Documentation

Explanatory notes

The IT'IS materials parameter database aims to provide the most complete, reliable and up-to-date database of EM and thermal tissue parameters and their uncertainty. Particular care is taken to provide material parameters for all of the tissues included in the 'Virtual Population' models. The thermal and dielectric parameters found in the database are calculated based on a critical study of the existing literature. Large variations in reported values exist for some parameters, which are due to factors such as the method used, the sample size and physiological conditions of studied subjects, inter-subject variations, measurement conditions, etc. In determining which studies to use to calculate our values, we had to decide whether to be very selective and use only the studies that we judged to be the most accurate, or to be more inclusive and incorporate studies that may have varying degrees of accuracy. We decided on the latter approach (after eliminating studies with major flaws) in order to increase the parameter sample size used to determine the average and to gain information about the variability of the parameters. General considerations used while establishing the database are detailed below.

The thermal parameter values were calculated for five key properties: tissue perfusion rate (heat transfer rate, HTR), thermal conductivity (TC), heat capacity (HC), metabolic heat production (heat generation rate, HGR), and density. A large number of different studies can be found throughout the literature for the different parameters, in particular for the blood perfusion rate. Data on these five properties are represented unevenly in the scientific literature and many educated judgments were made in order to arrive at the best values.

Determining the HTR presented a considerable challenge. One reason for this is the natural variability within the species caused by the current physiological condition of the studied subject. In order to compensate for the different values, we calculated the mean HTR (ml/min per kg of tissue) from data compiled from studies performed in humans and animals. If values were recorded as percent of cardiac output (% CO), we calculated the mean blood flow rate based on the standard conditions proposed by Williams and Leggett in 1989 [5]. In most cases we included only data from young and healthy subjects. When data from young subjects was unavailable, such as values for tongue tissue, we included data from older subjects.

Another problem with determining the HTR is the lack of published material for many organs. Data from animal studies were included when no human data was available. When possible, we included only animals that have similar physiological properties to humans and should therefore also have similar tissue perfusion rates. The methodology for animal experiments was at times more accurate than for human experiments. In these cases we included the values from the human as well as the animal studies in our calculations. When no experimental data was available for a given tissue, we determined the HTR based on that of tissues of similar function and/or tissue composition.

TC and HC, two of the key properties in thermal parameters, are strongly dependent on the composition of the tissue, in particular on the tissue water content. TC and HC measurements can only be found in the literature for a selected number of tissues. When no data was available, we calculated the TC and HC based on the tissue water content as proposed by McIntosh and Anderson in 2010 [3]. If the water content could also not be specified, we assumed TC and HC to be similar to an organ of similar tissue composition and/or function. If a tissue is a mixture of two tissues with known TC and HC, we calculated the average of the two tissues (e.g. thymus is the average of lymph node and fat).

As we also used review articles for the determination of TC and HC, values from the same original study may have entered our calculations several times. However, this should not have a strong influence on the calculated mean as most values are within a narrow range. Nevertheless, this issue will be resolved in future versions of our database.

The HGR is proportional to the HTR and was calculated based on the formula proposed by McIntosh and Anderson in 2010 [3], with some modifications due to what appears to be unit conversion errors in the original formula: to convert from cal/100g/min to W/kg we used a factor of 0.6973 instead of 0.4184 as used by McIntosh and Anderson. The HTR values used in the formula were derived for the IT'IS materials database as explained above.

The density values were derived from several publications. Where no values could be determined for a specific tissue, we assumed the density to be equal to a tissue of similar composition and/or function. Similar to TC and HC, if a tissue is a mixture of two tissues with known densities we calculated the average of the two tissues.

Our dielectric parameter values are based on the tissue dielectric property database generated by Gabriel et al. in 1996 [1]. The dielectric properties for this database were calculated for a frequency spectrum ranging from single Hz to several GHz. As this spectrum contains four dispersion regions, the values can be fitted using a 4-cole-cole dispersion model. However, the Gabriel et al. database contains only a restricted number of organs and tissues. For tissues not included in the work presented by Gabriel et al., we took the dielectric values of an organ of similar function and/or tissue composition with known dielectric properties. More work has been published about measurements of dielectric properties of biological tissues, although most of it focus on a specific frequency range. As these cannot be described by a 4-cole-cole expression, they were not included in this database. Some applications in specific frequency ranges could gain from those values. Users are encouraged to discuss these possibilities in our forum: forum.database.itis.ethz.ch.

New low frequency EM-field values

Health risk assessment of electromagnetic fields at low frequency is of great public interest, for example, many electronic appliances operate at low frequencies and the utility frequency is 50 to 60 Hz, depending on the country. It is of upmost importance that the research community has easy access to the most up-to-date, complete and reliable parameter values required for their research.

The IT'IS dielectric parameter values for frequencies between 10 Hz and 20 GHz are based on the work of Gabriel and colleagues [1]. However, the authors point out a limitation: "*The predictions of the model can be used with confidence for frequencies above 1 MHz. At lower frequencies, where the literature values are scarce and have larger than average uncertainties, the model should be used with caution in the knowledge that it provides a 'best estimate' based on present knowledge.*" In 2009, Gabriel and colleagues further investigated this issue and measured the dielectric properties of several pig tissues at frequencies below 1 MHz [2]. In addition, they provide a comprehensive review of the most recent literature on the topic.

The compilation presented on our webpage is based on property values for frequencies from 0 to 120 Hz as reported in the recent publication of Gabriel et al. in 2009 [2]. Whenever possible, we accounted for the anisotropy of the tissues. To include studies that did not consider the tissue anisotropy, we additionally calculated the mean of all studies independent of the direction of measurement. To assure highest accuracy we excluded values that were not reliable as discussed in [2]. To provide information on the uncertainty of the values we calculated the standard deviation and the spread of values.

Known Issues

The following list contains some of the issues that arose during the compilation of the material parameter database. Whenever possible, we will address these issues in future updates.

• There is no data available in the literature for the dielectric properties of urine over the frequency spectrum (single Hz to a few GHz), mandatory for a 4 cole-cole fit. Therefore, for the dielectric parameter values of urine, we have chosen the values for the urinary bladder wall. In addition note that for the thermal properties we calculated the mean value of bladder wall and urine.

• The dielectric properties database generated by Gabriel et al. in 1996 [1] contains only values for a selected number of glands (thyroid, testes and ovary). For all glands of the reproductive system we chose the same values as for testes and for all other glands the same values as for thyroid gland.

• It is a well-documented phenomenon that the thymus increases in size until puberty and then, with advancing age, undergoes a process known as involution, where the thymus slowly reduces in size and is replaced by adipose tissue [4]. Since the percentage of replaced thymus tissue varies with age, we have chosen for the thermal properties the mean values between thymus and fat tissue. However, since in young adults most of the thymus did not yet turn into fat tissue but in elderly people the majority of the thymus underwent already involution, a different ratio between thymus and fat may be calculated. For the dielectric properties we have chosen to take the 4-cole-cole fit corresponding to lymph node. However, based on the age of the model in use, fat may be selected for the calculation of the dielectric properties.

• The content of the stomach and intestine depends on the diet of the subject. For the thermal properties we calculated an average of water and muscle which would correspond to a diet of 50% of water and 50% of meat. For the dielectric properties we have chosen the values for muscle only.

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References

[1] C. Gabriel. Compilation of the dielectric properties of body tissues at RF and microwave frequencies. *Report N.AL/OE-TR-1996-0004*. Brooks Air Force Base, 1996.

[2] C. Gabriel, A. Peyman, and E. Grant. Electrical conductivity of tissue at frequencies below 1 MHz. *Physics in Medicine and Biology*. 54(16):4863-4878, 2009.

[3] R. L. McIntosh, and V. A. Anderson. A comprehensive tissue properties database provided for the thermal assessment of a human at rest. *Biophysical Reviews and Letters*. 5(3):129-151, 2010.

[4] M. Nishino, S. K. Ashiku, O. N. Kocher, R. L. Thurer, P. M. Boiselle and H. Hatabu. The thymus: a comprehensive review. *Radiographics*. 26:335(26), 2006.

[5] L. R. Williams, and R. W. Leggett. Reference values for resting blood flow to organs of man. *Clinical Physics and Physiological Measurement*. 10:187-217, 1989.