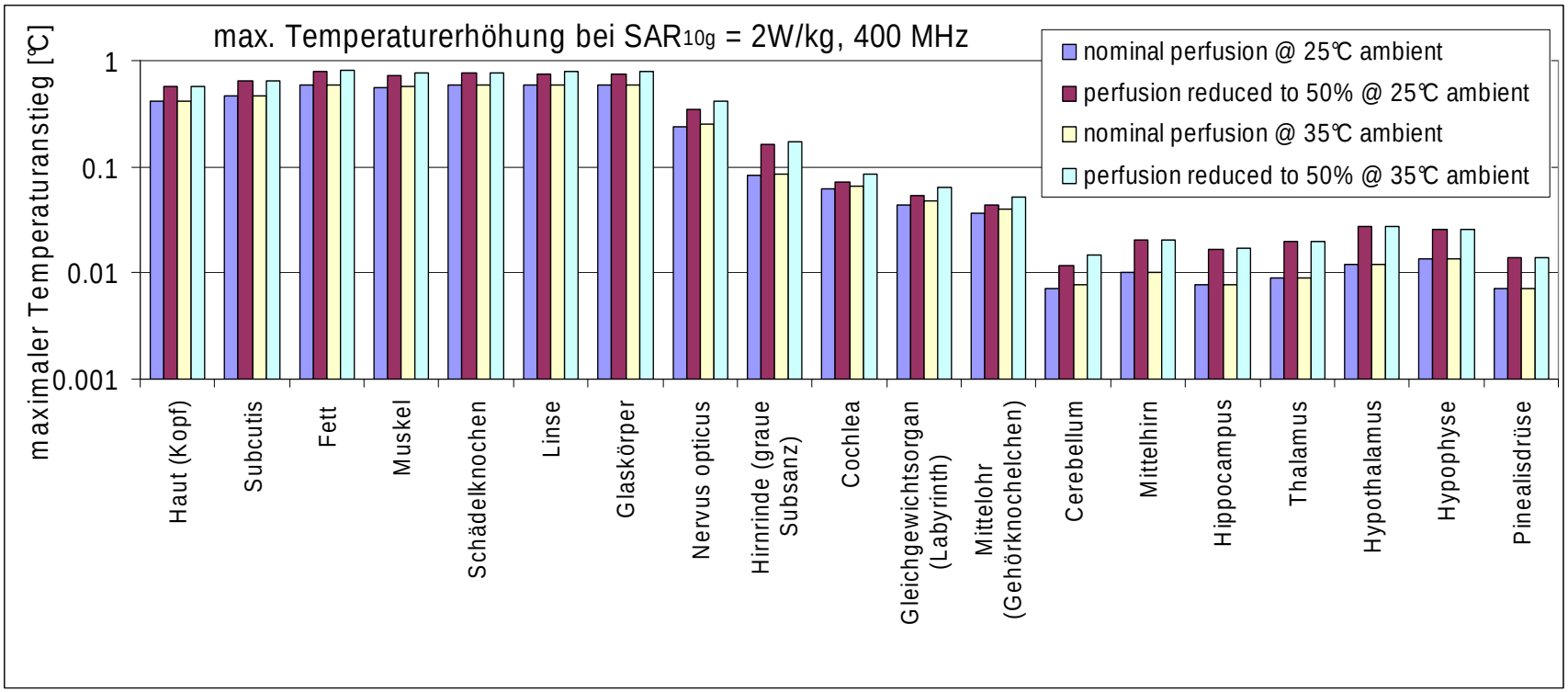



⇒ SAR-“Hot Spots“ **do not cause** relevant Temperature-“Hot Spots“

# *Front Exposure:* Maximum temperature elevations at ICNIRP-SAR Limit



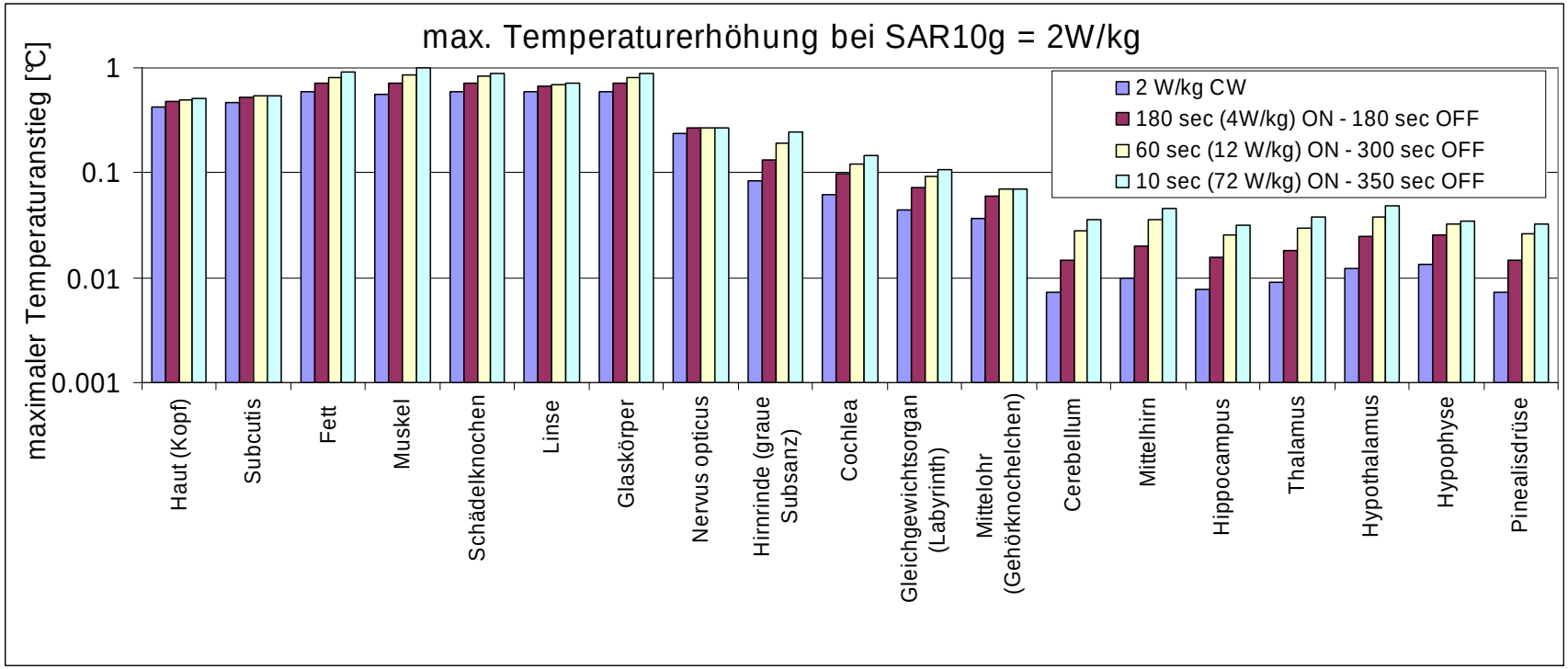
# *Front Exposure:* Influence of perfusion and ambient temperature (400 MHz)




⇒ Perfusion most relevant for inner tissues (no direct heat exchange with ambience)

## *Front Exposure:* Influence of (Worst Case) pulsed exposure (400 MHz)

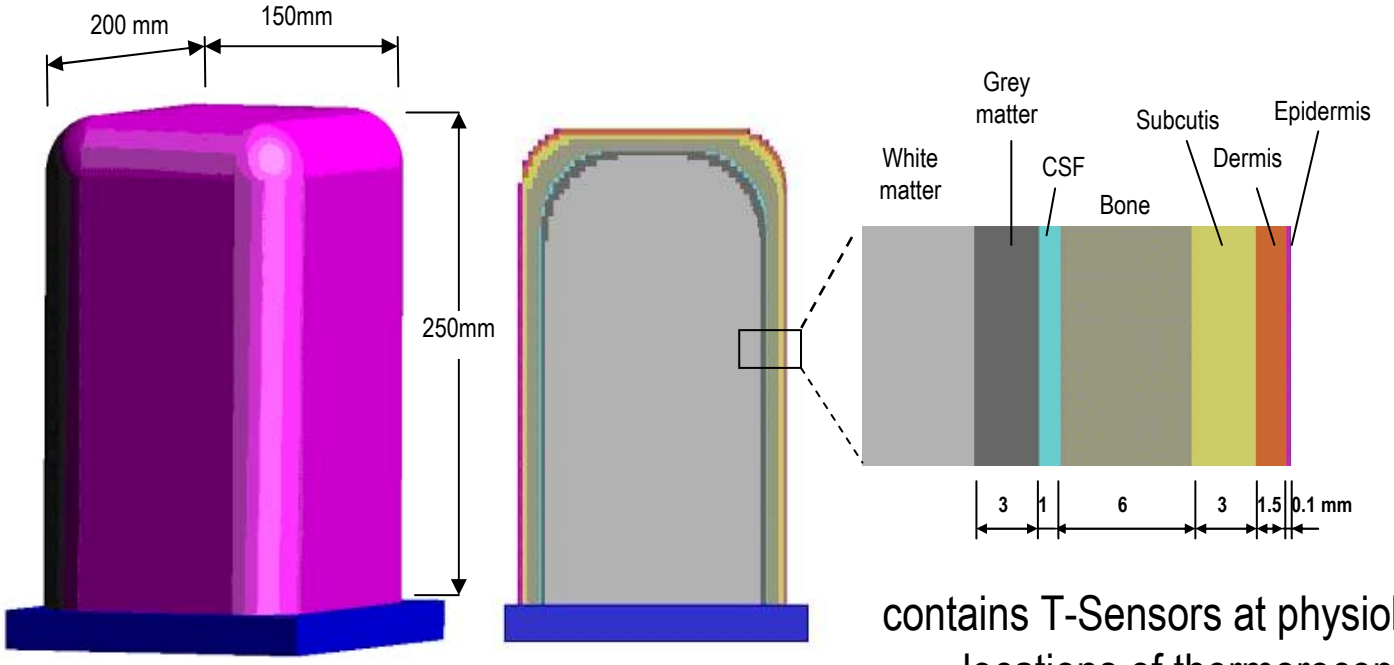
(not representative for current handheld communication devices)




⇒ Deeper tissues (relatively) more affected than superficial tissues

# Question of Temperature Sensations in the Skin

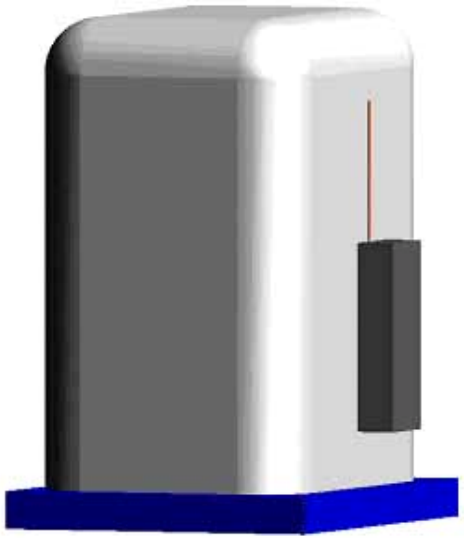
## Generic Skin Model:



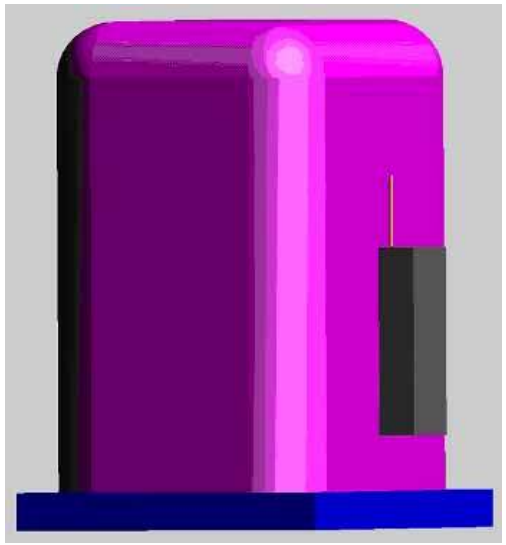

contains T-Sensors at physiological locations of thermoreceptors
(Hendler et al. 1963)

## *Comparsion for 900 MHz and 1850 MHz:*

**900 MHz**

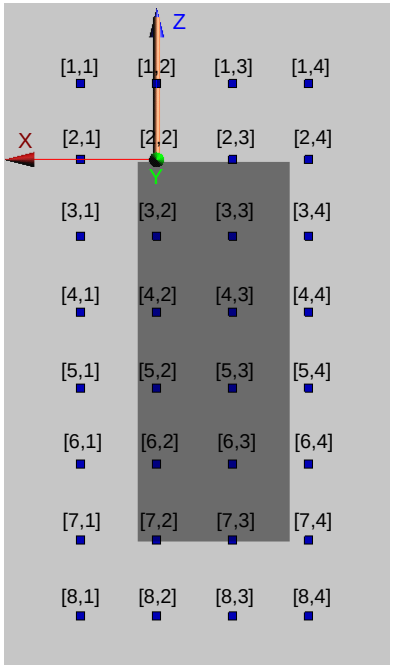


**1850 MHz**



**Phone case touches the skin**

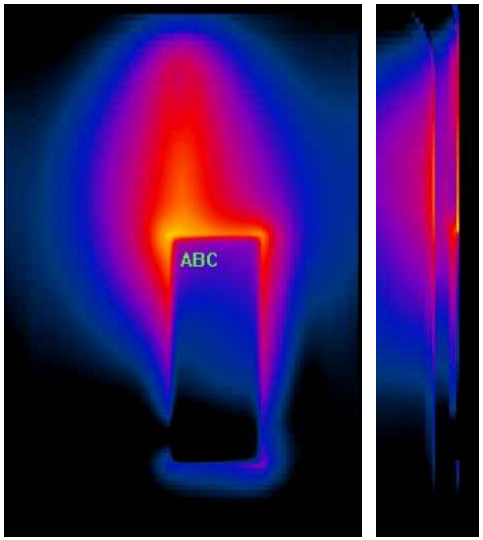
Locations of T-Sensors at physiological locations of thermoreceptors (200µm and 1 mm deep in the skin)

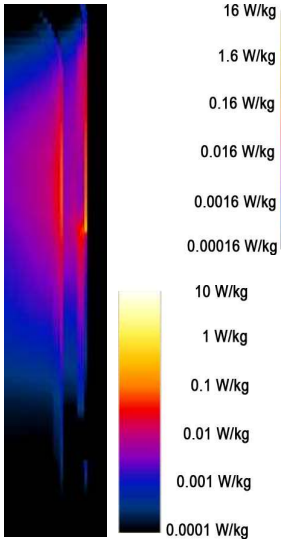


# *Comparsion for 900 MHz and 1850 MHz:*

**SAR-Verteilung 900 MHz (250 mW)**

**in 1mm Tiefe** **Querschnitt**

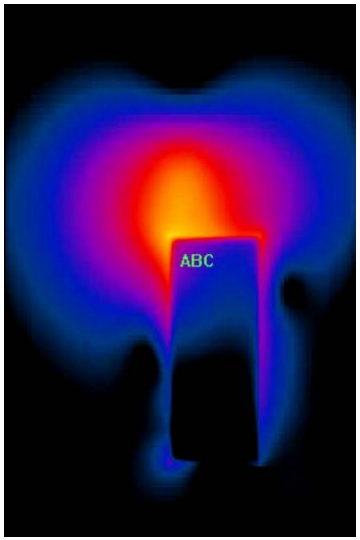


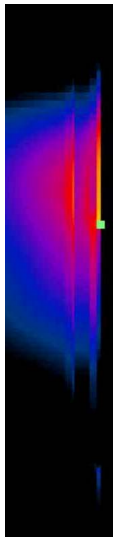






**SAR-Verteilung 1850 MHz (125 mW)**

**in 1mm Tiefe** **Querschnitt**

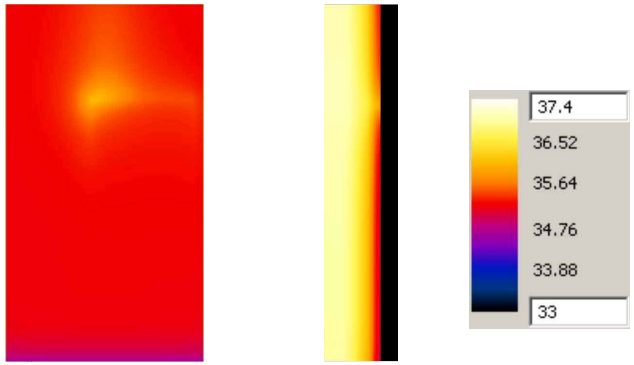


## T-Distribution 900 MHz

in 1mm depth

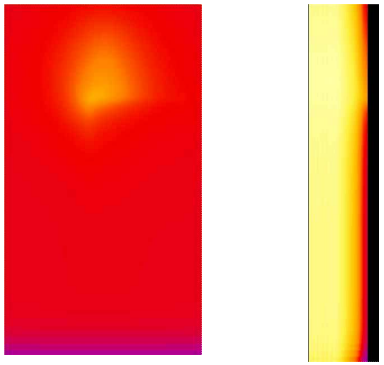
cross section




## T-Distribution 1850 MHz

in 1mm depth

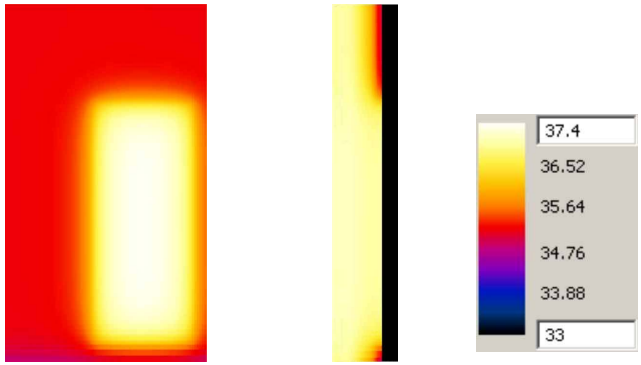
cross section



## T-Distribution due to heating by case (~250 mW power dissip.)

in 1mm depth

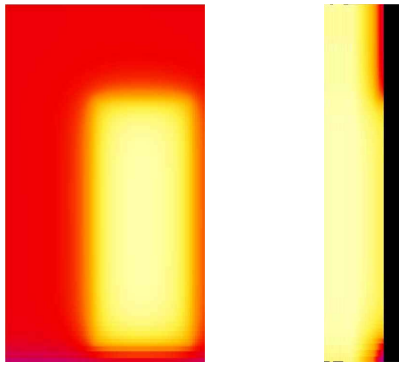
cross section




## T-Distribution due to isolation by case

in 1mm depth

cross section



## *ad perception of heating during mobile phone usage:*

- perception is caused by shift of temperature difference **ΔT** between superficial (200µm) and deep (1 mm) thermoreceptors (Hendler & Hardy 1960, Hendler et al. 1963)

| | **ΔT natural [°C]** | **min. ΔT [°C]** | **max. Δ (ΔT) [°C]** | **max. $\Delta T_{200\mu m}$ [°C]** |
|---|---|---|---|---|
| Isolation by case | 0,133 | 0,000 | -0,133 | 4,896 |
| Heating by case (16 W/m$^2$.K) | 0,133 | -0,026 | -0,159 | 5,285 |
| RF-Absorption 1850 MHz (125 mW) | 0,133 | 0,106 | -0,027 | 0,820 |
| RF-Absorption 900 MHz (250 mW) | 0,133 | 0,102 | -0,031 | 0,827 |

⇒Warmth perception by case isolation and case heating and not by RF absorption
(in line with experimental data by Straume et al 2005)

# Conclusions (1):

- Consideration of small anatomical structures shows the possibility of local SAR maxima (*SAR-'Hot' Spots*) in highly conductive tissue regions (high SAR gradients possible, due to heterogeneity of the head)
- However, these *SAR-'Hot' Spots* **do not cause** *Temperature Hot-Spots* due to highly efficient heat transfer mechanisms inside the tissue (no possibility of high temperature gradients)
- Therefore, as long as exclusively thermal adverse health effects of RF-absorption are considered, SAR averaging over 10g of tissue seems to be sufficient in order to prevent adverse RF-induced temperature elevations in the tissue.
- However, when hypothetically assuming that non-thermal adverse effects are existing, i.e. effects directly associated to field strength, smaller averaging volumes will be necessary for specific organs in order to give appropriate information about the organ- or tissue-specific amount absorbed RF power.

# Conclusions (2):

- A reduction of blood perfusion mainly affects (less exposed) inner tissues with respect to the RF-induced temperature elevations; for outer tissue layers both direct heat exchange with the ambient (ambient temperature) and blood perfusion is important
- (Worst case-) pulsed RF-exposure at constant time averaged SAR (i.e. time constants of the RF-signal envelope larger than thermal time constants inside the tissue) affects deep tissues significantly more than superficial tissues
- Pulsed RF-exposure as emitted by most mobile communication devices (with time constants of the RF-signal envelope smaller than thermal time constants inside the tissue) resulted in similar temperature elevations as caused by CW RF-exposure (at the same time averaged SAR level)
- Maximum RF-induced temperature elevations to be expected from mobile phones (GSM900, GSM1800, UMTS) are less than approx. 0,1°C in the brain and less than approx. 0,5°C in superfical tissues (skin, fat, muscles)

# Conclusions (3):

- At frontal exposure sitiations with Walky Talkies of high transmit power (e.g., 400 MHz, 1 W) maximum RF-induced temperature can elevate the temperature in the eye by approximately 0,5-1,0°C
- Frequently reported heat sensations during usage of mobile phones are rather due to heating or isolation by the phone case than by RF-absorption
- All results were obtained with one specific head model based on the Visual Human Data Set. Variations in resulting RF-induced temperature elevations for different head models should be further investigated.

# THANK YOU FOR YOUR ATTENTION !