Power Dissipation in Cortical Implants

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Sources

- **"Thermal Impact of an Active 3-D Microelectrode Array Implanted in the Brain"**, S. Kim, P. Tathireddy, R. A. Normann and F. Solzbacher, IEEE Transactions on Neural Systems and Rehabilitation Engineering, 15(4) 2007
- **"Numerical Analysis of Temperature Elevation in the Head due to Power Dissipation in a Cortical Implant"**, K. M. Silay, C. Dehollain, and M. Declercq, 30th Annual International IEEE EMBS Conference, 2008

Motivation

- Biomedical implants are becoming more popular
- Development of miniature electrode arrays
  - recording the neural activity
  - stimulating the neurons of the central nervous system

Where do People Like Their Implants?

According to references: eyeball and brain

Issues with Implantable Circuitry

- Heat generation
- Brain temperature higher than 40.5°C results in heat stroke in humans
- As an extreme clinical case, a patient with an implanted deep brain stimulator (DBS) suffered significant brain damage and subsequently died

Possible Approaches

- Simulation
  - without any complex in vivo measurements
  - precautions can be taken during the design stage of the implant
- In vitro
  - Proof-of-concept measurements and model verification
- In vivo
  - The reality of what to expect
- And we will talk about all of the above!

Hardware

- Utah electrode array (UEA)
- The UEA
  - 3-D silicon-based structure
  - 10 by 10 array of tapered silicon spikes
  - base of 80 microns and a length of 1.5 mm

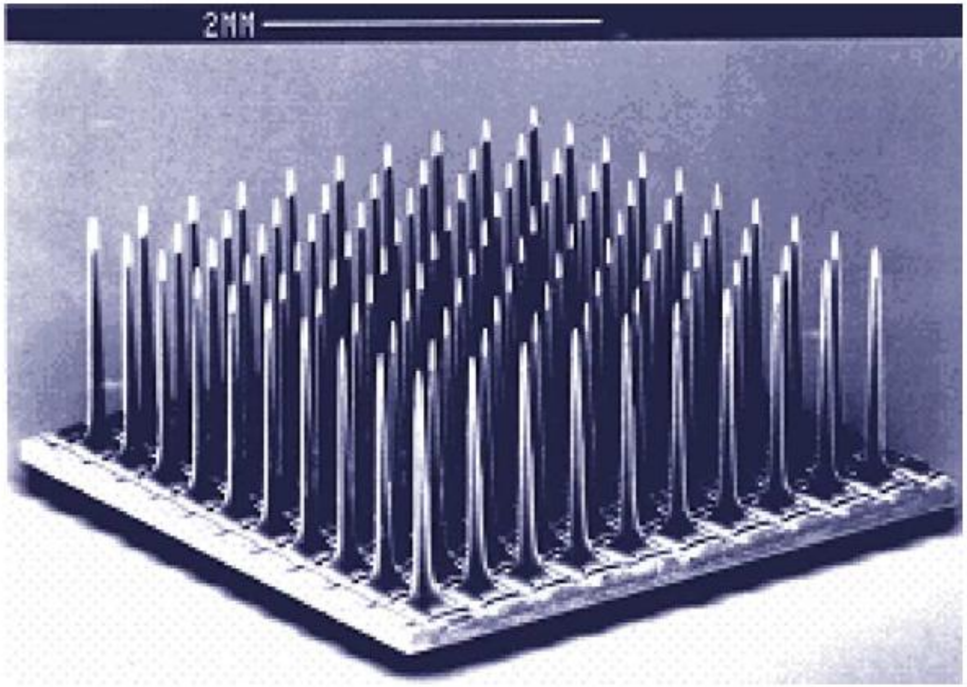


Fig. 1. Scanning electron micrograph of the UEA.

UEA Properties

- fully implantable
- wireless device
- custom designed integrated circuit (IC)
- amplifies and processes detected neural signals, and transmits them to an extracorporeal machine

Numerical study

Model Description

- Model parameters:
  - heat conduction - the most important mechanism of heat transfer within biomaterials
  - convection through blood flow
  - metabolic heat generation in the tissue
  - heat generation by the IC
- finite element analysis (FEA)
- $10e^{-6}$ convergence for the solver

Pennes Bioheat Equation

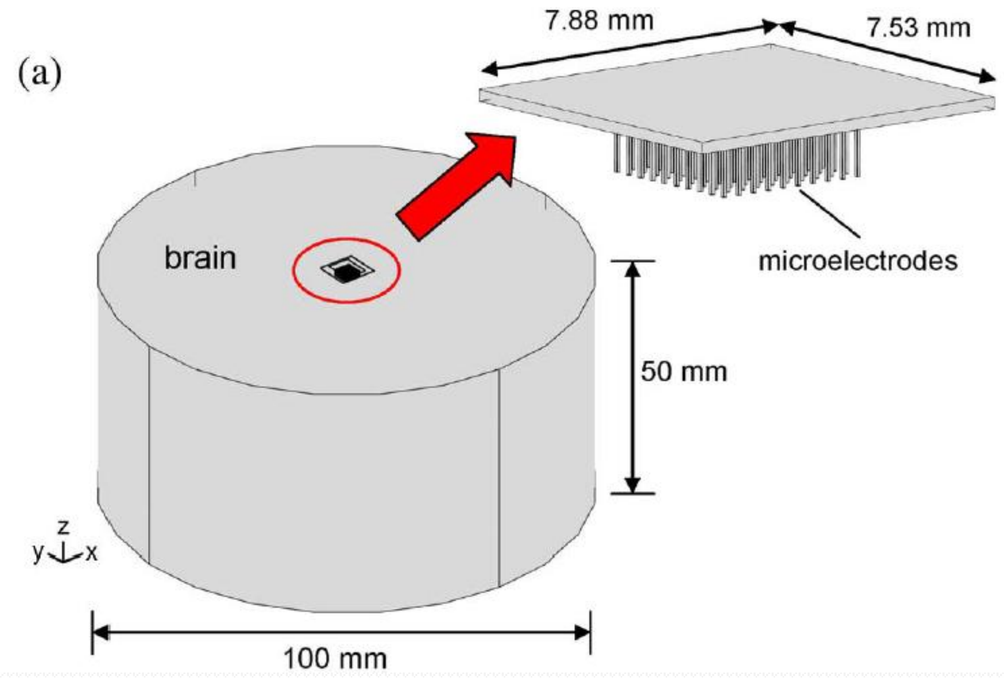
$$\rho C \frac{\partial T}{\partial t} = k\nabla^2 T - \rho_b C_b w(T - T_b) + Q_m + Q_{\text{ext}}$$

ρ	mass density
C	specific heat capacity
k	thermal conductivity
T	temperature
Q_m	metabolic heat production
Q_{ext}	heat produced by the IC
w	blood flow rate

The ***b*** subscript stands for property of the blood

Pennes Bioheat Equation

boundaries of the selected region except the surface exposed to the air is considered to be at body temperature



Assumptions

- Tissues of interest were assumed to be homogeneous and isotropic
- IC has uniform heat distribution throughout
- Heat transfer by radiation at the surface into the air is neglected
- Grey matter and white matter are considered to have the same thermal and physical properties

Parameters

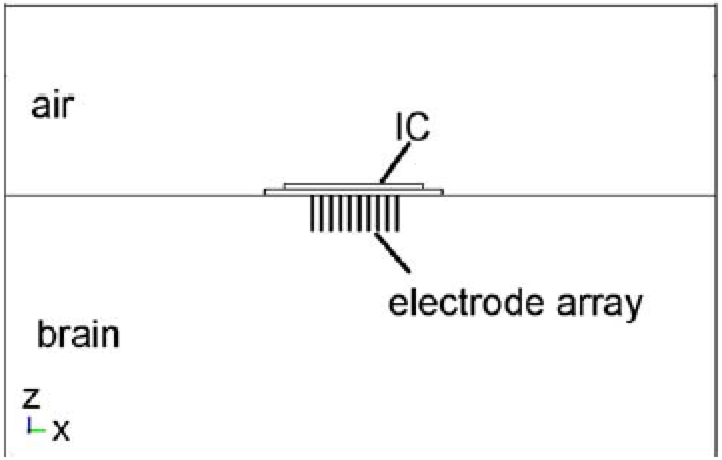
TABLE I

PHYSICAL AND PHYSIOLOGICAL PROPERTIES OF TISSUES AND ENGINEERING MATERIAL USED IN THE SIMULATIONS [31], [33], [35], [36]

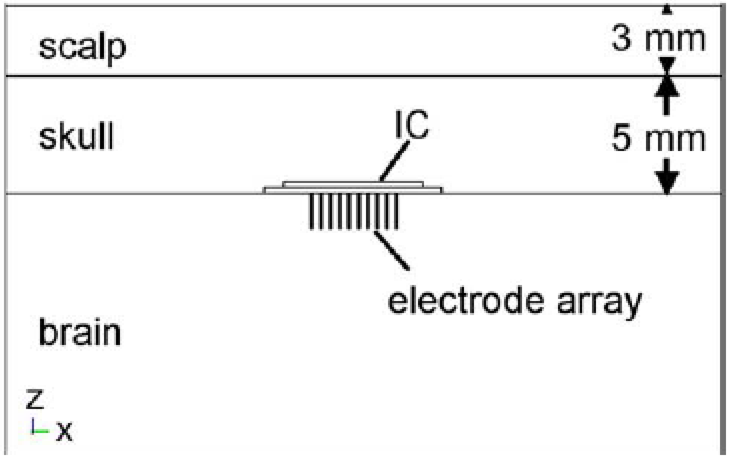
	Density (kg/m^3)	Specific heat capacity ($J/kg \cdot K$)	Thermal conductivity ($W/m \cdot K$)	Blood perfusion rate ((ml/s)/ml)	Metabolic heat generation (W/m^3)
Brain	1041	3640	0.528	0.0097	10383
Skull	1990	1300	0.650	0.00099	26
Scalp	1100	3150	0.342	0.0022	1100
Blood	1060	3840	0.530	-	-
Silicon	2329	702	124.0	-	-

Two Models

1. to validate the numerical model with experimental measurements, in which the UEA/IC system is not covered by the skull and scalp, and exposed to the air



Two Models

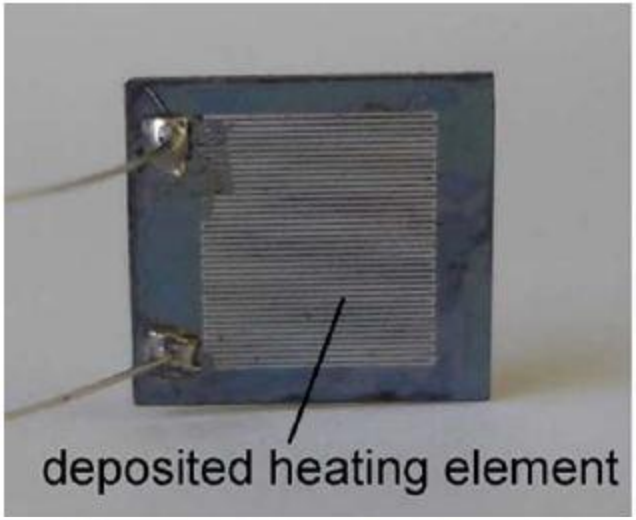


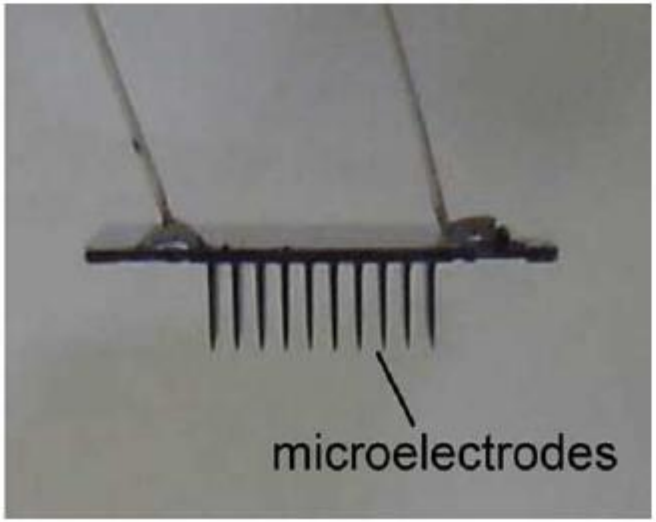
2. simulate the actual implantation condition in the brain with the skull and scalp present above the implant system

Experimental study

IC Under Load Simulation

- To mimic the heat generation by the IC, a Ti/Pt micro heating element was deposited on the backside of the UEA
- microheater element has a meander shape with a width/spacing of 70 microns and an effective area of 5x6 mm^2, which is equivalent to the area of the IC



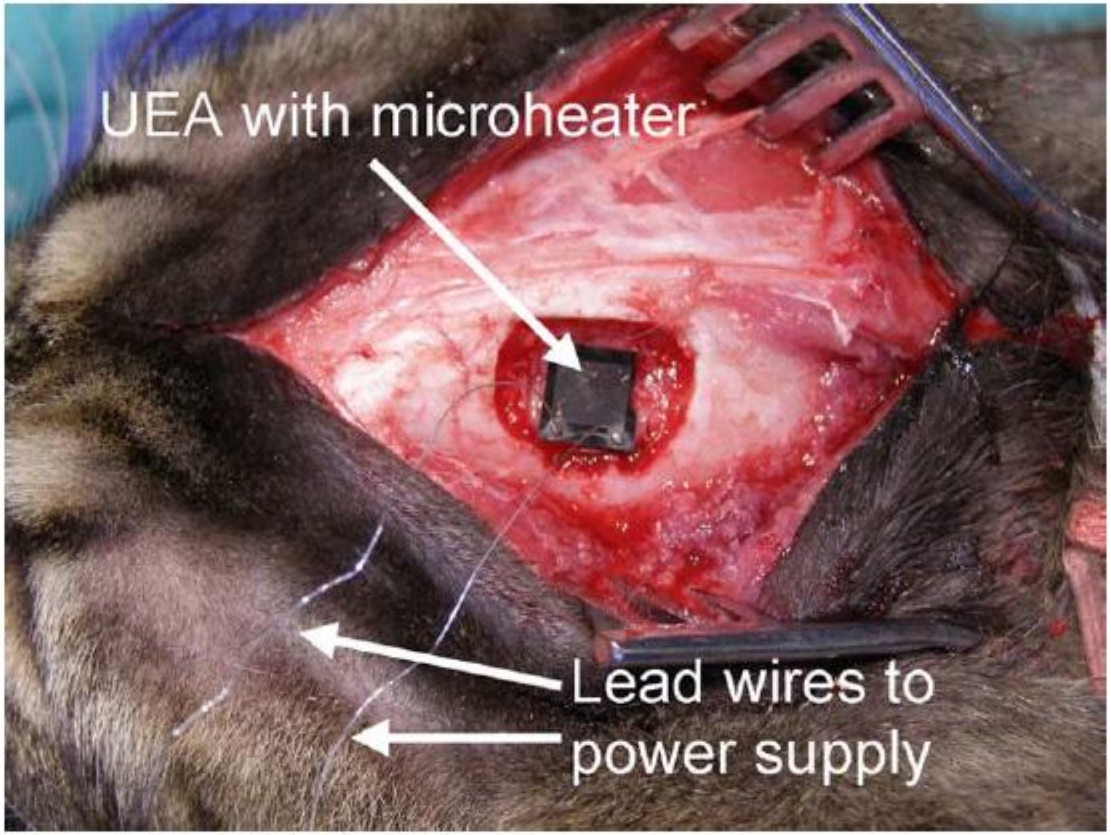


In Vitro Preparation

- Agarose gel (1.5%) is used to simulate the brain tissue as it has a thermal conductivity of 0.6 W/(M K)
- The temperature of the water bath was kept at 37°C so that the temperature at the boundary of the volume of agar gel was also kept at 37°C

In Vivo Preparation

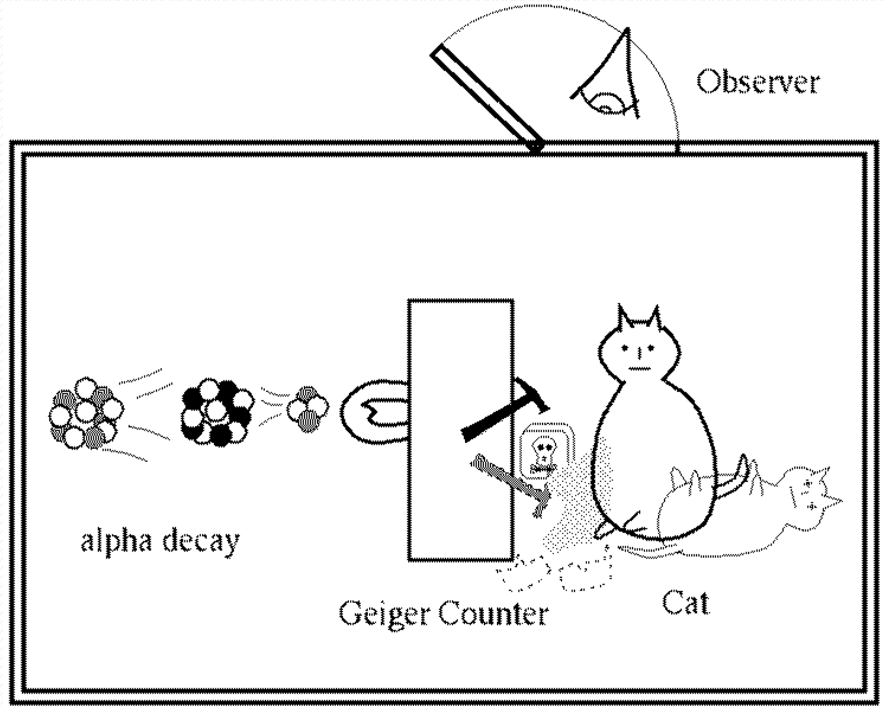
- Cerebral cortex of anesthetized cat
- The cortex of the cat remained exposed during measurements



Why the Cat

"Since the in vitro experiment employing agar gel ***cannot*** *reflect the contribution of* ***convection through blood circulation*** *which in fact plays a significant role in thermal regulation of a living body"*

He is probably better off than the Scrödinger's Cat (for the physics aficionados out there)



Temperature Measurement

- Infrared (IR) thermal camera
- five infrared images were taken at each level of power dissipation as the power dissipation amount ranged from 0 to 40 m

TABLE II
TECHNICAL SPECIFICATIONS OF THE IR THERMAL IMAGING CAMERA USED FOR TEMPERATURE DETECTION

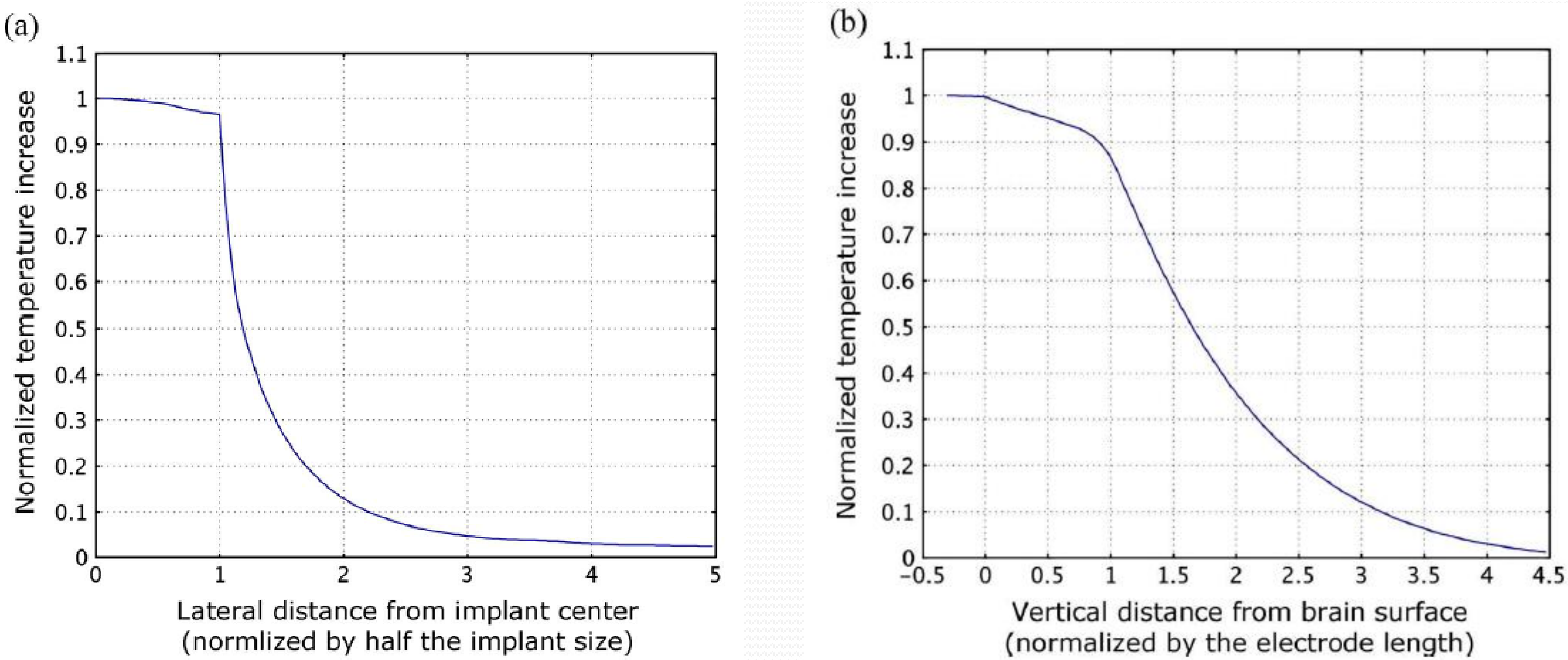
Measurable temperature range	-20 to 450 ºC
Wavelength	3.4 to 5 µm
Sensitivity	< 0.1º C
Spatial resolution	170 µm

RESULTS

Numerical Model Results

1) Spatial Heat Distribution
2) Influence of Blood Perfusion and Metabolic Heat Generation
3) Influence of the Presence of Scalp and Skull Covering the Implant and the UEA Geometry

Spatial Heat Distribution



(a) Temperature increase on the surface of the array and surrounding tissue due to power dissipation through the implant **(b)** Temperature increase in the tissue along with the electrode length -- normalized temperature and distance

Blood Circulation

Influence of Blood Perfusion and Metabolic Heat Generation

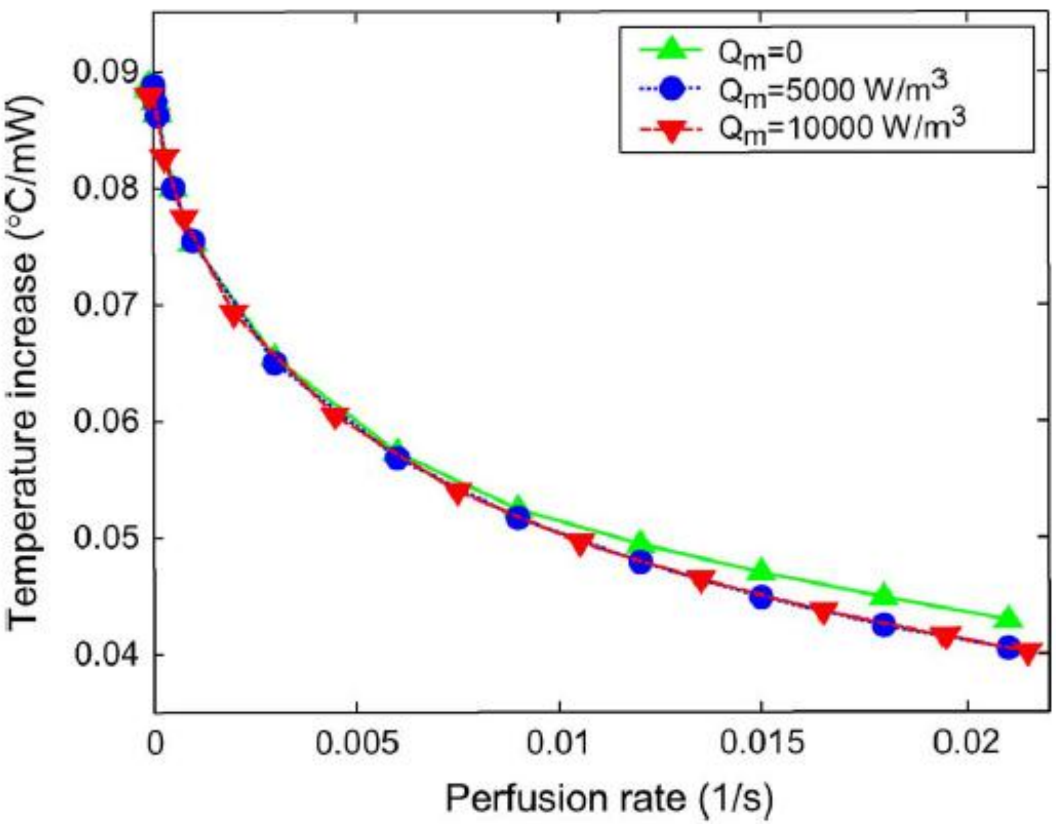
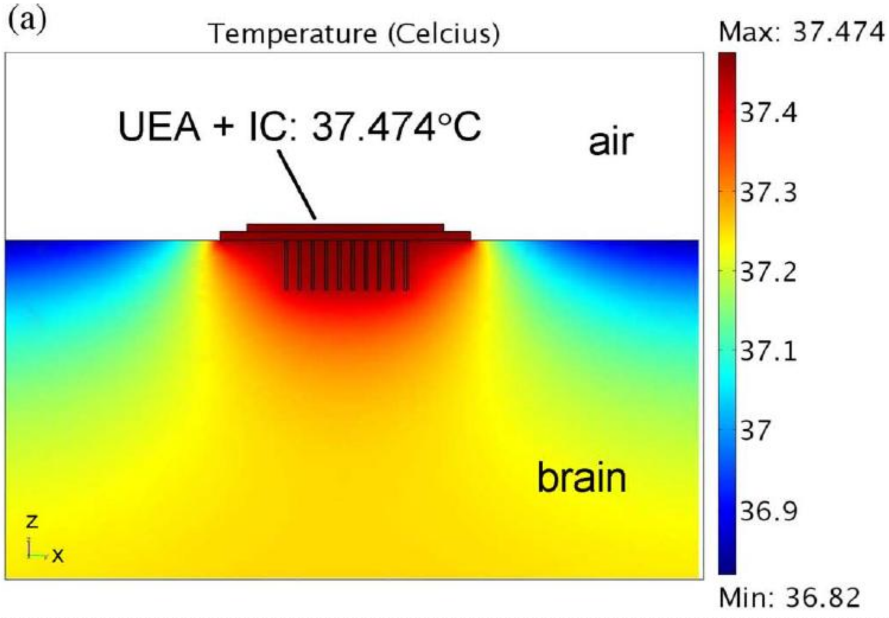
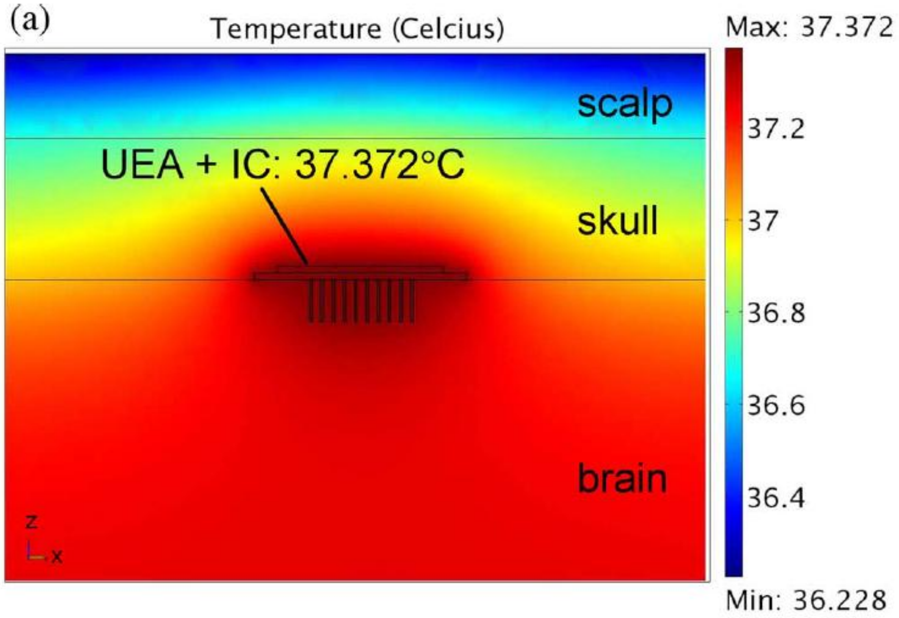


Fig. 10. Computed temperature increase in the UEA as a function of blood perfusion rate and metabolic heat generation.

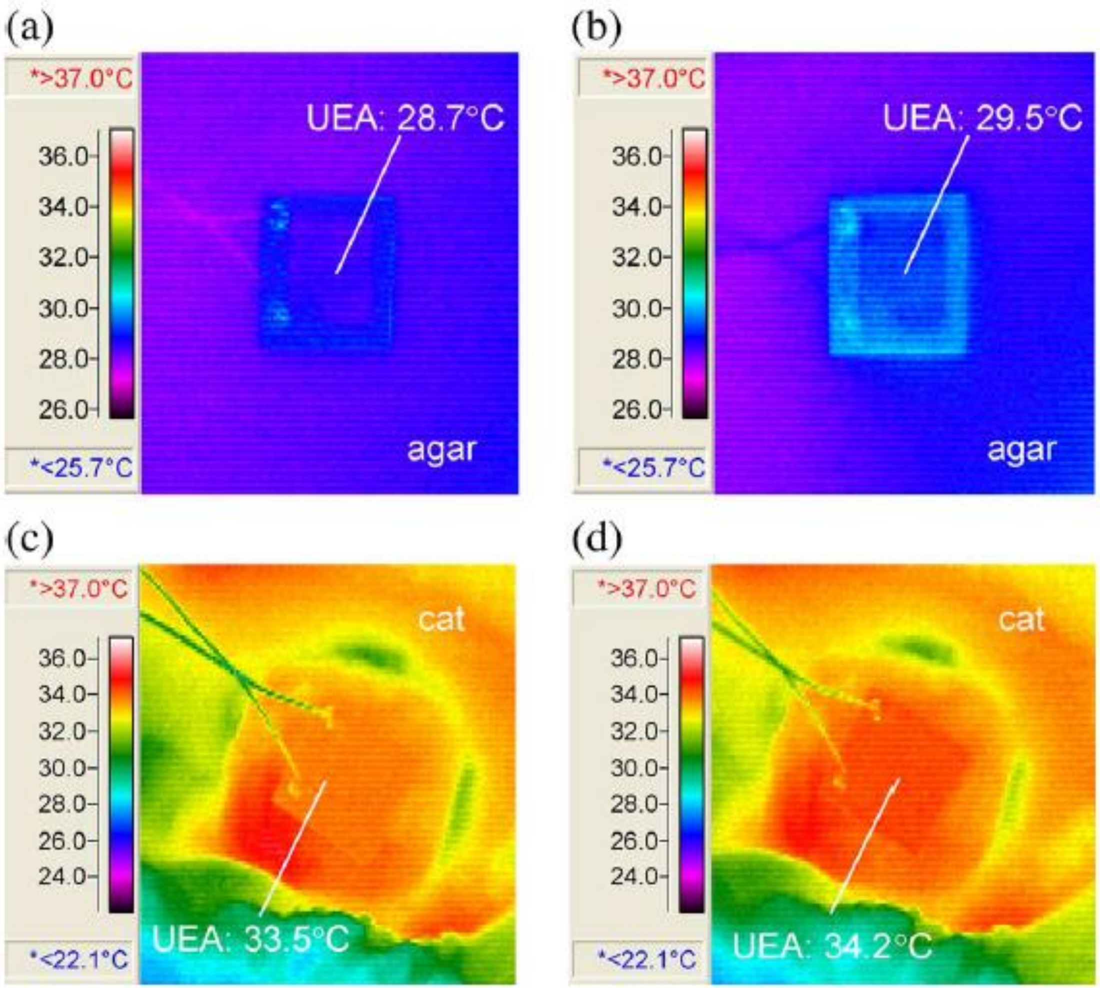
Scalp Cover

Influence of the Presence of Scalp and Skull Covering the Implant and the UEA Geometry





Experimental Results



Thermal images of the surface of the UEA and surrounding medium in **(a)** *in vitro* (agarose gel) condition with no power and **(b)** with 13 mW power dissipation, **(c)** in vivo (cerebral cortex of a cat) condition with no power and **(d)** with 13 mW power dissipation

Model Validation

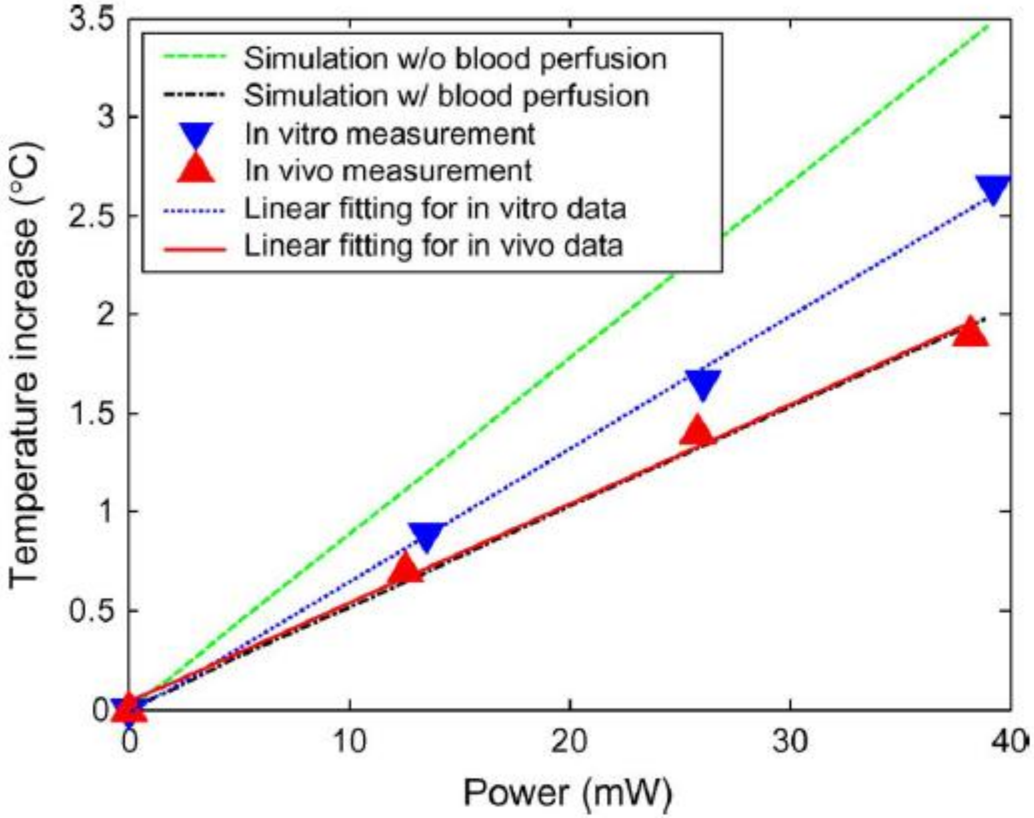


Fig. 8. Temperature increase in the UEA obtained from numerical simulations and from both *in vitro* and *in vivo* measurements as a function of power dissipation through the UEA.

questions

Thank you for your attention