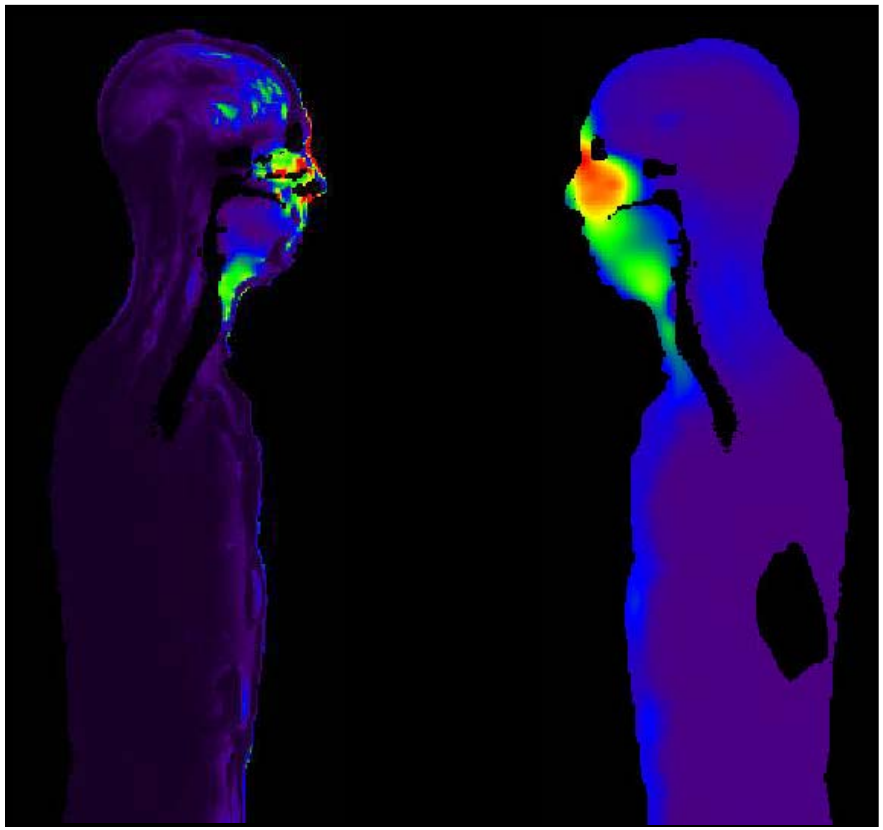
A Comprehensive Tissue Properties Database Provided for Human Body Thermal Assessments



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Thermal modelling of the human body

Pennes' bio-heat equation

$$\rho c \frac{\partial T}{\partial t} = k\nabla^2 T \quad +q \quad + A_0 \quad -b\left(T - T_b\right)$$

Heat from external sources

Heat sink strength by blood perfusion (*m*)

Equation's main simplifying factor

Metabolic heat production

Boundary condition

$$k\frac{\partial T}{\partial n} = -h\left(T - T_a\right)$$

Assessment of RF exposure

In Penne's equation set

$$q = \rho.SAR$$

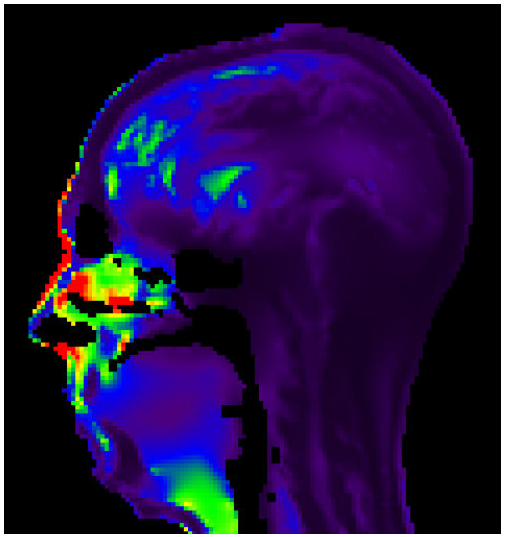
where *SAR* is the Specific energy Absorption Rate (W/kg^3)

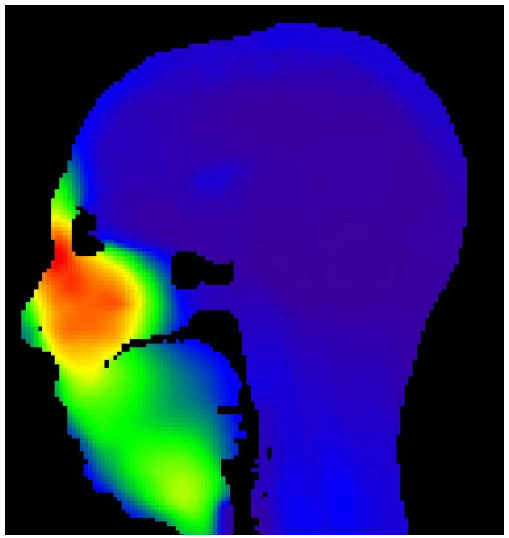
SAR

Peaks:

3.3 W/kg unaveraged

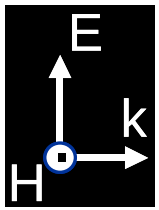
0.64 W/kg 10 g averaged





Temperature increase due to SAR

Peak: 0.19 °C



1 GHz

plane-wave

10 W/m^2

linear scale (15% between main colours)

peak for ΔT = 0.19 °C, peak for SAR = 1 W/kg

Tissue thermal properties

The accurate determination of human body temperature requires reliable estimates of the following five tissue properties:

c	specific heat capacity (J/(kg.°C))
k	thermal conductivity (W/(m.°C))
m	blood perfusion rates (ml/min/100 g)
A_0	metabolic heat production (W/m^3)
ρ	density (kg/m^3)

Water content (w, as a %), can also be used to derive c and k

The Database

- We have documented 140 key papers and books and developed a database for 44 human tissues:

  6 properties x 44 tissues = 264 values

  including min, max, # values, & source
- A key premise for the database is that only values from original measurements are listed
- Estimates or use of references without clear measurement details were only made if no original measured values were found

The Database

- Recorded in MS Excel spreadsheet
- Sheet for each reference, including
  - Values
  - Range
  - Sample size
  - Animal used
  - Measurement method
- Summary table on front sheet
- Data plotting facility

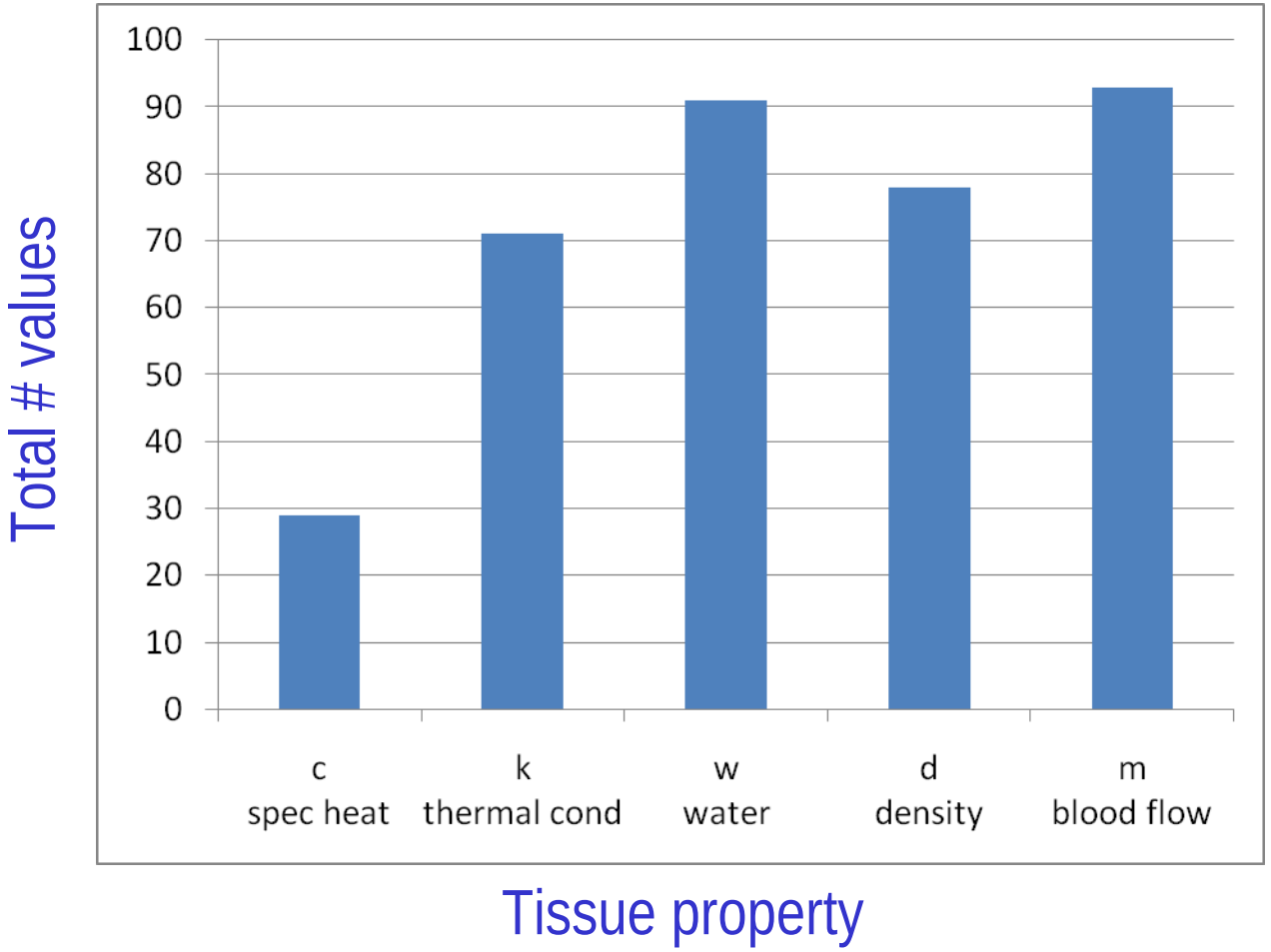
Benefits of tissue properties database

- Improved accuracy
- A standardised set of thermal tissue values would lead to greater consistency between modellers and those setting safety standards
- Helps consolidate the limited data there is available
- This database to be made freely available for use by those interested in biological thermal modelling

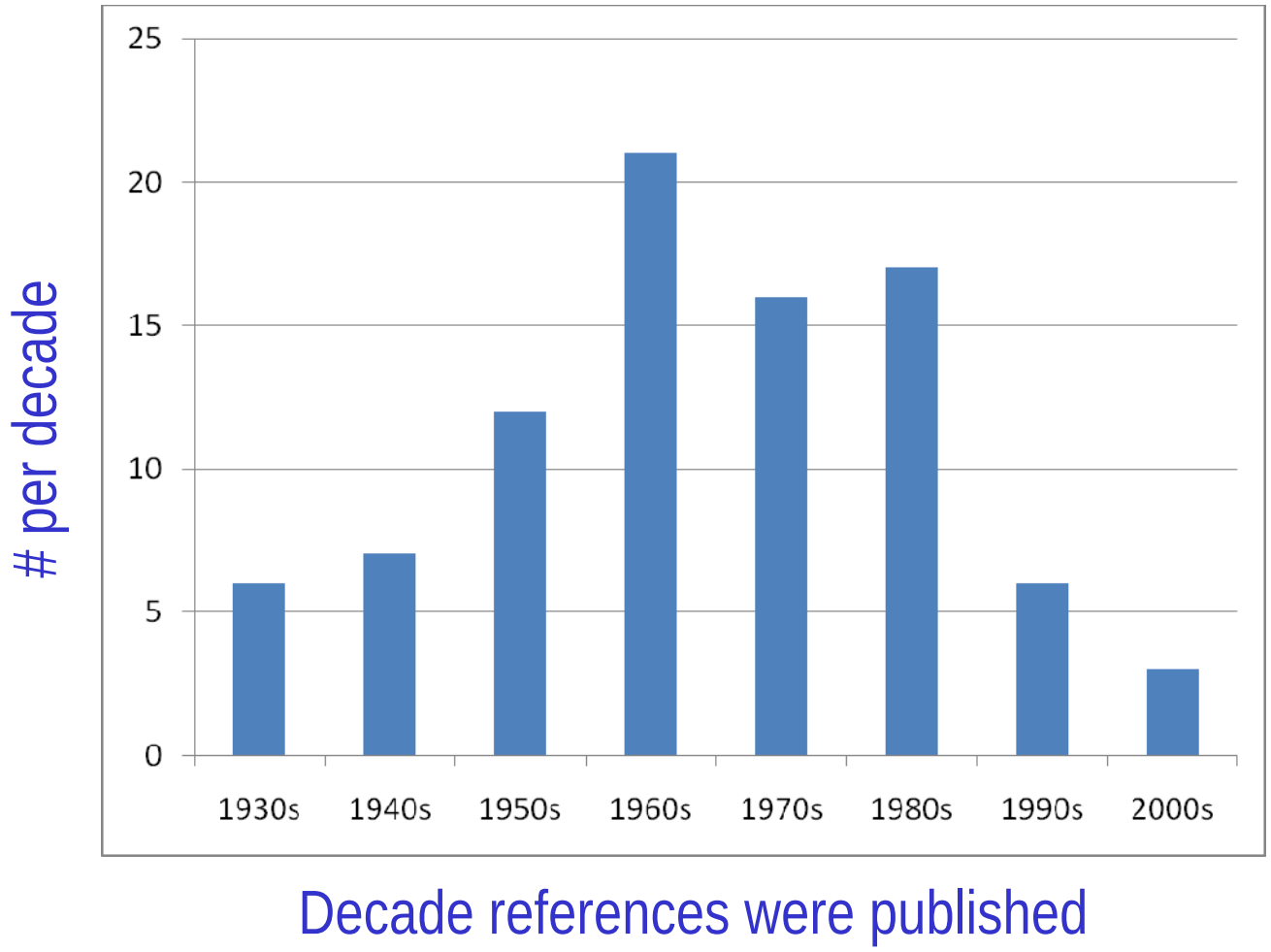
Type of data used

- Outliers ignored
- Precedence of human data over animal
- Data for early adult to 70 yo's
- Data measured at or extrapolated to 37°C
- Data for people at rest

Amount of data



When measurements were made



Estimation of thermal properties

- Close relationship between tissue water content, *w,* and *k* & *c*

  Spells (1960), Cooper & Trezek (1971), and Poppendiek et al. (1966)

  $$k = 0.0502 + 0.00577.w$$

  $$c = 1670 + 25.1.w$$

- Formulas fill in missing data:
  - only *c* value for 21 tissues (e.g. muscle, intestines, stomach)
  - only *k* value for 13 tissues (e.g. glands, small intestines)

- Oxygen consumption values or blood perfusion values used for deriving A_0

  Gordon et al. (1976)

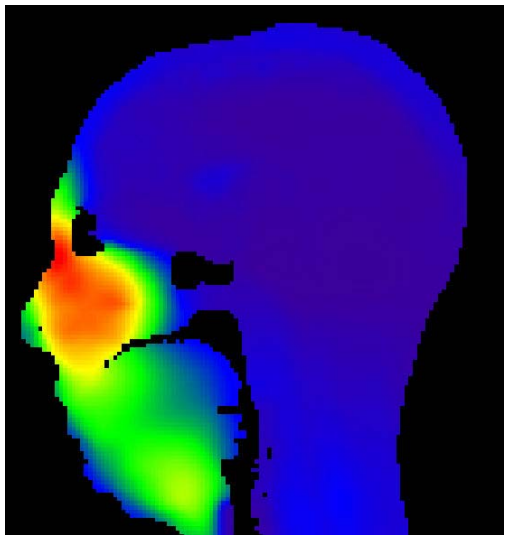
Comparison with values used by Bernardi et al. 2003

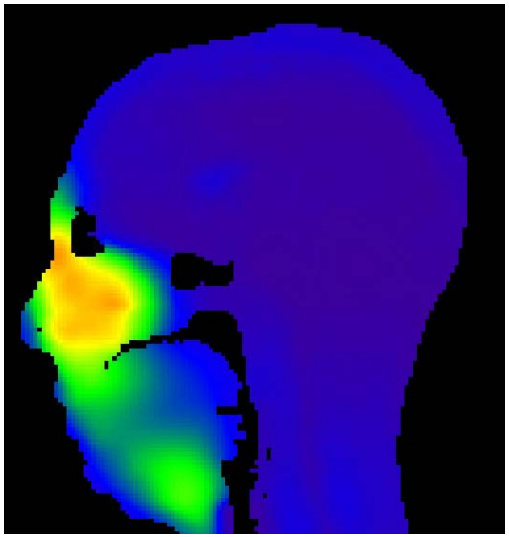
	k (W/(m.°C))		b (W/(m³.°C))	
Tissue	Database	Bernardi 2003	Database	Bernardi 2003
Cancellous bone	0.29	0.40	770	3,300
Brain	0.55	0.54	35,200	40,000
Muscle	0.51	0.50	2,000	2,700
Fat	0.19	0.25	1,630	1,700
Skin	0.43	0.42	4,270	9,100

Comparison with Bernardi et al. 2003

Database values

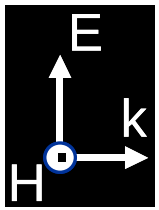
Peak ΔT: 0.19 °C





Bernardi et al. values

Peak ΔT: 0.15 °C



1 GHz

plane-wave

10 W/m^2

linear scale (peak = 0.20 °C (100%))

Sensitivity of ΔT to k and b

- Study varied

  k +/- 10%

  b +/- 10%

- Used human body models at 0.5, 1, 3, 6, & 10 GHz

Max change in peak temperature at 1 GHz

Tissue	k +/- 10%	b +/- 10%
Cancellous bone	15.8%	8.5%
Brain	2.0%	8.0%
Muscle	5.0%	6.0%
Fat	2.3%	4.7%
Skin (peak in body)	2.8%	4.2%

Notes:

- In the above, the peak ΔT for the database values are: skin 0.21 °C, fat 0.19 °C, cancellous bone 0.13 °C, muscle 0.10 °C, brain 0.05 °C (at 10 W/m^2)
- Generally, as k increases ΔT decreases; as b increases ΔT decreases, and vice-versa

Acknowledgements

- The grant sponsor was The Mobile Manufacturers Forum and the GSM Association under the Phase 2 Work Package 4 of the RF Dosimetry Program. The views expressed here are those of the authors and may not represent the views of the sponsors.
- We would very much like to thank Joanne Cohen, our Information Officer, for sourcing many of the papers, and performing extensive literature searches for us.