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Explanatory Notes

With the tissue properties database, IT'IS aims to provide the most complete, reliable, and up-to-date database of values and associated uncertainties of electromagnetic (EM) and thermal tissue parameters. Particular care is taken to provide material parameters for all tissues included in the 'Virtual Population' models. The calculations of the thermal and dielectric parameters found in the database are based on a critical study of the existing literature. The fact that reported values for some parameters vary widely may be traceable to factors such as the method used, the sample size, the physiological condition of subjects studied, inter-subject variations, measurement conditions, etc. In our process to select studies to use to calculate the values in the database, we could have chosen to be very selective and use only the studies we judged to be the most accurate; we decided instead to choose a more inclusive approach and incorporate studies with varying degrees of accuracy – after eliminating studies with major flaws – to increase the parameter sample size used to determine the average values reported and to gain information about the variability of the parameters. General considerations used while establishing the database are detailed below.

Thermal parameters
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 these parameters, in particular for the blood perfusion rate. Data on these five properties are unevenly represented in the scientific literature, and we have had to make many educated judgments to arrive at the best values to include in the database.

HTR
Determination of the HTR was a considerable challenge, in part because of the natural intra-species variability related to the physiological condition of the subject when the measurement was made. To compensate for the different values, we calculated the mean HTR in terms of ml/min per kg of tissue from data compiled from studies performed in humans and animals. When values were reported 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 include only data from young and healthy subjects. When data, such as values for tongue tissue, from young subjects was unavailable, we include data from older subjects. Another problem with reporting HTR values is that published material for many organs is lacking. Data from animal studies are included for cases where no human data is available, and whenever possible, only animals with physiological properties similar to those of humans – and thus should have similar tissue perfusion rates – were included. The methodologies used in the

animal experiments were often more accurate than those used in human experiments. In many cases, we combine values from human and animal studies in our calculations. When no experimental data was available for a given tissue, the calculation of the HTR is based on values determined for tissues of similar function and/or with similar cellular composition.

TC and HC

TC and HC, two of the key properties of thermal parameters, are strongly dependent on the composition of the tissue, water content in particular. TC and HC measurements can be found in the literature for only a selected number of tissues. For tissues for which no data is available, we calculated TC and HC values on the basis of the tissue water content as proposed in McIntosh and Anderson, 2010 [3]. When water content is not specified, we assume the unknown TC and HC values to be similar to those of an organ of similar tissue composition and/or function. When a tissue is a mixture of two tissues types with known values for TC and HC, we calculated these parameters as the average of the two tissues, e.g., the TC and HC values for thymus are reported as averages of the values for lymph node and fat.
We have also used review articles as sources for the determination of TC and HC values, thus, we may have included certain values from a single original study in our calculations multiple times, giving those values undue weight in the reported value. However, these values fall within a narrow range and are unlikely to skew the calculated mean. Nevertheless, we are working to resolve this problem in future versions of our database.

HGR

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

Density

The density values were derived from several publications. For specific tissues for which no values have been reported, we assume that the density is the same as that of a tissue of similar composition and/or function. As in the approach for TC and HC values, for tissue that is a mixture of two tissue types of known density, we report the density as the average of the densities of the two tissues.

Dielectric parameters

We report dielectric parameter values based on numbers published in the tissue dielectric property database generated by Gabriel et al., 1996 [1], for which dielectric properties were calculated over a frequency spectrum ranging from single Hz to several GHz. This spectral range contains four dispersion regions, and the values can be fit by means of a 4-cole-cole dispersion model. However, the Gabriel et al. database covers only a limited number of organs and tissues; for tissues not addressed by Gabriel et al., we use reported dielectric values for an organ of similar function and/or tissue composition. Most other work published about measurements of dielectric properties of biological tissues are restricted to a specific frequency range and cannot be described by a 4-cole-cole expression, and are thus not included in this database. There may be applications for which data from specific frequency ranges could be useful, and users are encouraged to discuss these possibilities at the database forum: forum.database.itis.ethz.ch.

Low-Frequency Conductivity Values

Health risk assessments of EM fields at low frequency is of great interest to the public, since the utility frequency is 50 to 60 Hz, depending on country, and many electrical appliances operate at low frequencies. It is of utmost importance that the research community has ready 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 et al., 1996 [1]. However, these authors state that: "*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 [2] published measurements of the dielectric properties of several pig tissues at frequencies below 1 MHz, and provided as well 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 – 120 Hz, as reported in the more recent publication of Gabriel et al., 2009 [2]. Whenever possible, we account for the anisotropy of the tissues. To be able to include studies in which tissue anisotropy is not taken into consideration, we calculate additionally the mean of all reported values independent of the direction of measurement. To assure highest accuracy, we exclude values considered unreliable by Gabriel et al., 2009 [2], and we provide information on the uncertainties in the values we calculated in the form of standard deviations and ranges.

Known Issues

The following list covers some of the problems 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 of single Hz to a few GHz mandatory for fitting to the 4 cole-cole dispersion model. Therefore, for the dielectric parameter values of urine, we have chosen the values for the urinary bladder wall, and for the thermal properties we calculate the mean value of bladder wall and urine.
- The dielectric properties database generated by Gabriel et al., 1996 [1] contains values for only a few endocrine tissues: thyroid, testes, and ovaries. For all reproductive organs, we use the values reported for testes and, for all other glands, those of thyroid.
- 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, whereby it gradually

becomes reduced in size and the lost volume is replaced by adipose tissue [4]. Since the percentage of thymus tissue replaced varies with age, we express the thymus thermal properties as the mean of the thymus and fat tissue values. However, since, in young adults, most of the thymus has not yet converted to fat tissue and, in the elderly, the majority of the thymus is already involuted, different thymus:fat ratios should be calculated. For the dielectric properties, we have chosen to fit the 4-cole-cole dispersion model corresponding to the lymph node. However, based on the age of the model in use, fat may be selected for the calculation of the dielectric properties.

· The contents of the stomach and intestines depend on the diet of the subject. For the thermal properties, we calculate an average of water and muscle corresponding to a diet of 50/50 water and meat. For the dielectric properties, we have chosen the values for muscle only.

References

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