Introduction:

Magnetic resonance imaging (MRI) techniques have become important tools in medicine and biology. Conventional MRI, however, produces no information about the electrical properties of the body. Since electrical properties are important characteristics of living organisms, techniques for impedance tomography to visualize impedance distribution have been developed with great interests. This article proposes three new and noninvasive methods for imaging electrical properties such as conductivity and impedance based on MRI techniques.

Experimental methods:

We propose three different methods for conductivity imaging via MRI; i) a large flip angle method, ii) a third coil method and iii) based on diffusion tensor MRI.

i) When conductive tissues are subjected to a radiofrequency (RF) field in MRI, eddy currents are induced, which results in a reduction of the net RF fields. By this shielding effect, the flip angles (i.e., nutation angles of the macroscopic magnetization of excited spins) are reduced in varied degrees, depending on the electrical characteristics of the tissues. When a precise 180, 360 or 540 excitation pulse is applied to conductive tissues, the tissues do not yield a signal due to the absence of the transversal components of magnetization. Meanwhile, resistive tissues yield signals because they are less electrically shielded than conducting tissues and simultaneously undergo different flip angles. Also, the resistive tissues leave transversal components with magnitudes determined by the sine wave functions of flip angles. The difference in signal, therefore, reflects the conductivity of tissues.

ii) To obtain a conductivity-enhanced images at an arbitrary frequency, an additional time-varying field parallel to the main static field B_0 can be introduced via a solenoidal coil. By the perturbing field or Bc field, slice positioning of the image is affected, and the slice selection fluctuates. Spatial information in the read-out and phase-encoded directions are also affected. Conducting tissues are less affected by Bc field, because of the shielding effects and conductivity-enhanced images can be obtained at any frequency but in the direction perpendicular to the Bc field.

iii) The diffusion components of biological tissues are usually divided into a fast and a slow component. Thanks to the proportionality between conductivity and diffusion coefficient, we can estimate the tissue conductivity by measuring the fast diffusion component, which corresponds to diffusion in the extracellular fluid.

Results and discussion:

All the described methods lead to qualitative in-vivo MRI conductivity imaging of brain tissues in rats and humans without the need of invasive techniques. Furthermore, using the third method the spatial distribution of anisotropic conductivity of the human brain was obtained. We observed that the gray matter did not have a clear dependence of conductivity on direction, whereas the internal capsule and the corpus callosum had higher values of mean conductivity and anisotropy. This anisotropy is attributable to the anatomical structures of these regions, diffusion of water molecules in the extracellular fluid is disturbed by the cell membranes, and the fact that diffusivity is higher in the direction of neuronal fibers than in other directions.

Conclusion:

This work proposes innovative methods to visualize in-vivo the electrical properties of tissues based on MRI techniques without the need to attach electrodes to the surface of the body. The described methods also enable the quantification of conductivity for clinical applications of EEG and MEG in 1 h does not require complicated image processing and are practical to be carried out.