Tissue-mimicking phantoms for a combined magnetic resonance (MR)/ultra-wideband (UWB) Radar technique

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Introduction

Multi-modal diagnostic approaches combine complementary information from different sources and with different sensitivity or resolution, e.g. to remove the ambiguities from inverse problems. Hence, deriving correlated parameters from multi-modal imaging is the primary motivation for the development of these techniques. Recent trends include in vivo cardiac imaging, with enormous challenges related to motional displacements due to the heart beat and respiration. Several attempts have been made to combine MRI with other imaging techniques such as ultrasound, positron emission tomography, single photon emission tomography, electro-encephalography, electro-cardiography (ECG), and optical tomography. Some of these approaches are routinely used in clinical practice, e.g., ECG for triggering cardiac MRI. The specific advantages of ultra-wideband (UWB) Radar sensors are high temporal and spatial resolution, deep tissue penetration, low integral power, and co-existence with established narrowband systems [1]. The UWB sensors operate with ultra-low power signals and are, therefore, suitable for human medical applications including mobile and permanent non-contact supervision of vital functions. The technique permits non-invasive sensing with no potential risks, in contrast to catheter or X-ray techniques. Our research is aimed towards the synergetic technological development of UWB sounding combined with magnetic-resonance imaging (MRI), to access innovative fields of application such as the imaging of cardiac blood vessels and heart beat monitoring, accurate modelling of electromagnetic wave propagation through heterogeneous, malignant and benign, biological tissue for high-field MRI, and fast and precise identification and localisation of breast cancer. As our first step towards this ambitious aim we report on multilayer tissue-like phantoms specifically designed for testing and development of a UWB-MRI combination setup.

Materials and Methods

Traditionally, phantoms that closely mimic the physical properties of various human tissues have been invaluable for the development and testing of medical imaging modalities such as ultrasound, magnetic resonance imaging (MRI), and computed tomography (CT) [2]. To evaluate a combined MRI/Ultrawideband (UWB)-Radar technique, MR-compatible tissue mimicking phantoms are needed reflecting the dielectric properties of biological tissue in the frequency range covered by UWB technology (1-10 GHz). Exposure of these phantoms to electromagnetic waves should produce reflection signals similar to those acquired from human subjects. The in vitro dielectric properties of biological tissue are well known in a broad frequency range [3] and can be very well modelled utilizing a 4 dispersion Cole-Cole model [3]. In the desired frequency range the highest values of ε' and ε'' (i.e. σ) are very similar to those of aqueous solutions. The lowest values are defined by fat tissue. Therefore we used oil in water emulsions to create human tissue phantoms. Even at very high mixture concentrations the dielectric spectra are, therefore, expected to be dominated by contributions of the solvent water. This mixture is then stabilized in agarose gel (Typ II-B, Sigma-Aldrich) which retains a certain flexibility allowing the creation of bendable layers for dynamic phantoms. Furthermore, the agarose wrapping prevents segregation of the mixture components. Conductivity is adjusted by adding NaCl. Industrially available oil in water emulsions like several cosmetic products, e.g. sun-creams with different sun protection factors (SPF), facilitates the production of such mixtures. We built planar, circularly shaped slices (thickness 10 mm, ∅ 150 mm) utilizing aqueous sun-cream (SPF>20)/Agarose/NaCl mixtures (fig. 1) to form multi-layer dielectric phantoms (s. fig. 2). Materials with low ε', like fat, are formed by a silicon gel. To account for the limited conductivity of fatty tissue the silicon gel (Sylgard A&B) is doped with glycerol (propane-1,2,3-triol), which also can be used to adjust the dispersive behaviour of the aqueous mixtures and the silicon gel. We measured the dielectric properties of the mixture samples using a network analyser. Figure 1 depicts a MR-image measured with a 3 tesla MR scanner (Bruker MEDSPEC 30/100) and the corresponding values of ε' and σ of three mixtures mimicking the first three tissue layers of the human thorax.

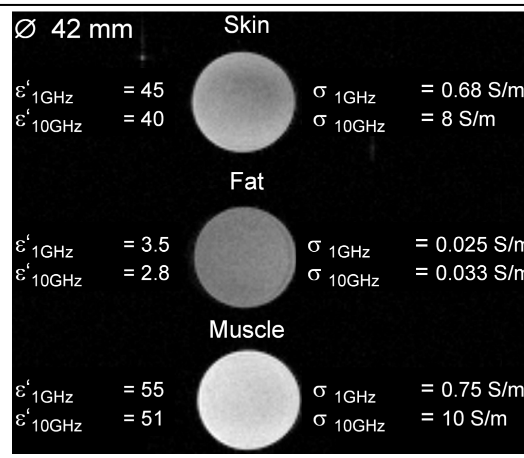

Fig. 1: MRI coronal slice of three tissue-mimicking mixture samples and their corresponding measured values of ε' and σ at 1 and 10 GHz.

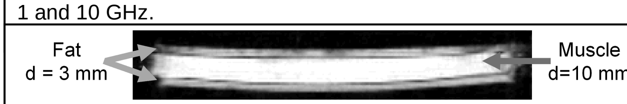

Fig. 2: Coronal slice of a muscle-equivalent layer phantom (∅ 150 mm) embedded in two fat-equivalent layers of 3 mm thickness (Propane-1,2,3-triol doped silicon gel).

Results

The mixtures for static and dynamic phantoms can be created quickly, easily, and cost effectivly without special equipment or advanced knowledge in chemistry [2]. They can be adjusted to mimic the dielectric properties of all organic tissue in the desired frequency range of 1-10 GHz within the biological variability of 15-20 % [3]. Moreover the mixtures are homogeneous and MR-compatible (fig. 1 and 2). Since higher ε' comes along with higher water content the MR-image contrast also increases proportionally with ε' (fig. 1 and 2).

References

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