FEASIBILITY STUDY OF EARLY BREAST CANCER DETECTION USING INFRARED IMAGING

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Mid Infrared Sensing Diagnostics and Control Consortium

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MOTIVATION

- Breast Cancer is a leading cause of deaths in women due to cancer.
- Mammography is FDA approved gold standard methodology for screening women.
- Early detection is the best defense against breast cancer.
- Alternate imaging modalities like Ultrasound, PET and MRI are being explored. (Drawbacks)

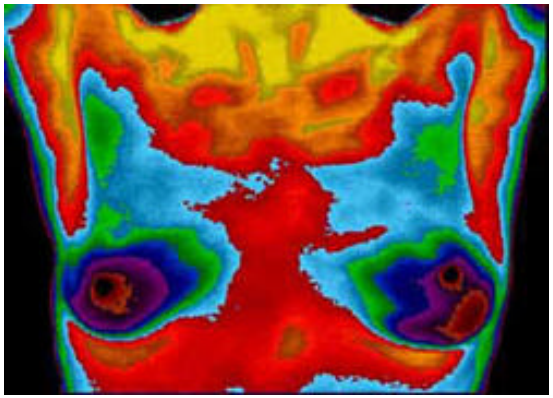
Why alternate imaging modalities are being sought ?

- Early detection is the best defense against breast cancer
- Mammography has limitation in terms of sensitivity (~ 70 %), specificity (~ 80 %), physical discomfort and ionizing dose to the patient.

Why thermography ?

CLINICAL THERMOGRAPHY

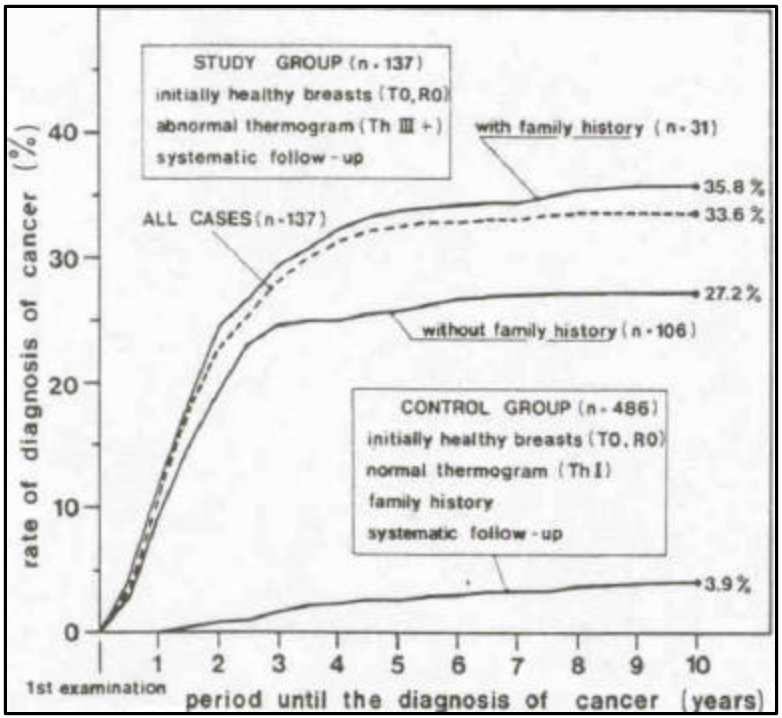
- Single point vs. multi point diagnostics
- Planck's function
- Skin temperature is a function of local metabolism, underlying nervous system and other energy imbalances.
- Breast tumor cell produce excessive nitric oxide leads to vasodilatation [Thomsen et al., 1995]
- Breast tumor cell have a much higher metabolic activity
- Heat diffuses to the surface and may be captured
- Function of physiology rather than anatomy



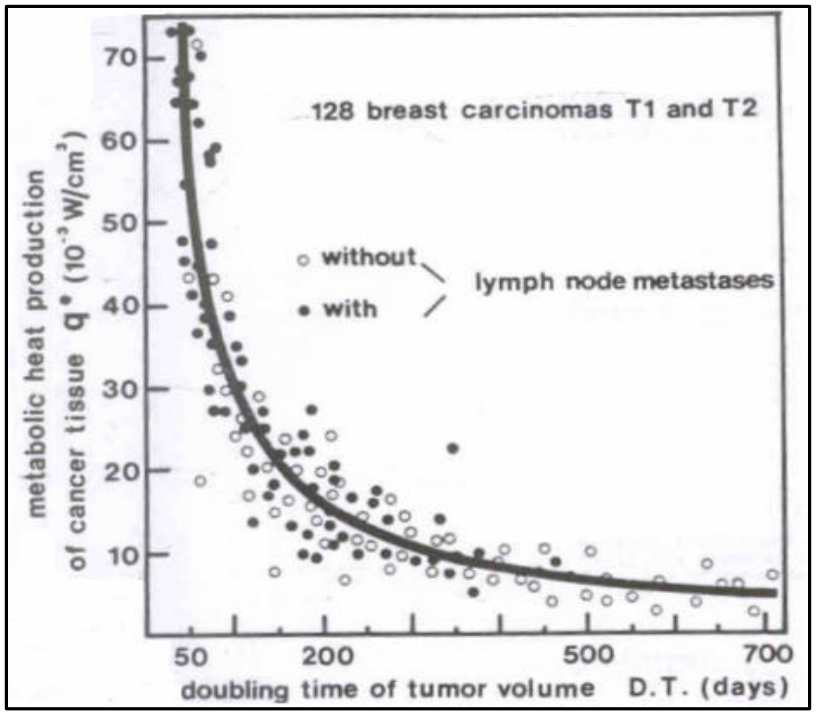
A pseudo color breast thermogram

- Fundamental basis but non specific in nature, thus must be used as an adjunct imaging modality

GAUTHERIE, 1983 (FRANCE)

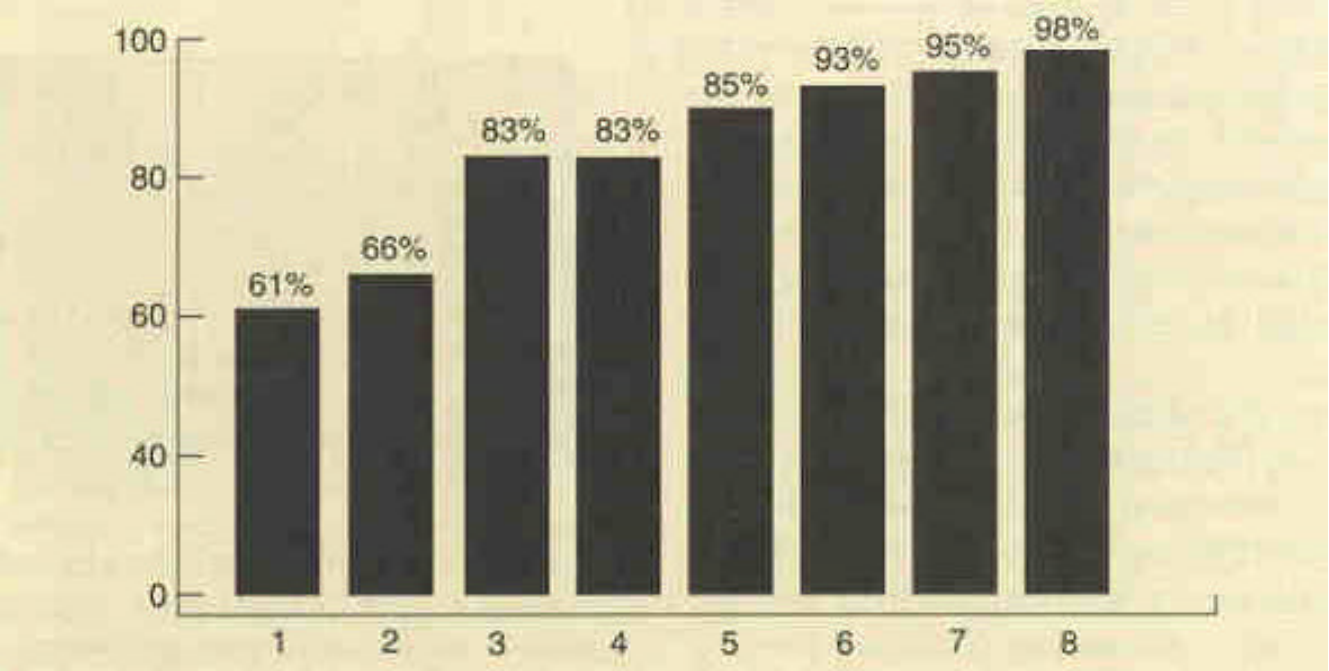


Evolution of cancer in patients with normal mammogram and abnormal thermogram



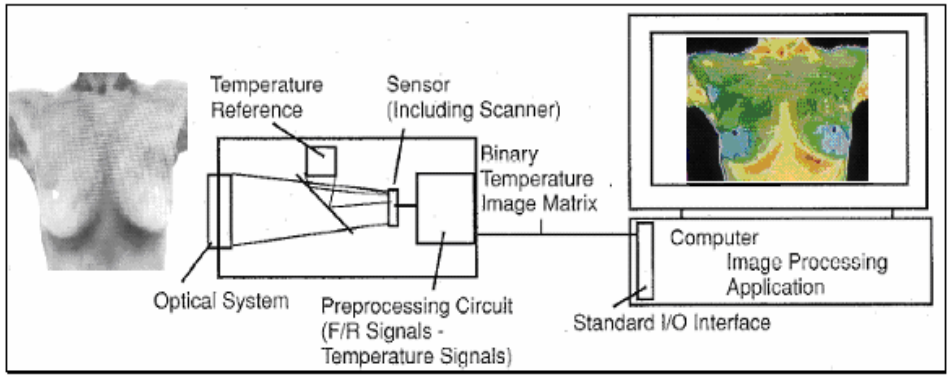
Growth rate and heat production of breast cancer tumors

KEYSERLINGK et al., 1998 (CANADA)



Relative sensitivity of clinical exam, mammography, and IR imaging in 100 cases of DCIS, Stage 1 and Stage 2 breast cancer. 1: Positive clinical exam. 2: Positive mammography.**3**: Positive clinical or positive mammography. 4: Abnormal IR imaging. 5: Positive or equivocal mammography. 6: Positive clinical or positive or equivocal mammography. 7: Abnormal IR or positive mammography. **8**: Abnormal IR or positive mammography or positive clinical

MAIN OBJECTIVES OF RESEARCH



- To evaluate thermography as a conjugate detection technique to mammography
- Use computations to simulate breast cancer techniques with goal of understanding / improving their usage.

✓ Mammography

✓ **Thermography**

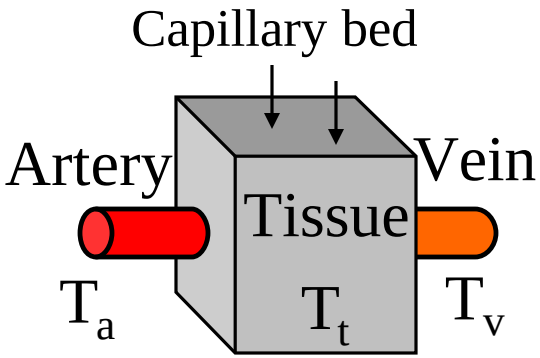
PENNES BIOHEAT TRANSFER EQUATION

$$r.c_p.\frac{\partial T_t}{\partial t} = \nabla.(k_t.\nabla T_t) + w_b.(r.c_p)_b.(T_a - T_v) + q_m$$

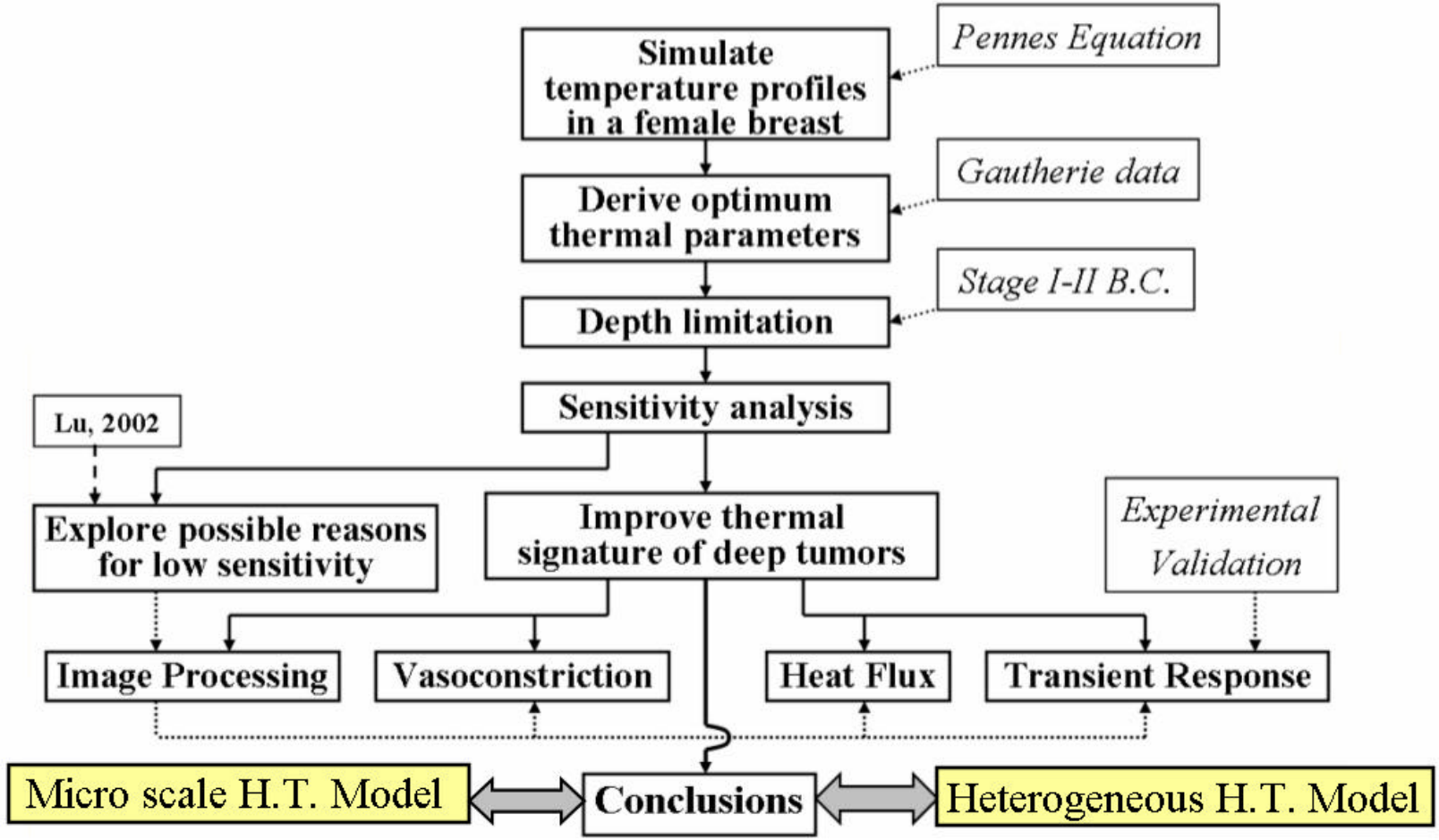
- Key assumption: No change in blood temperature until it reaches the capillary bed where blood – tissue thermal equilibrium takes place

$$T_v = T_t + \alpha . (T_a - T_t)$$

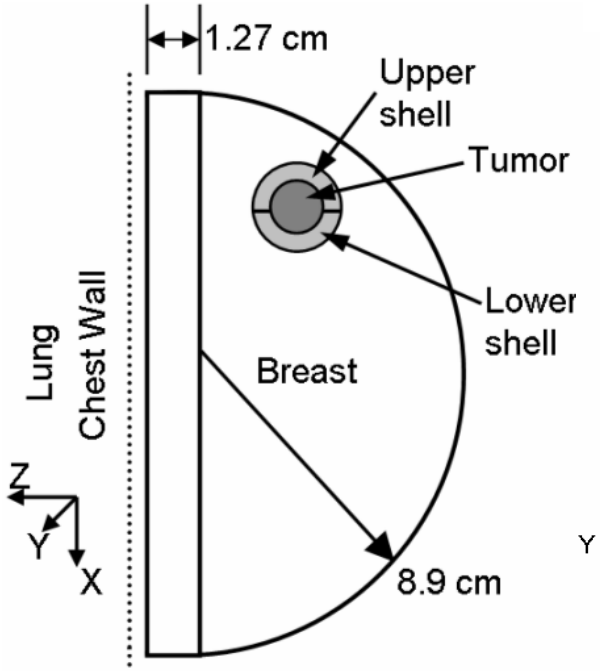
- Assuming $\alpha = 0$ (complete thermal equilibrium)
- w_b is the blood flow rate (ml / s / ml of tissue) and q_m is the volumetric metabolic heat generation (W / m^3).



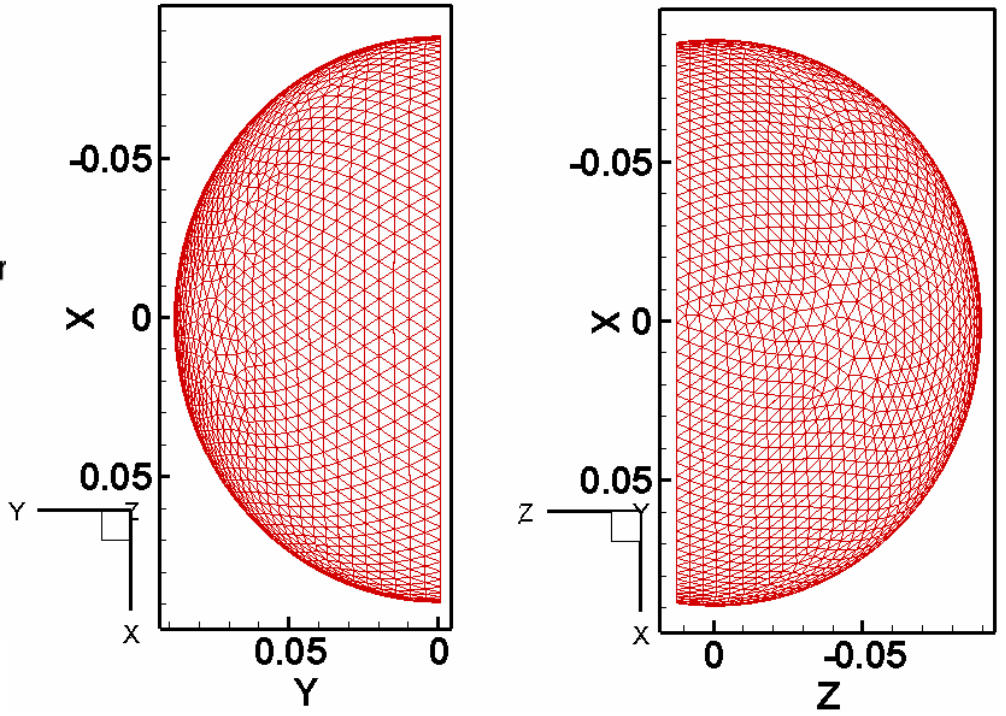
FLOWCHART OF THERMOGRAPHY PRESENTATION



NUMERICAL CALCULATIONS OF TEMPERATURE PROFILES



Dimensions match Gautherie data

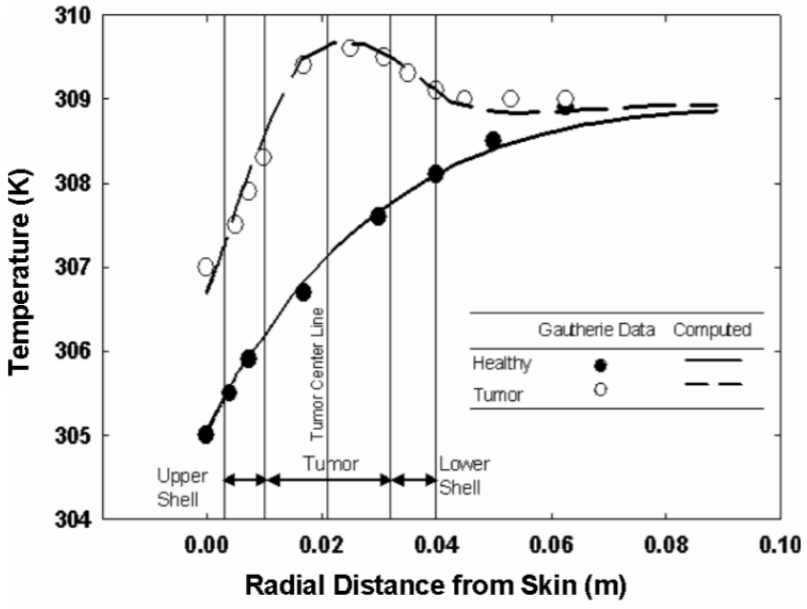


A tumor is modeled as a sphere of 2.0 cm diameter with its center located 2.1 cm beneath the skin surface (GAMBIT and FLUENT)

TEMPERATURE PROFILES IN A FEMALE BREAST

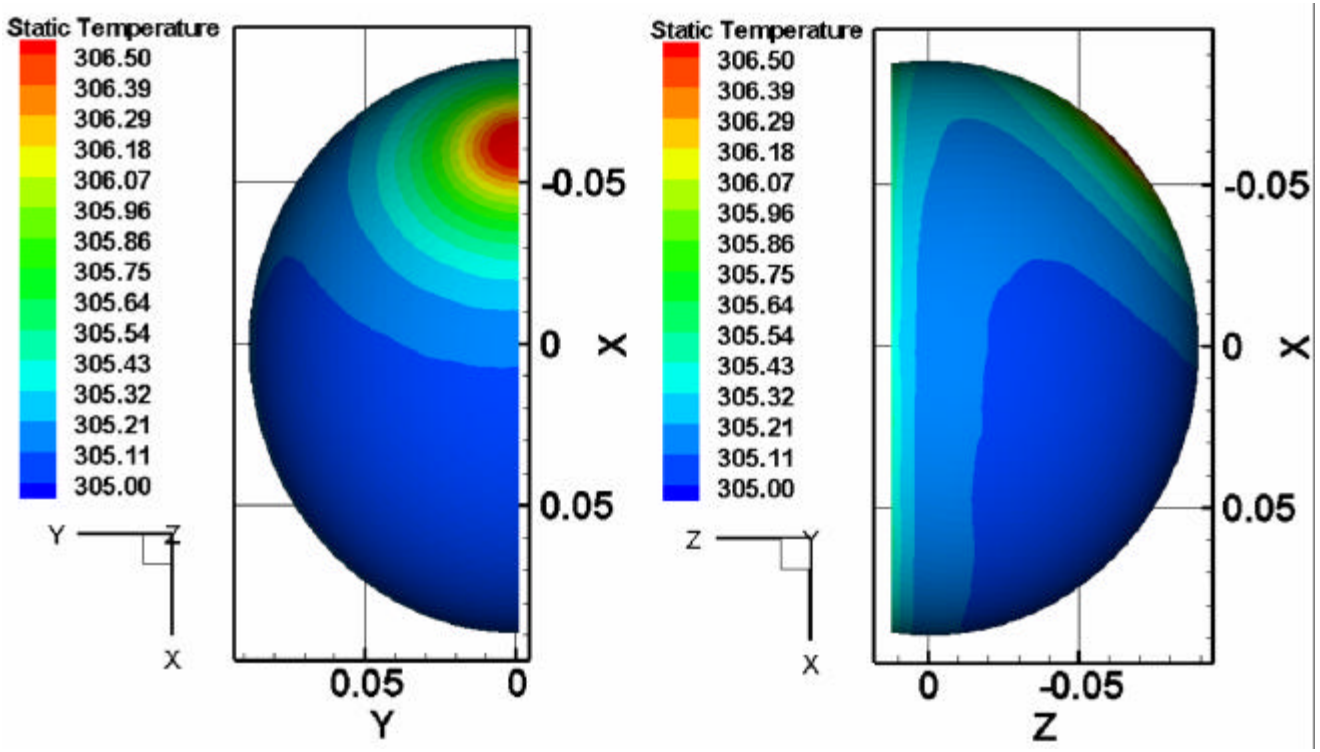
The blood perfusion and metabolic heat generation values used for an optimum fit (χ_0) with the Gautherie data

	q_m (W / m^3)	w_b (ml / s / ml of tissue)
Normal	450	0.00018
Tumor	29000	0.00900
Lower Shell	11700	0.00360
Upper Shell	4725	0.00144



- The temperature distribution inside a female breast can be replicated with proper knowledge of parameters
- Shells are required to match the profile
- Tumor may have 1 – 2 order of magnitude perfusion and heat generation

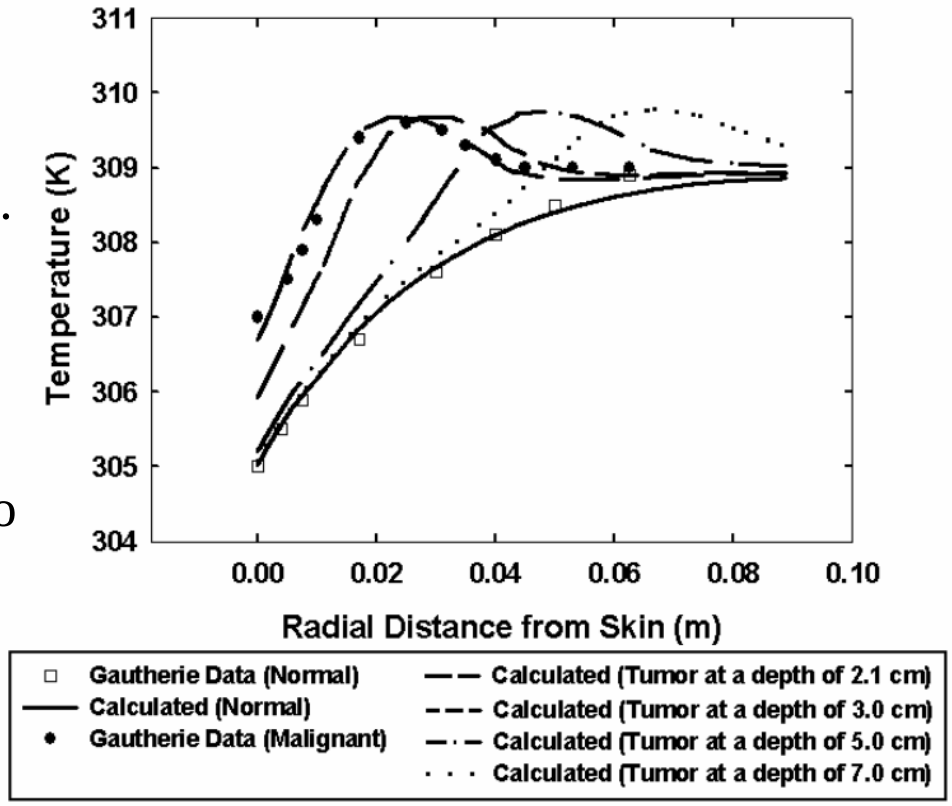
SKIN TEMPERATURE PROFILES OF A FEMALE BREAST



An abnormal **hot spot** is observed on the skin over the 2.0 cm diameter tumor

DEPTH LIMITATION OF A STAGE I B.C.

- A 2.0 cm diameter tumor with derived parameters, is always detectable up to a depth < 5.0 cm.
- Sensitivity analysis was done.
- Skin temperature were found to be most sensitive to heat transfer coefficient by several orders of magnitude as compared with other parameters.

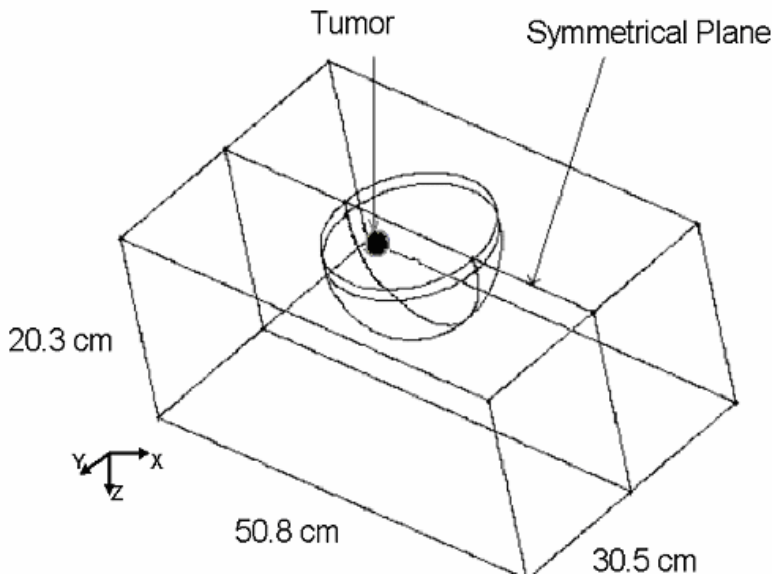


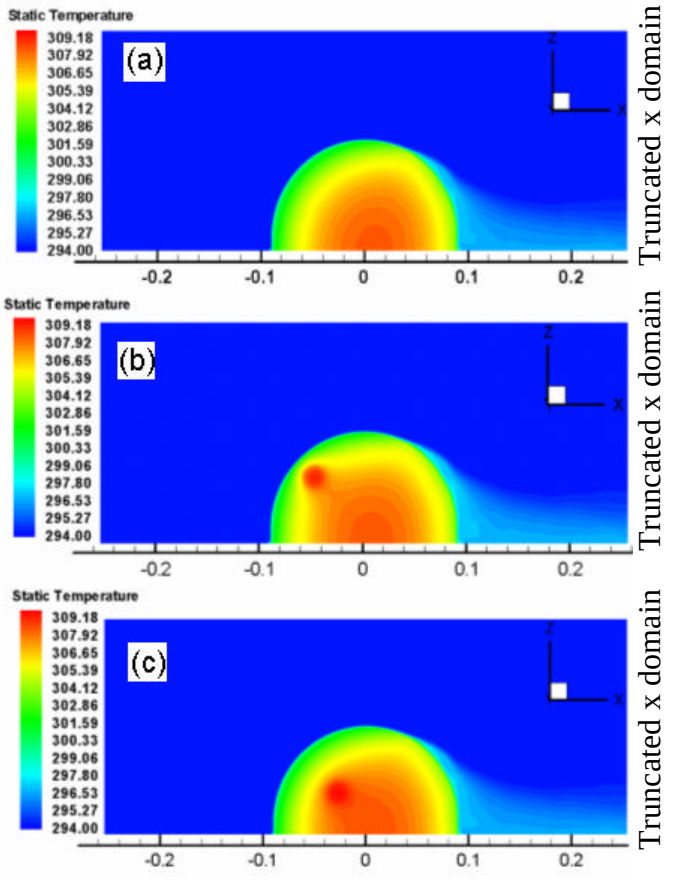
Effect of uncontrolled laboratory environment on skin temperatures ?

EFFECT OF AIR DRAFTS IN LAB

- The skin temperatures are most sensitive to ambient conditions

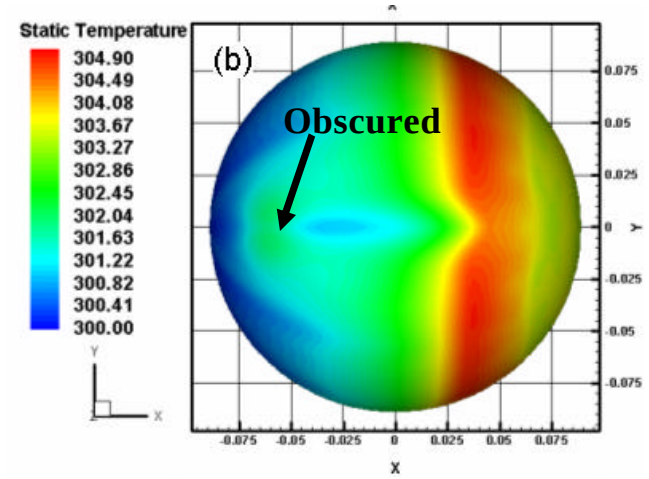
v_{inlet} = 1 m / s



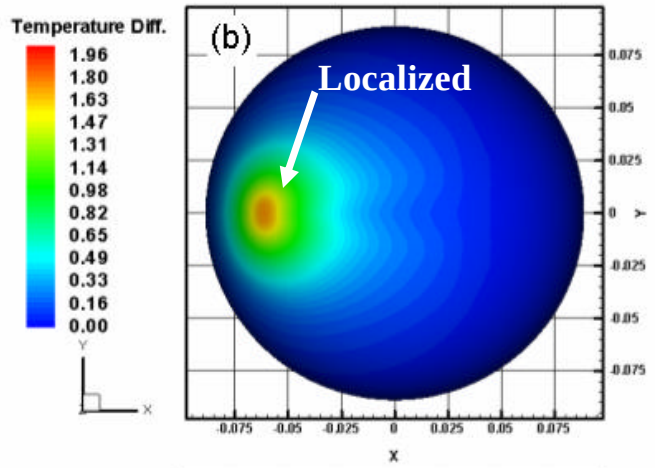


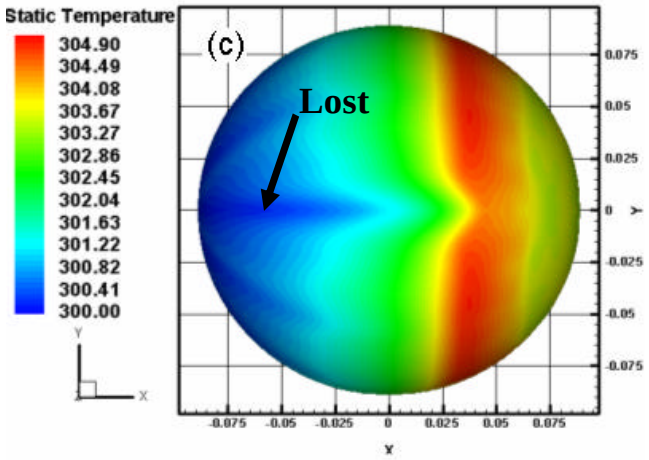
Temperature plots of cross section

IMAGE PROCESSING

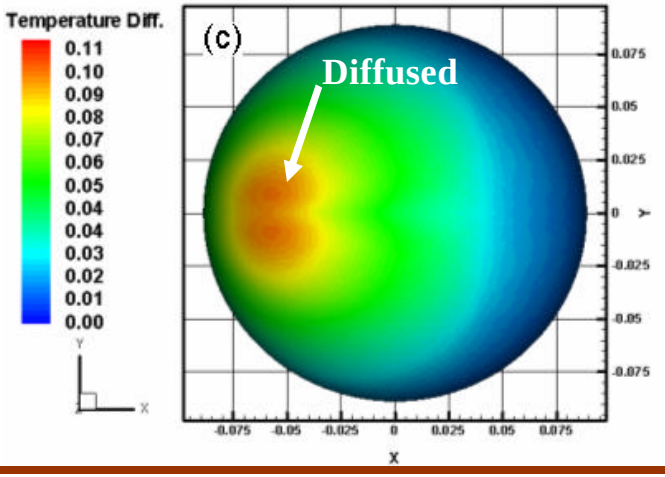


2 cm deep

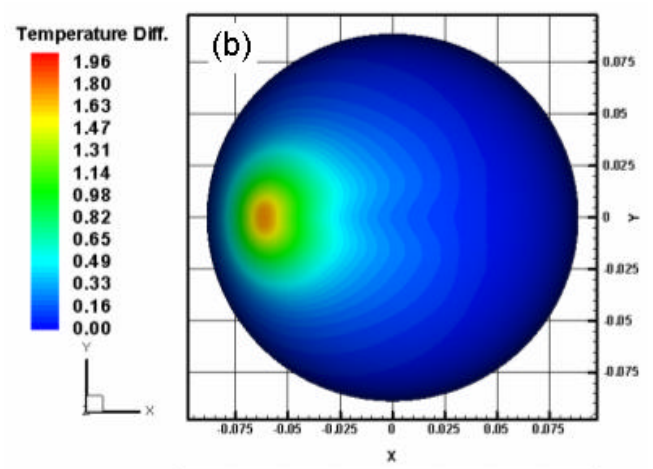




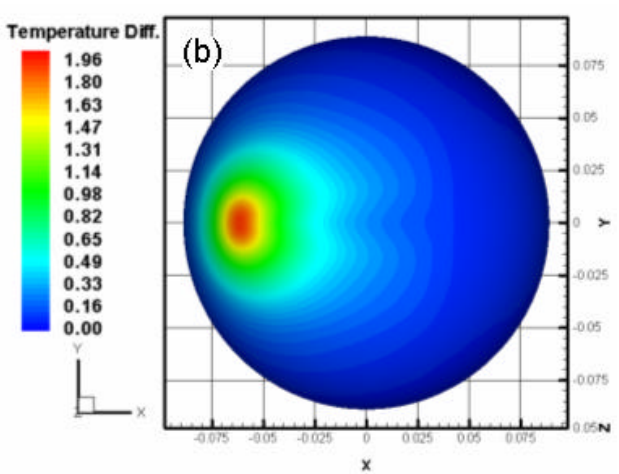
5 cm deep



VASOCONSTRICTION

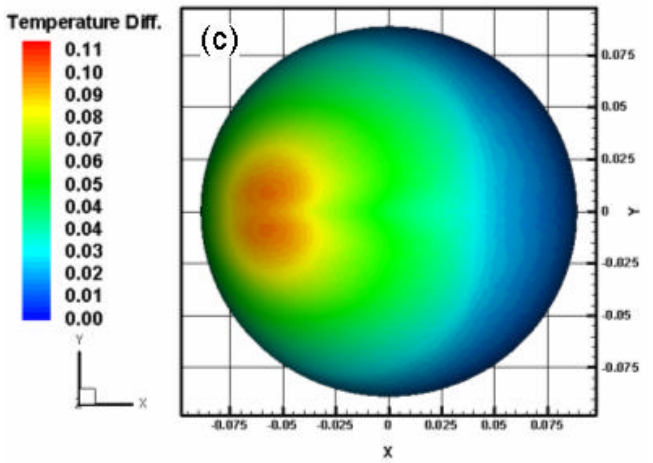


2 cm deep

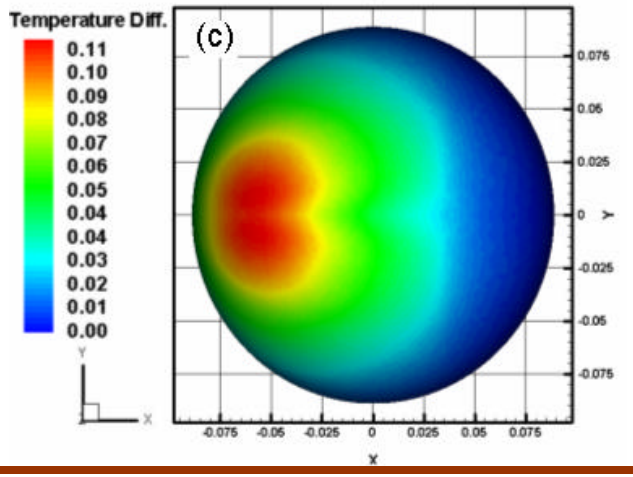


60 %

Increase

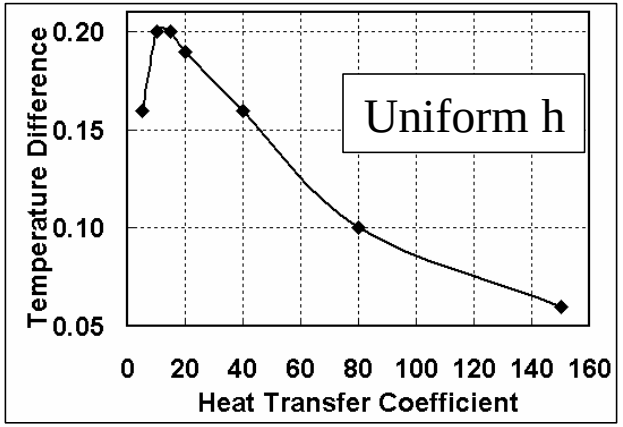


5 cm deep



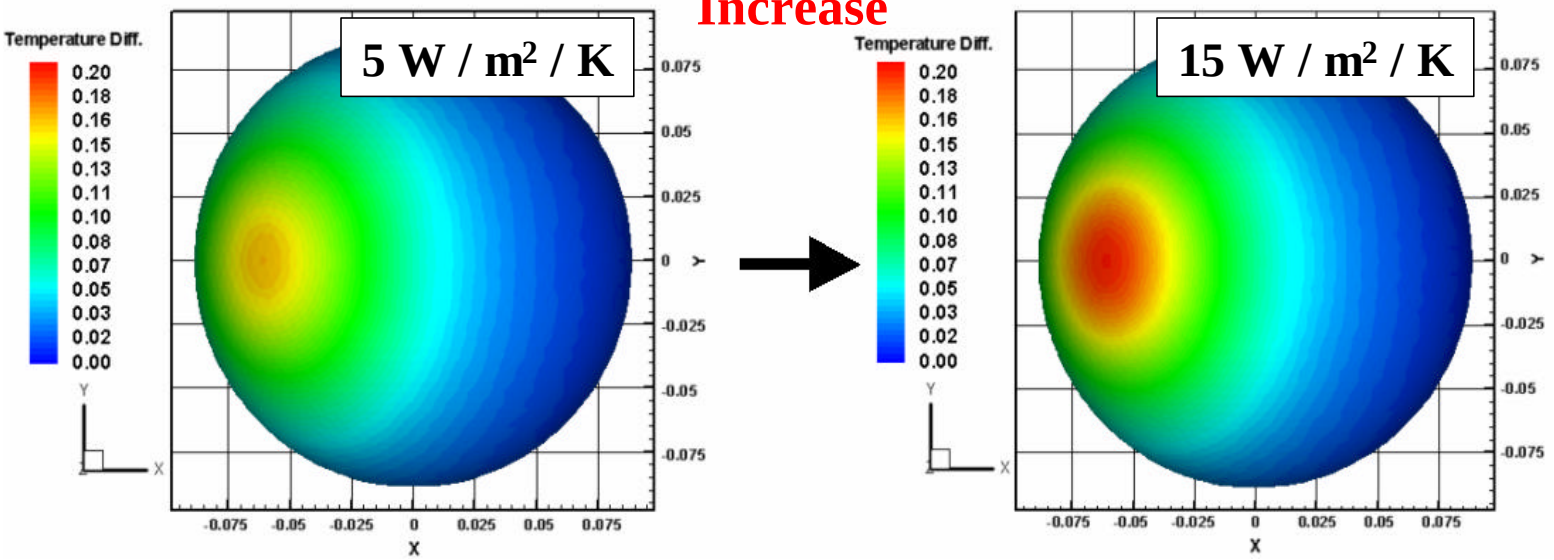
EFFECT OF ENHANCING SKIN H.T.C.

- Increasing v_{inlet} to 3 m / s lead to further improvement in thermal signature, but signature degraded at v_{inlet} of 5 m / s.



25 %

Increase



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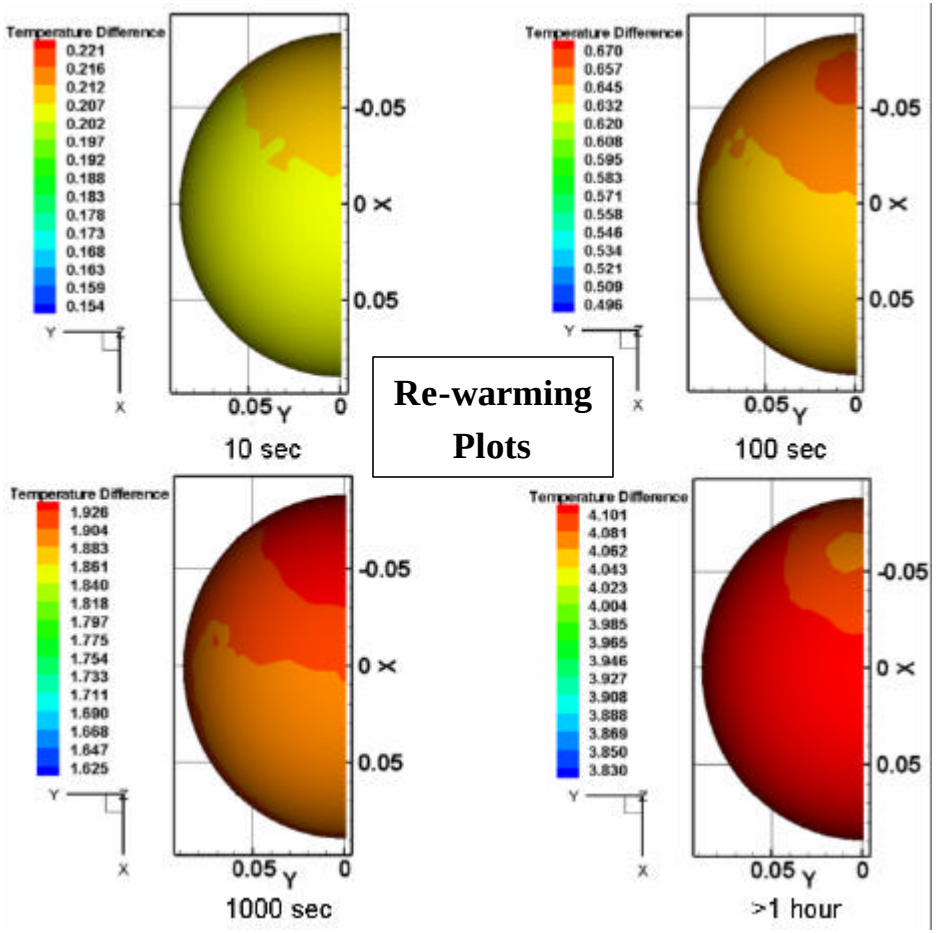
TRANSIENT RESPONSE

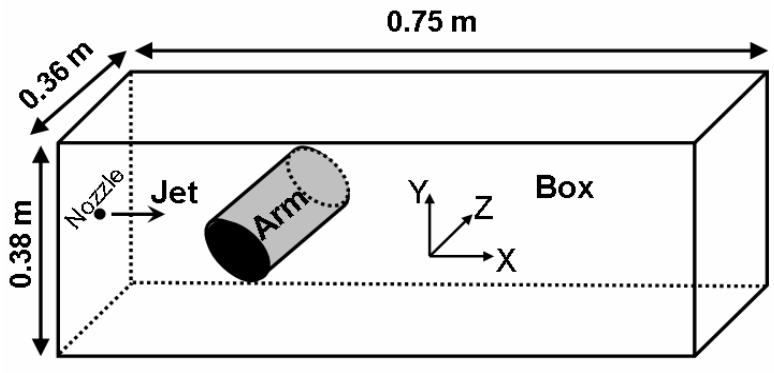
Malignant Image (t)-Malignant Image (t=0)

- Normal image might not be available.
- Change in the surface heat transfer coefficient or ambient temperature and dynamic imaging.
- Cooling predictions provided **no** improvement.
- Re-warming predictions showed **35 % Increase** with respect to steady state

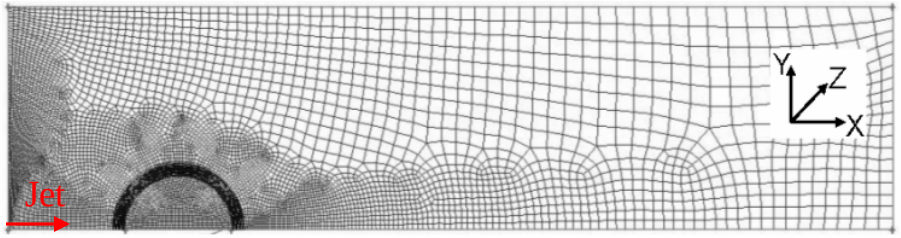


EXPERIMENTAL INVESTIGATION

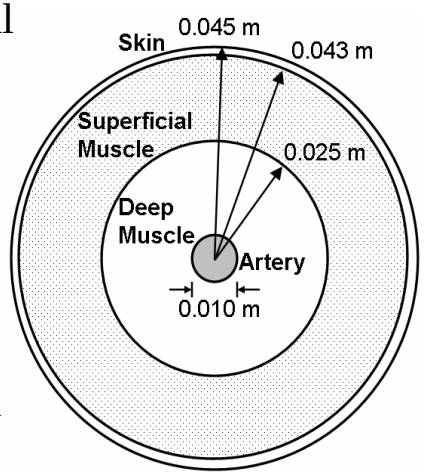
Thermal Response of Human Arm to Jet Impingement



Experimental Setup

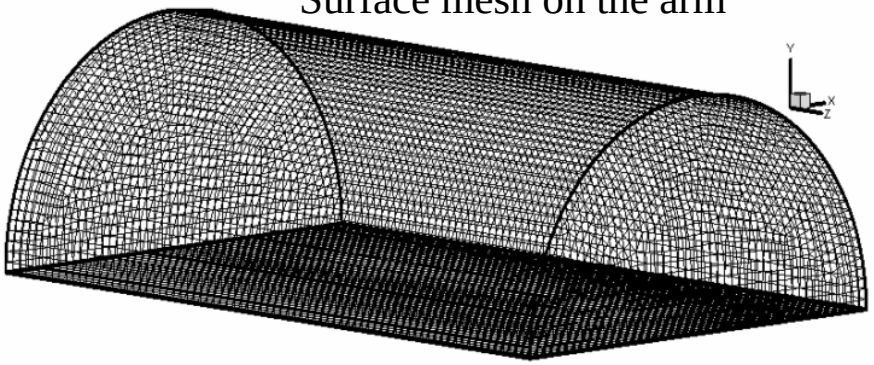


Mesh in cross section of computational domain



Schematic of Arm Model

Surface mesh on the arm



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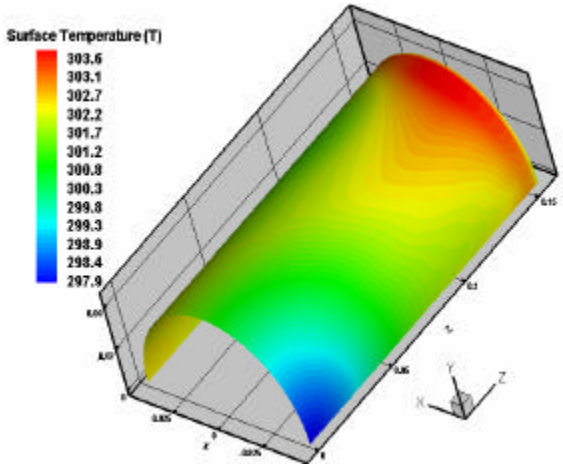
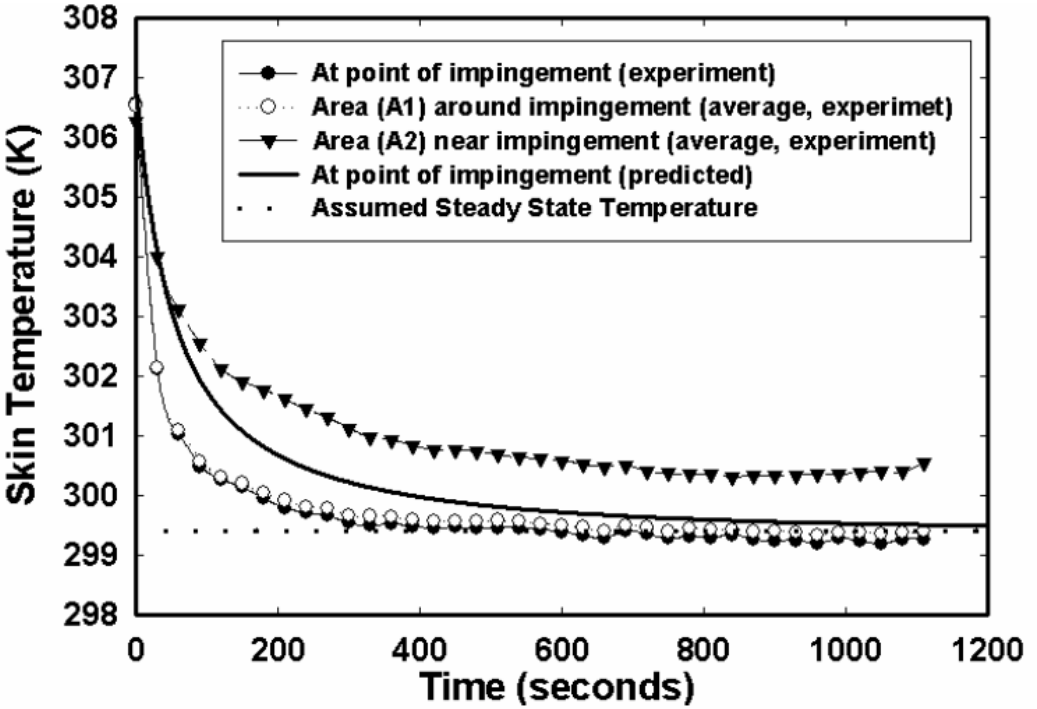
NUMERICAL COMPARISION

Experimental Investigation of Jet Impingement

FLIR SC 3000 camera



Skin temperature predictions on the human arm



Comparison of experimental and predicted transient decay of temperature. A1 is an area of 127×10^{-4} m^2 surrounding the point of impingement and A2 is an area of 13×10^{-4} m^2, 0.025 m away from point of impingement.

CONCLUSIONS

- **The temperature distribution inside a female breast can be replicated with proper knowledge of parameters.**
- **Skin temperatures are highly sensitive to surface heat transfer coefficients.**
- **Image processing is required for an accurate thermogram interpretation, especially for deep tumors.**
- **Tumor signature may be significantly improved by vasoconstriction, thermal stress (limit) and dynamic imaging.**
- **Detailed understanding of vasomotor action is required to accurately predict the transient response to thermal stress**

Above models assumed a homogenous breast and a homogeneous tumor with averaged properties. Individual specific breast models !

DEVELOPMENT OF HETEROGENEOUS H.T. MODEL OF THE BREAST

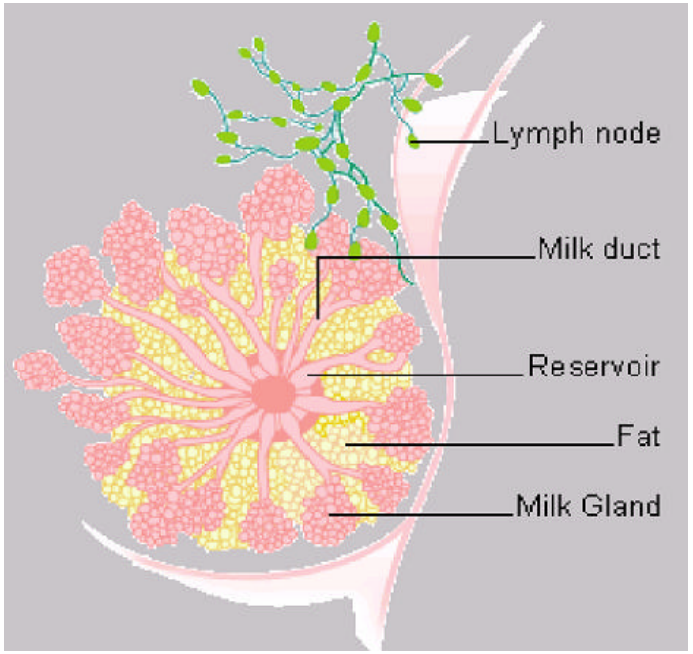
- Patient specific computational heat transfer model

  i. Edge detection (MATLAB)

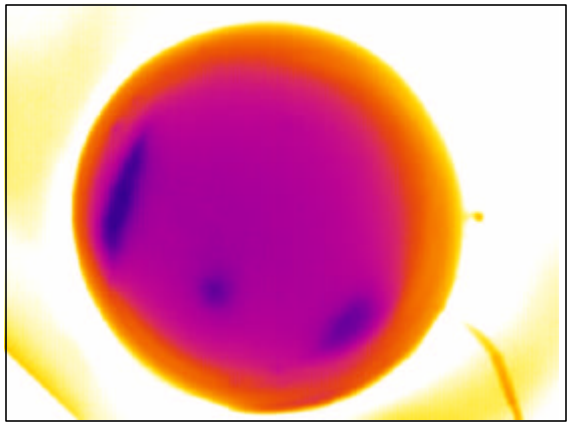
  ii. Surface generation (MATLAB, GAMBIT)

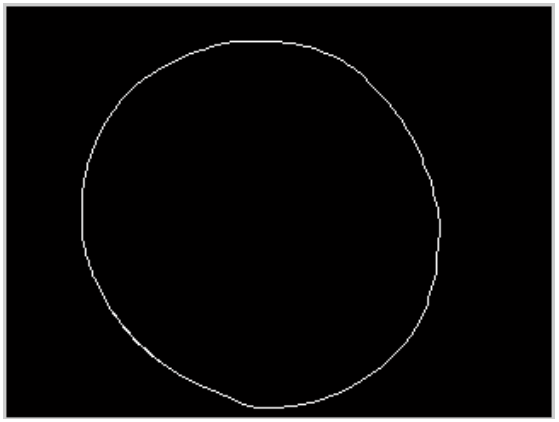
  iii. Mathematical model with tissue details

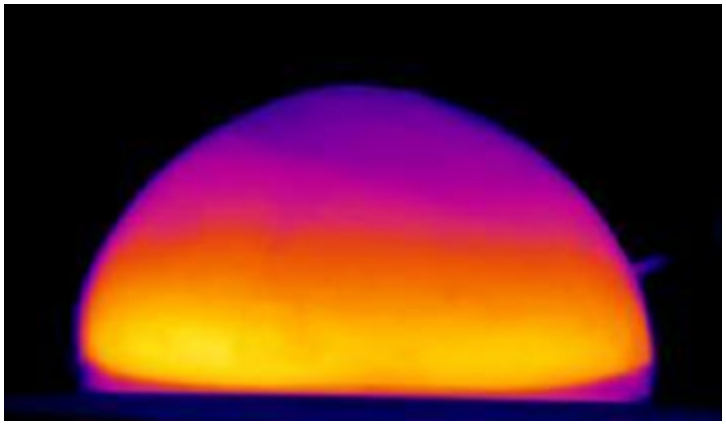
  iv. Predict the effect of thermal stress

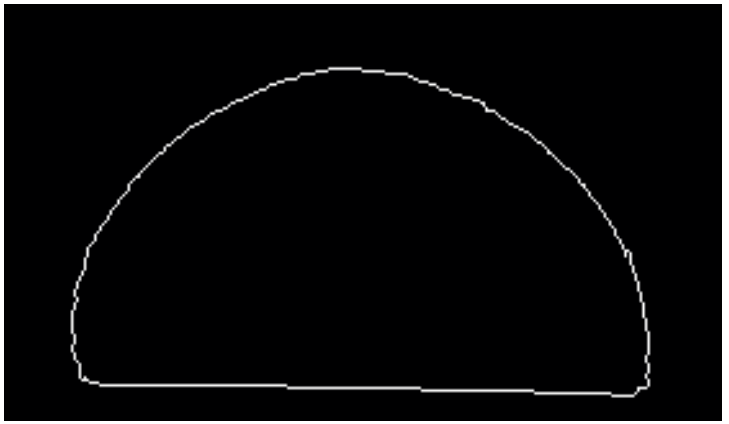


EDGE DETECTION





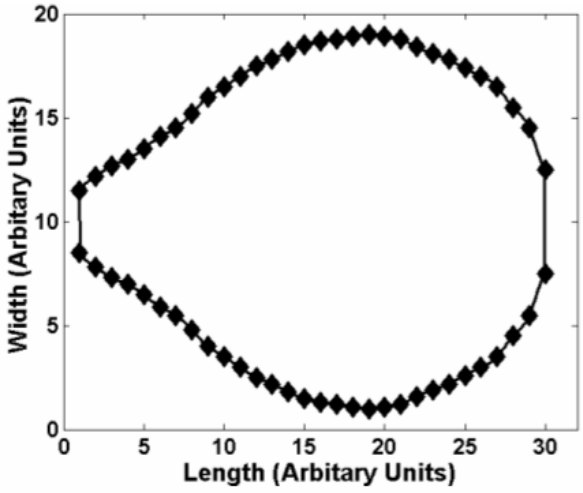


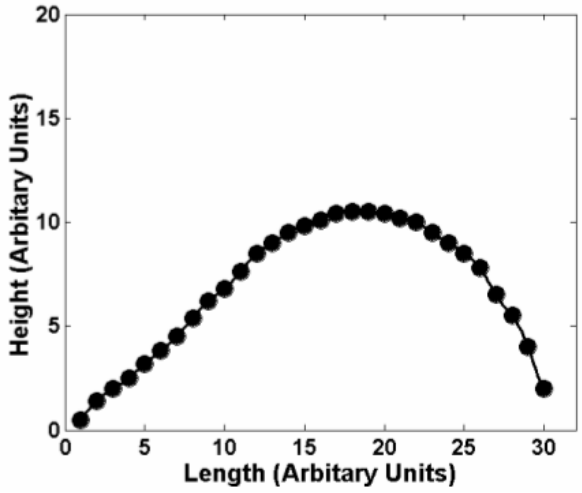


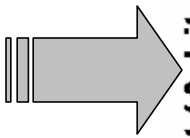
Thermograms of an instrumented phantom mold

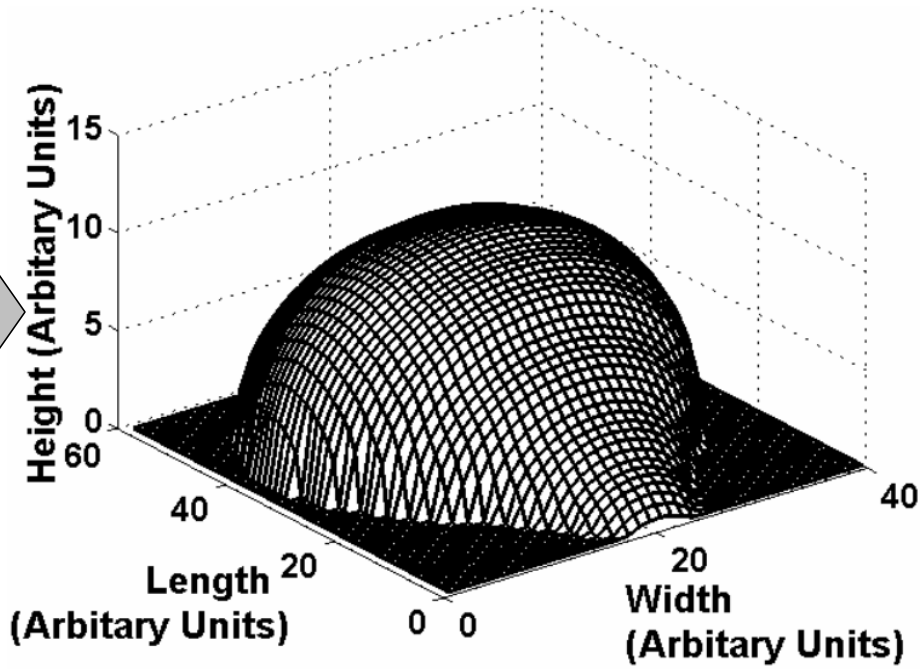
Results from the edge detection algorithm

SURFACE GENERATION

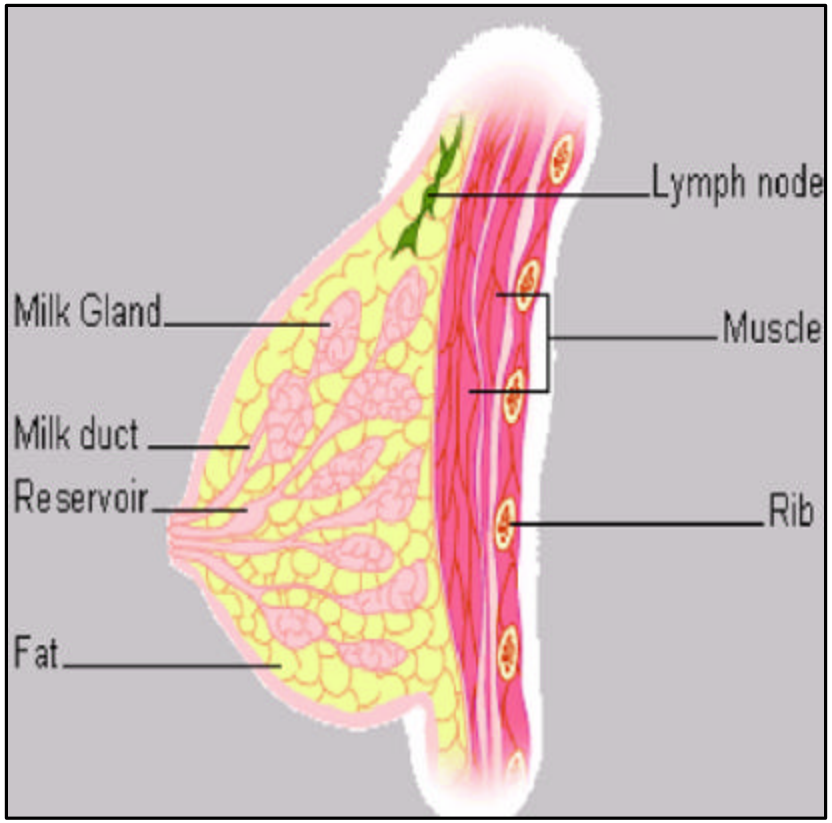


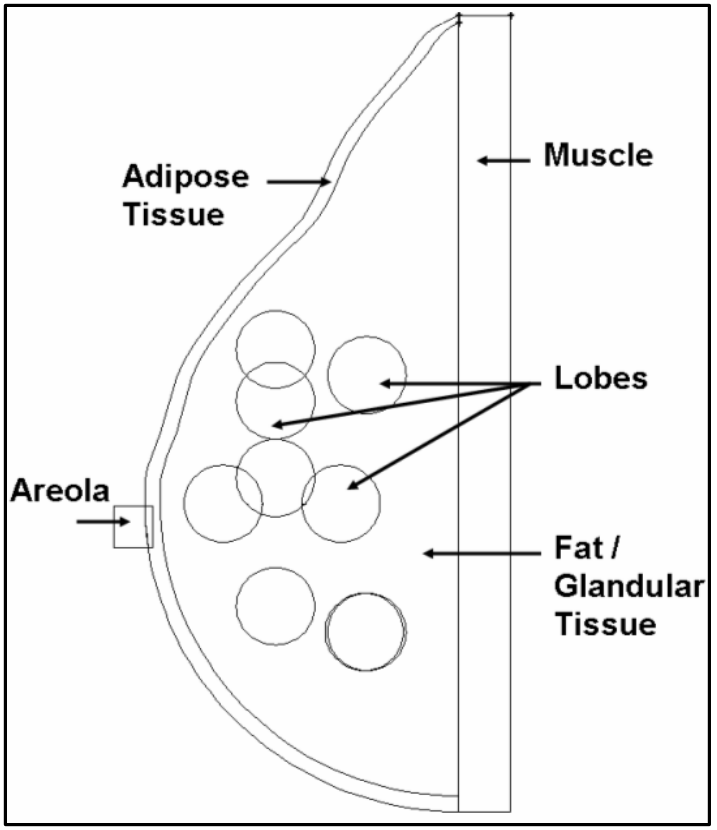




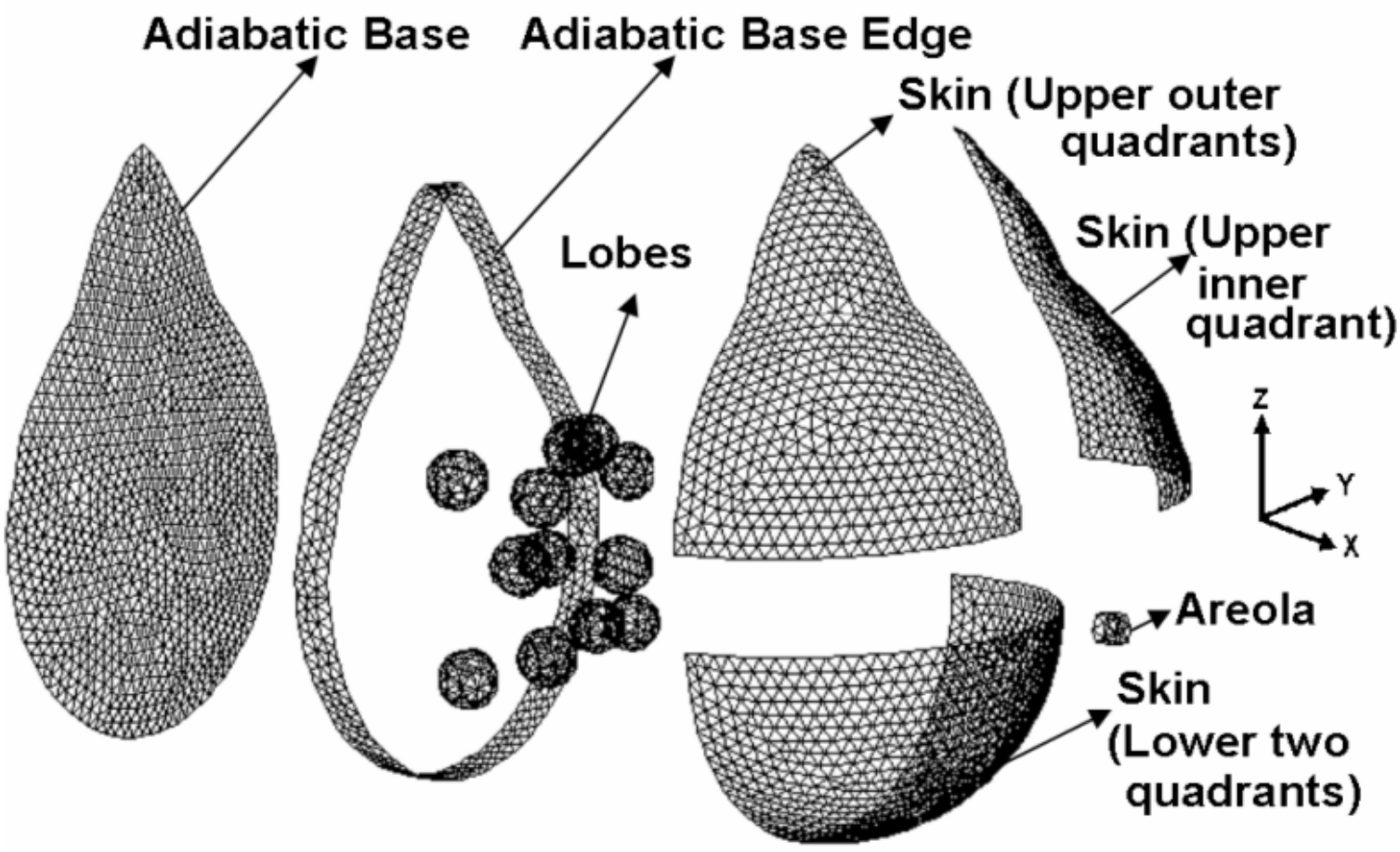


HETEROGENEOUS MODEL OF BREAST

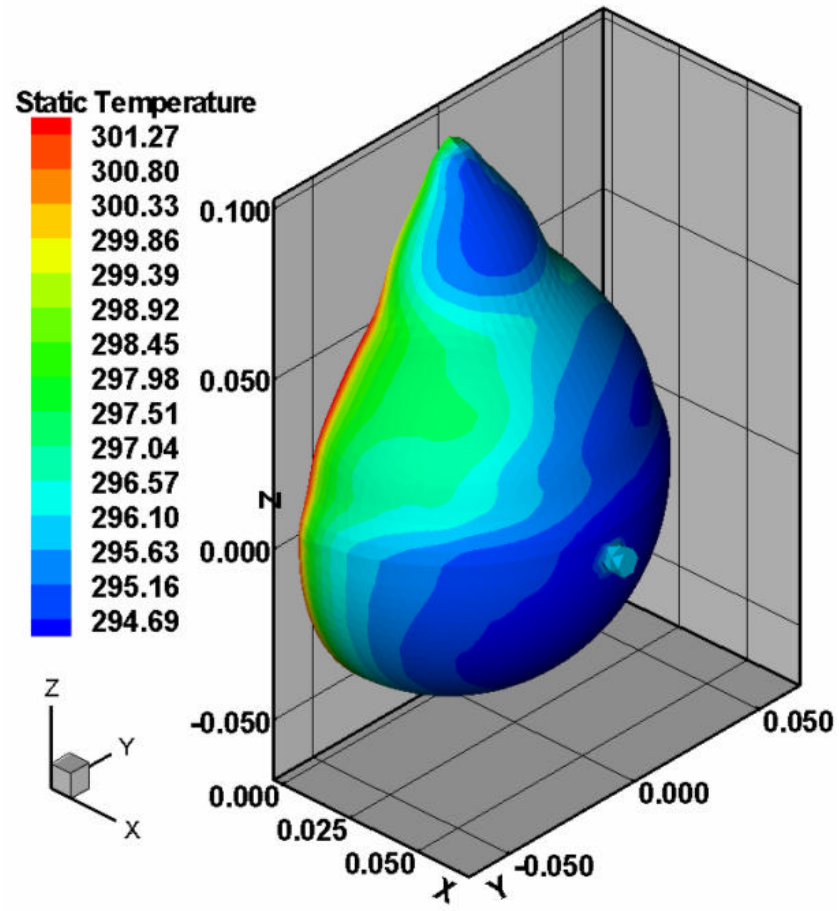


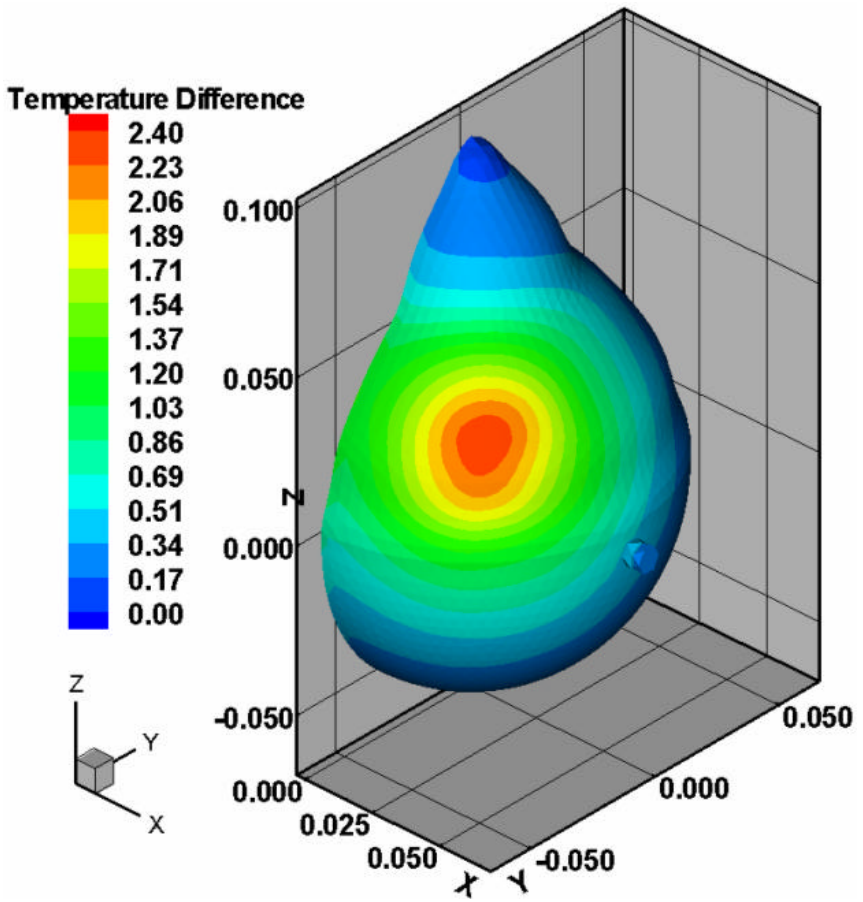


GRID IN THE HETEROGENEOUS MODEL



SKIN TEMPERATURE DISTRIBUTION





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END OF PRESENTATION

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