Human abdominal fat imaging considering anisotropy of bioelectrical conductivity

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Epidemiological studies suggest that visceral fat accumulation is associated with a higher risk for metabolic syndrome. Therefore, measurement of the visceral fat area is essential for the prevention of metabolic syndrome. While X-ray CT is a standard method of measuring visceral fat, the radiation exposure is not negligible when considering the risk-benefit balance. Using another imaging method such as MRI is also possible, but it is very expensive. On the other hand, a device utilizing ordinary bio-impedance is not sufficiently accurate for clinical use.

The objective of the present study is the development of a radiation-free and low-cost visceral fat estimating device using electrical impedance tomography to image a cross-section of the human abdomen by utilizing the fact that body fat has a low electrical conductivity compared with other tissues. Although we used a relatively high frequency for the probing current, the tissues especially skeletal muscles show bioelectrical conductivity anisotropy. Therefore, the conductivity in the longitudinal direction and transverse direction of the human body were estimated separately.

The device has a mechanism for attaching 64 electrodes with double-ring allocation. In this study, 32 upper ring electrodes were used only as current electrodes, whereas 32 lower ring electrodes were used only for voltage electrodes to eliminate the switching mechanism at the front end that reduces the high input impedance of the instrumentation amplifiers. An alternating current of 1 mArms with a frequency of 500 kHz was applied at the umbilical level, and the potential differences between every pair of adjoining electrodes and the abdominal outline were measured.

After that, the conductivity image was derived by the iteration of forward estimation (i.e., solving the forward problem) and backward updating (i.e., solving the inverse problem) of longitudinal and transverse conductivities. We used the three-dimensional finite element method for the forward estimation, assuming uniform conductivities and geometry in the computational model of the longitudinal direction. The electrical potential at every node, including where the electrodes were attached, was computed in accordance with Laplace's equation. The difference between the computed potential in the model and the experimentally measured potential was calculated, and the square error was obtained. Backward updating of the conductivities in every element was performed with minimization of the sum of the square error. We used the Levenberg-Marquardt method for the backward updating. Furthermore, we put the singular value decomposition once per five iterations for diagonalization of the matrix in the simultaneous equation for the updating and omitted extremely small singular value mapping for the stable solution. Finally, the derived conductivity image was treated with a spatial filter to eliminate unnatural discontinuity.

For the quantification of the abdominal fat area, we estimated the ratio of the abdominal fat by assuming truncated mixed distributions in the brightness of pixels in the image. From the fat ratio and the cross-sectional area, we estimated the abdominal fat area. The abdominal fat areas found in this way were compared with those determined by MRI images of several subjects.

The **R** programming language was used for all computation for better program readability and graphical representation of computation status and conductivity images. However, some of the subroutines were re-written with FORTRAN77 and C for higher computational speed. Those program codes were combined into the program package.

This human study was conducted in accordance with the Declaration of Helsinki and was approved by the local ethics committee of Tokyo Denki University. In the derived images, we can find subcutaneous fat and muscles surrounding viscera. By modifying the electrode allocation, electronic circuit design, and image reconstruction software considering the anisotropy, the derived images were notably improved compared with those from the preceding study (Yamaguchi T, et al., 2010), allowing us to achieve stable abdominal fat imaging and quantitative estimation.