Bundesamt für Strahlenschutz

Spotlight on EMF Research

Spotlight on “Estimation method for the anisotropic electrical conductivity of in vivo human muscles and fat between 10kHz and 1MHz” Kangasmaa and Laakso in Phys. Med. Biol. (2022)

Category [low frequency, dosimetry/exposition]

Spotlight - Jun/2023 no.8 (Eng)

Competence Centre Electromagnetic Fields (KEMF)

1 Putting the paper into context by the BfS

In the low frequency range (below 10 MHz), safety guidelines for exposure to electromagnetic fields (EMF) are determined by basic restrictions on the field strengths induced in human tissue. As the latter cannot be measured directly, reference levels for body external electric and magnetic field strengths are derived to allow for a practical exposure assessment. The derivation of reference levels is achieved by numerical dosimetry calculations based on measured values of dielectric parameters of human tissue. The measurement of electrical permittivity and conductivity at low frequencies is a major source of uncertainty [2,3]. Anisotropy of tissue, high variability of measurement techniques, differences between necrotic and in vivo tissue and many more factors impede precise and consistent measurements. Non-invasive methods such as electrical impedance tomography allow for a measurement of conductivity of in vivo human tissue.

2 Results and conclusions from the authors perspective

The aim of paper at hand is to estimate the conductivities of longitudinal (along the human leg) and lateral (across the human leg) anisotropic muscle and fat tissue in the frequency range of 10 kHz to 1 MHz. The technique is non-invasive and is based on a least square fit of numerically calculated to measured impedances.

Impedance measurements were performed at 8 different positions along and across the right leg of 10 persons with a 4-pole electrode. After the measurements, the positions of the electrodes were marked by placing fish-oil capsules (high visibility in MRI), followed by an MRI-scan of the leg. The MRI images were segmented into 8 different types of tissue: Blood, cancellous bone, cortical bone, cartilage, fat, muscle, skin and tendon. Muscle and tendon were combined into a single anisotropic tissue type, defined as anisotropic muscle along and across the leg. The mean volume fraction of muscle and tendon are noted as 41.7% and 1%, respectively, and hence the degree of anisotropy is roughly 2-3%.

Via numerically solving the quasistatic potential equation, impedances were calculated for varying anisotropic muscle and fat conductivities. All other conductivities are considered as fixed external parameters and their values are taken from the literature. The estimated conductivities for longitudinal/lateral muscle and fat were determined as optimal least square fits of the numerically calculated impedances to the measured impedances.

To assess the statistics of the measurements and to determine confidence intervals, the so-called bootstrap resampling method is used. In this case 100000 samples are generated out of the original dataset via random-drawing with replacement. The confidence intervals around the measured data, obtained from the generated samples, are then used to estimate of the true confidence intervals. Finally, the quality of the fits compared to the measured impedances is evaluated using the mean relative error.

The main result of the paper is a dataset on conductivities of human anisotropic skeletal muscle and fat for frequencies between 10 kHz and 1 MHz.

The authors compare their results to earlier measurements for similar tissue types. In [4], a similar indirect method was used to determine muscle conductivity of anisotropic muscle tissue of a frog species. This leads to lower conductivity values compared to the present paper and to other studies. The authors explain it by the difference in temperature of the probes in [4] (room temperature) and in the present work (human body temperature). In case of fat tissue, comparison with the literature is difficult due to the varying water content of the tissue probes used.

The presented dataset allows for an analysis of the differences in conductivities obtained by modeling muscle tissue as an isotropic material in contrast to including anisotropies caused by tendon. Finally, the obtained conductivities are used to analyze the effect of tissue anisotropy on induced fields from homogeneous magnetic field exposure. At 0.1 mT, the 99th percentile of the induced electric field lies below around 40% of the corresponding basic restriction for occupational exposure [5,6]. The relative error for induced electric fields caused by an isotropic modeling is calculated to be -20% to +40% for the lowest frequencies and decreases to around +/- 10% for high frequencies.

The authors summarize their work an application of method similar to impedance tomography, that they use to extract in vivo conductivity values of human anisotropic muscle and fat tissue. The method is used to obtain a dataset of conductivity values in the frequency range from 10kHz to 1MHz. This allows to examine the effect of tissue anisotropy on the induced electrical field values from exposure to magnetic fields.

3 Comments by the BfS

The method proposed by the authors to determine tissue conductivity is indirect: Numerically calculated impedances are least-square fitted to in vivo measured impedances. The optimal least-square estimator determines then the conductivities. The precision of the results depends on the accuracy of the impedance measurements and MRI resolution. In case of the former, several difficulties arise, such as parasitic currents, electrode polarization effects and hook artefacts, which are discussed in detail by the authors. In particular, measurements below 10 kHz are not possible. The model fit is achieved by numerically calculating impedances by varying the conductivity of three types of tissue (longitudinal, lateral muscle and fat) and keeping all other tissue conductivities fixed at a constant, frequency independent value. This clearly is an idealization, as conductivities in general are frequency dependent. An application of known variable selection methods could be useful to justify the chosen idealization.

Finally, to assess the body-internal induced electric field strength for homogeneous magnetic field exposure, the authors use the 99th percentile, which is the widely used procedure to suppress artefacts and in line with ICNIRP. In case of peak values of the induced electric field located in very small tissue regions this can possibly lead to an underestimation of the induced electric fields.

The method established in the paper provides a non-invasive way to extract tissue conductivities in vivo from bioimpedance measurements at low frequencies. As such conductivities still constitute a major source of uncertainty to derive reference levels from the corresponding basic restrictions, the subject of the work presented is highly relevant for risk evaluation of low frequency fields. An extension to frequencies below 10kHz would be highly desirable in the future. Dependent on the precision of impedance measurements and MRI resolution, an analysis of the effect of tissue anisotropy on body induced electric fields is possible. For the lowest frequencies considered, isotropic modeling would result in an error of 20-40% over- or underestimation of induced electric fields, depending on the field direction. The error decreases with increasing frequency.

In conclusion the presented method constitutes a valuable extension of existing methods to estimate induced electric fields.

References

The first reference is always the manuscript at hand and the reference in the curly braces at the end of a reference {xx} correspond to a reference in the manuscript at hand and is consistent with the manuscripts reference style.

[1] Kangasmaa O and Laakso I, Estimation method for the anisotropic electrical conductivity of in vivo human muscles and fat between 10kHz and 1MHz, Phys. Med. Biol. 67 225002, (2022) DOI 10.1088/1361-6560/ac9a1e

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Impressum

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urn:nbn:de:0221-2023072638643

Spotlight - Jun/2023 no.8 (Eng)