Nonhomogeneous heat transfer simulation using a female human model

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COMSOL CONFERENCE
2018 BOSTON

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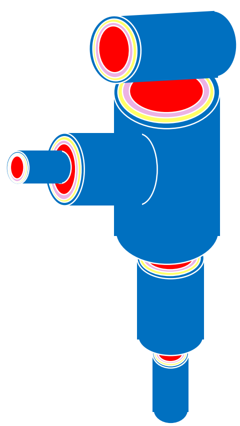
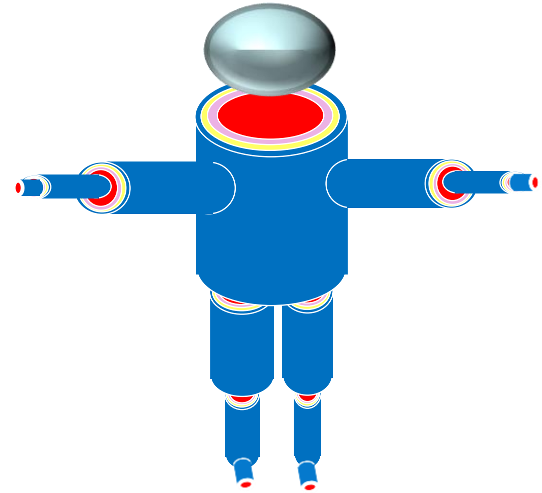
Disclaimer

Introduction

- Human thermoregulatory models have been developed and applied since early 1960s
- Most human body models have been constructed from cylinders and ellipses using CAD software
- Medical images can be used to create a more accurate representation of the human body
- Purpose of the study is to use a geometrically and anatomically accurate mesh to perform heat transfer analysis and create temperature profiles in the human body



Multiple cylinders or elliptical-cylinder



Mesh

Average American Female
Height:1.62 m (~5' 4")
Weight: 66 kg (~145 lbs.)
Body Fat: 36.1%
Age: 36 year
Volume: 0.0445 m^3
Surface Area: 0.777m^2

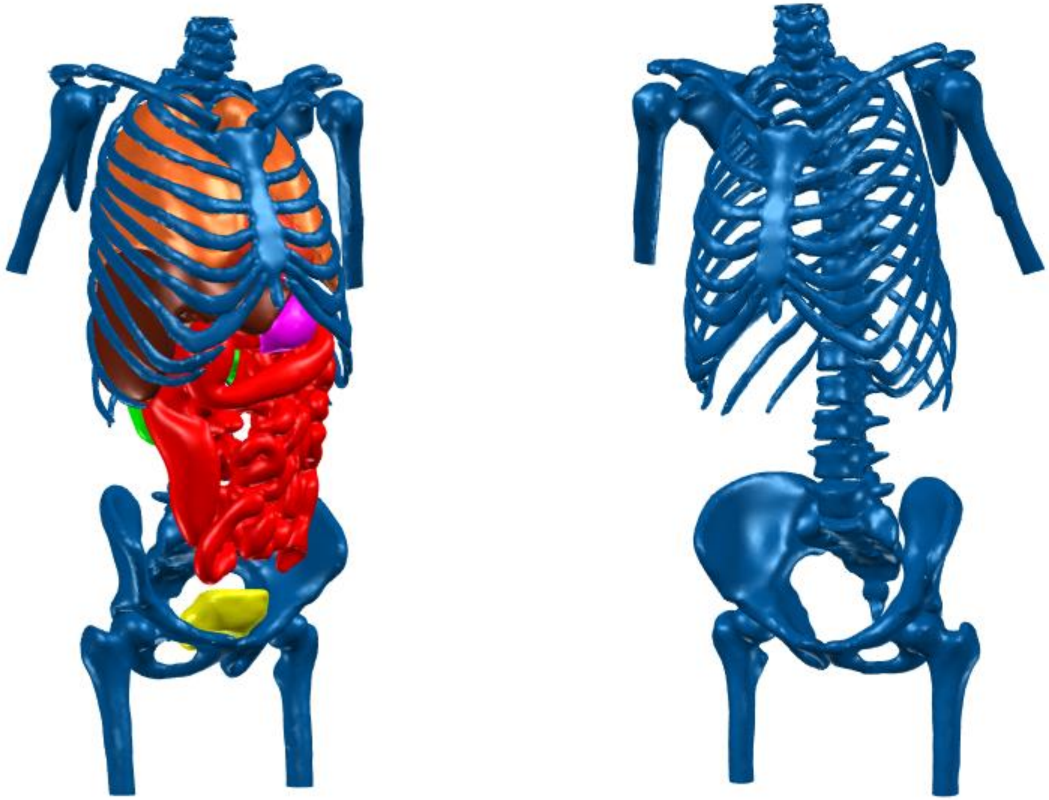
Vertices: 566,830
Tetrahedra: 2,985,530
Triangles: 802,750
Edge elements: 13,020
(Segars et al Med Phys 2010, Simpleware Inc)

Organs

Skin

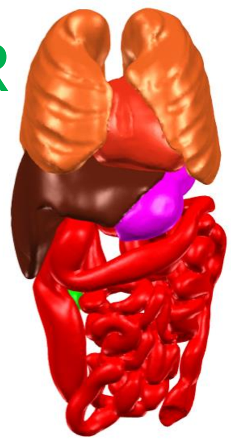
Muscle

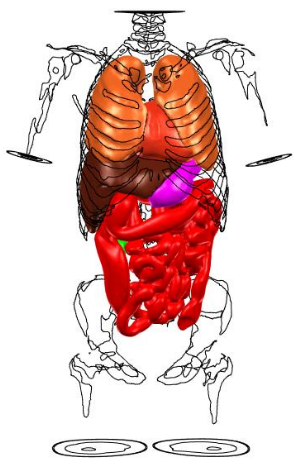
Bones and Internal Organs



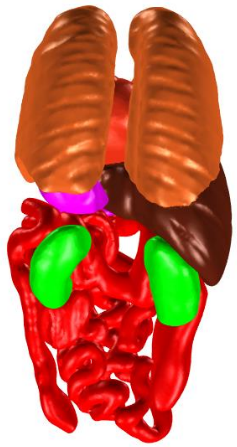
Internal Organs

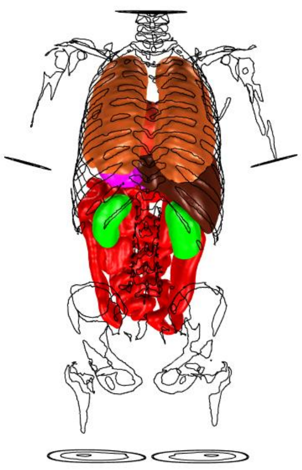
ANTERIOR





POSTERIOR





Biophysical Heat Transfer

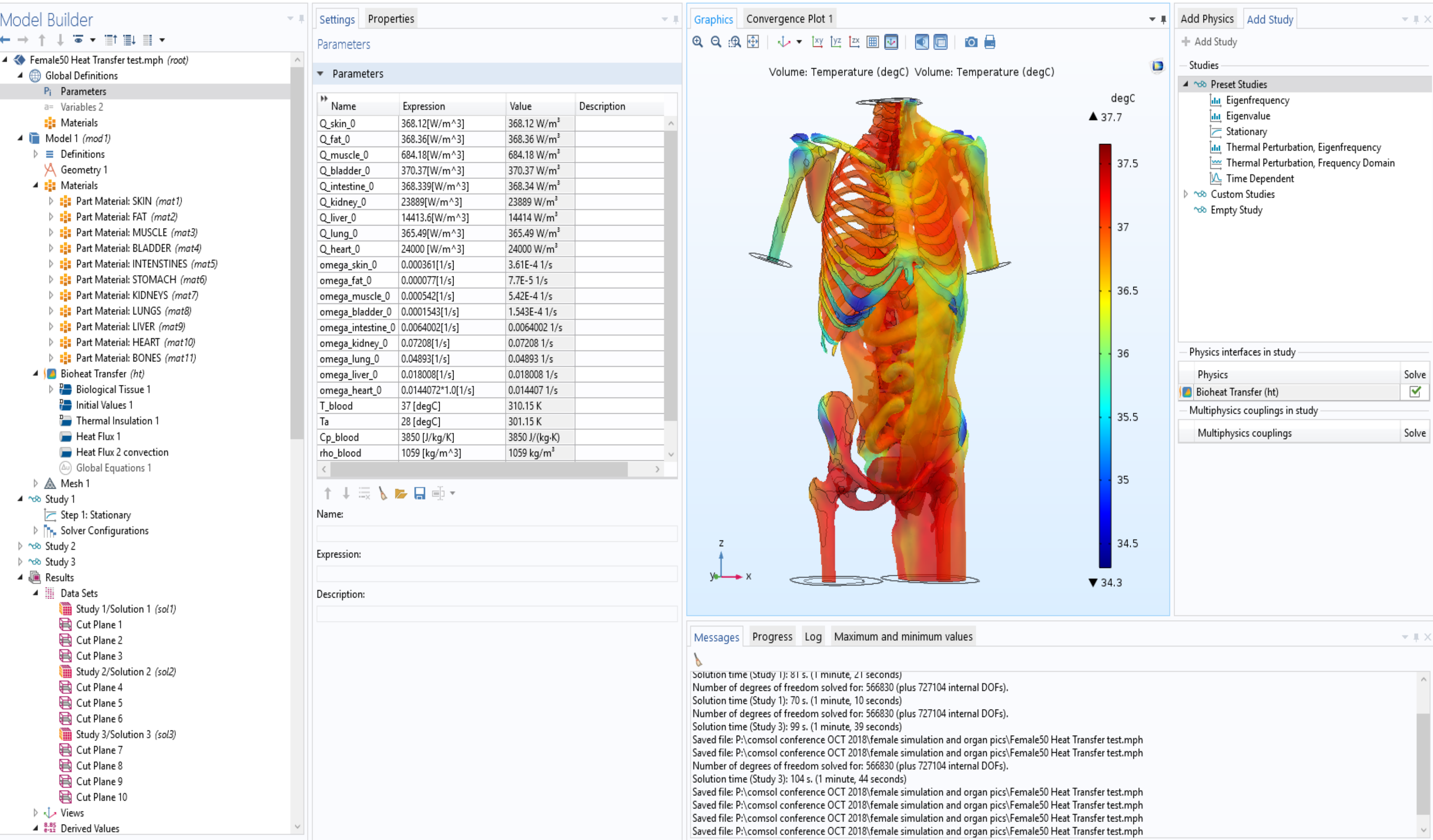
BIOLOGICAL HEAT TRANSFER WITHIN THE BODY:

$$\rho c_p \frac{\partial T}{\partial t} = \lambda \nabla^2 T + Q + \omega_b \rho_b c_b (T_b - T)$$

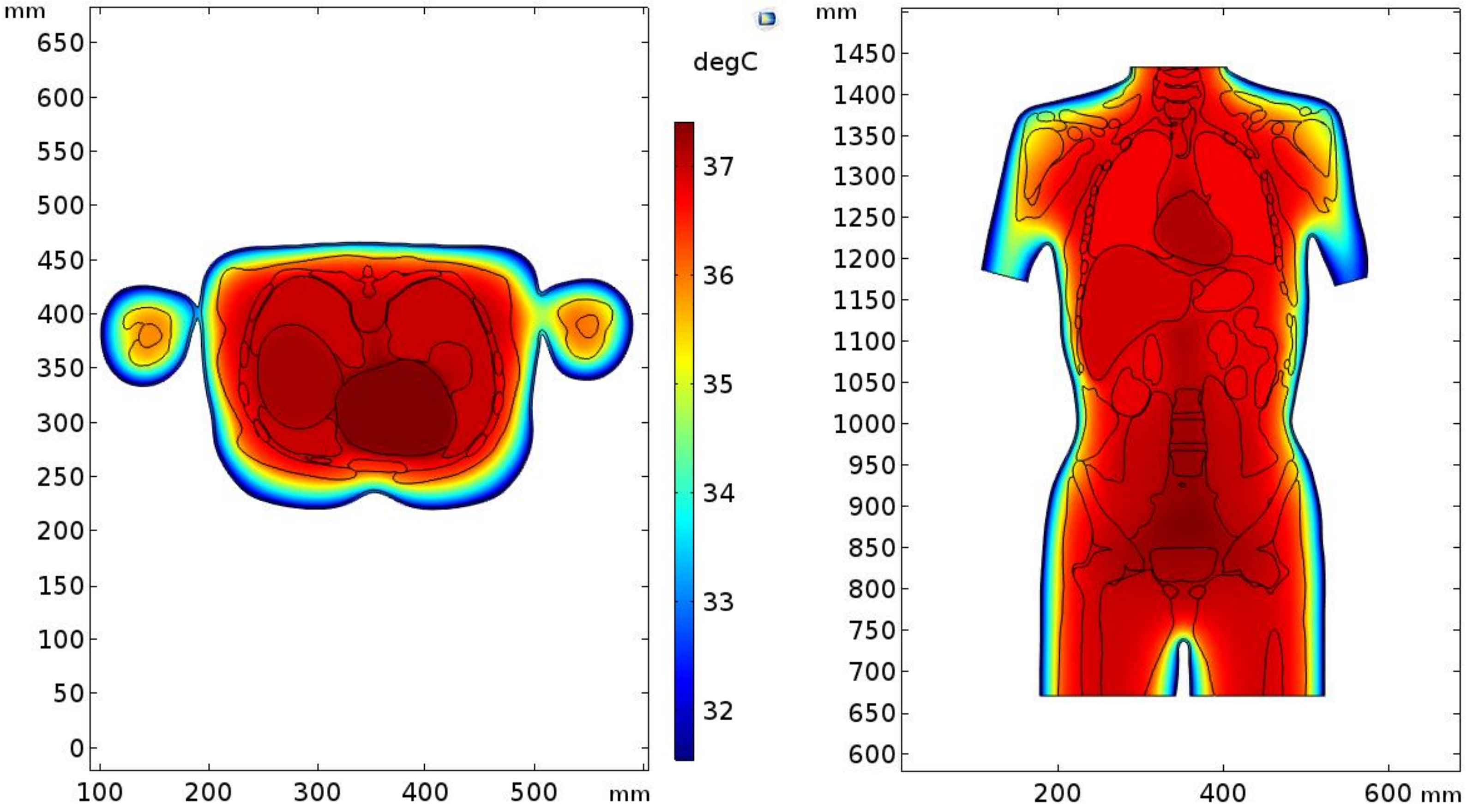
HEAT FLUX AT THE SURFACE:

$$q = (h_c + h_r) \cdot (T - T_a) + E$$

Comsol Implementation



Results


mm
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37
36
35
34
33
32
mm
1450
1400
1350
1300
1250
1200
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1100
1050
1000
950
900
850
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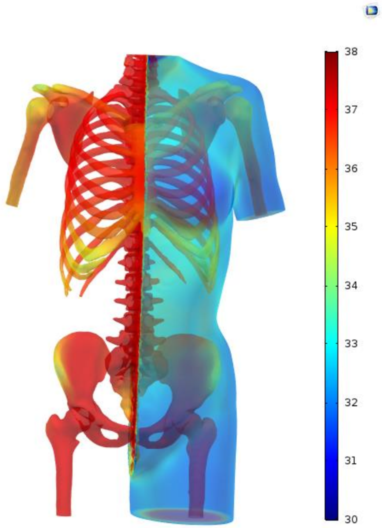
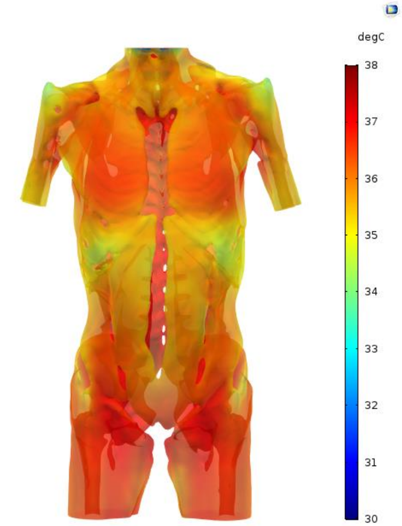
750
700
650
600
200
400
600 mm

Results

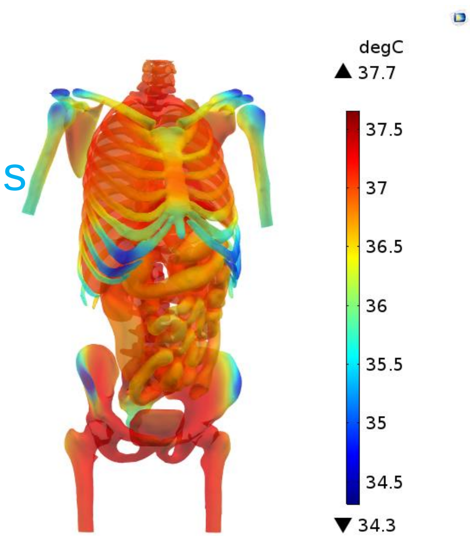
Skin & Bones



Muscle



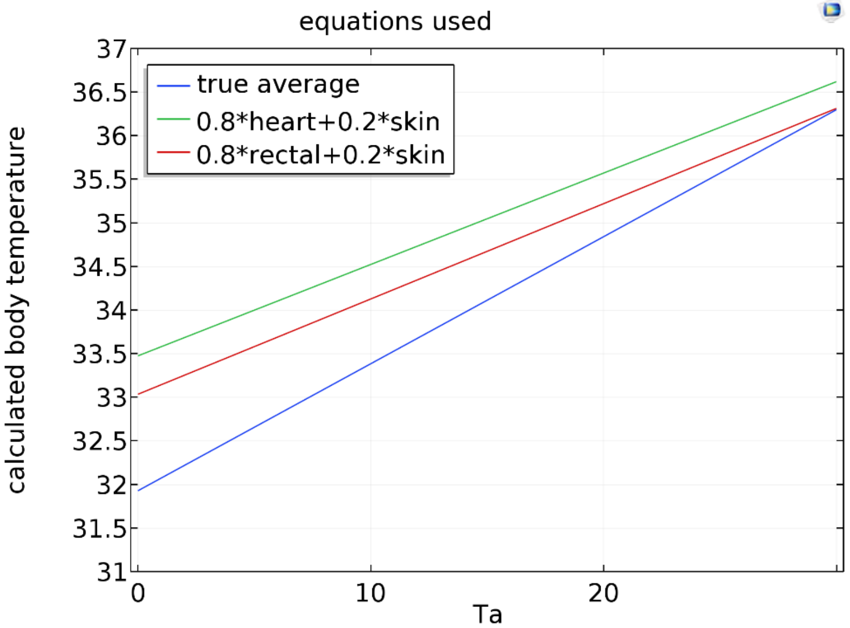
Bones & Internal Organs

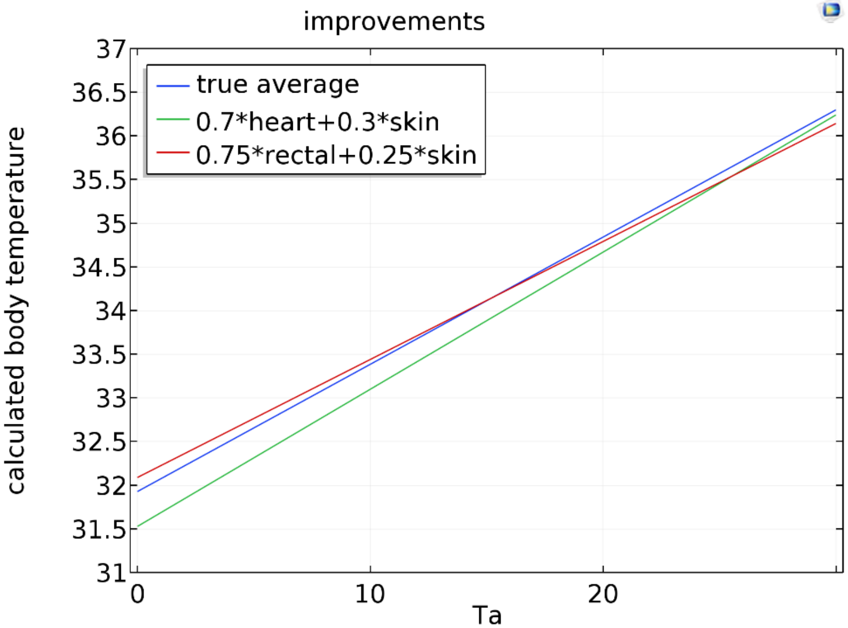


Skin

Calculating Average Body Temperature Application Example 1

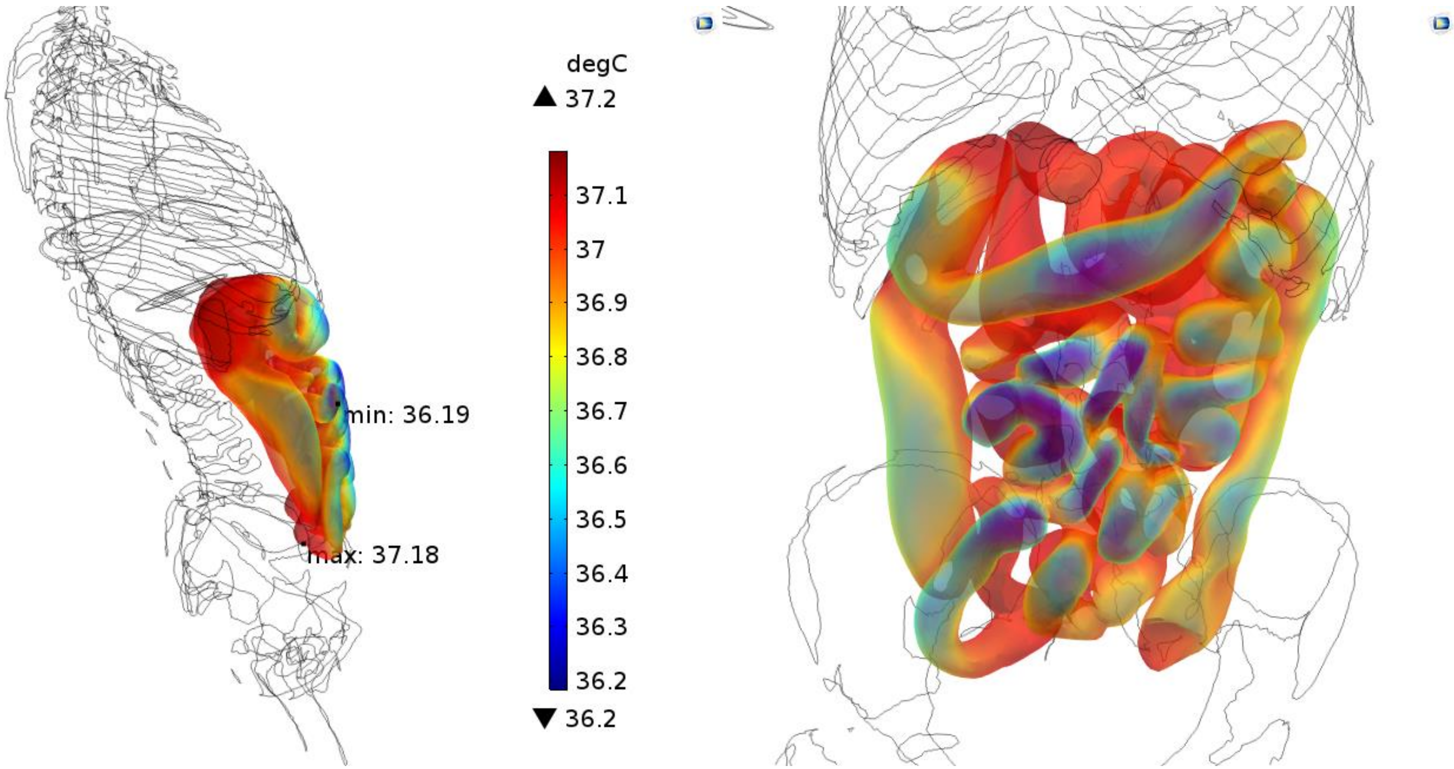
$$average\ temperature = \frac{\int T dV}{\int dV}$$





(Burton, Human Calorimetry, 1935)

What does a temperature pill measure? Application Example 2



Consistent with the finding from Goodman et al. Influence of Sensor Ingestion Timing on Consistency of Temperature Measures (Med. Sci. Sports Exerc, Vol. 41, No. 3, pp. 597–602, 2009)

CONCLUSION

- The simulations provide an accurate assessment of the human body temperature with respect to the inhomogeneity
- Detailed data can be obtained from the simulations, which would be difficult to obtain during human studies, and can aid in study design and result analysis
- Finite element methods (e.g., COMSOL Multiphysics™) and geometries of nonhomogeneous human bodies can be used to create a new approach in modeling physiology