Miniature Form-Fitting Transmission Line Resonator for in-vivo small-animal imaging at 2.35 T

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1. Introduction

In MRI with small samples, significant RF coil sensitivity improvement can be obtained by increasing their filling factor [1]. For this reason, the use of miniature surface coils matched to the investigated area is of great interest in small animal MR microscopy or for investigation of superficial regions on human such as skin micro-imaging. However, standard surface coils made of discrete elements are not well suited for miniaturization [2]. Moreover surface coils present a rapid decrease of the sensitivity along the coil axis. In the case of samples with non-planar surface, a significant diminution of the magnetic coupling between sample and coil can arise leading to a SNR penalty in regions where the sample surface is offset from the coil plane. In this work we present a miniature surface coil based on the Multiturn Transmission Line Resonator (MTLR) design [3] and fabricated on a flexible substrate using microtechnological processes [4]. Monolithic design such as MTLR allows for a millimeter-scale miniaturization of the coil. The flexible substrate allows the coil to be form-fitted onto the surface of samples of any shape thus improving the magnetic coupling and the coil sensitivity. The form-fitting MTLR is compared to a similar but flattened MTLR and to the standard volume coil of a 2.35 T small animal system.

2. Material and methods

A form-fitting MTLR with 11 mm mean diameter (Fig 1) was made by UV copper micromoulding. It is constituted by two 4-turn conducting band (band spacing of 300 µm and band width of 400 µm) deposited on both faces of a 50 µm thick polyimide film (Kapton™). The geometrical parameters have been set to reach the Larmor frequency of protons in a 2.35 T magnetic field. The form-fitting MTLR was curved in order to fit within a 1 cm diameter half-pipe support. Its performances were compared to those obtained with the flattened MTLR and the standard 10 cm diameter volume coil. Comparative SNR measurements were performed as a function of the distance along the coil axis on phantom images performed on a 2.35 T Biospec system (Brüker, Germany) using a gradient echo sequence with voxel size of 156×312×1000 μm^3 and a scan duration of 2 minutes. The phantom consisted in a 1cm diameter syringe filled with Vistarem (Guerbet, France) at 0.1 mM.

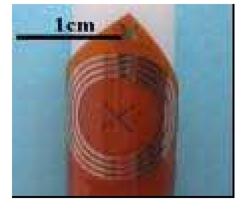

Fig 1 : Flexible MTLR

3. Results

The phantom images are displayed on fig 2 a), b) and c). Corresponding SNR data computed from the standard deviation measured on the background noise and from the signal intensity measured along the coil axis are shown on fig 3. The volume coil achieved a constant SNR of 30 over the whole phantom, while the SNR obtained with the form-fitted MTLR and the flattened MTLR reached 250 and 200 respectively at a distance of 1 mm inside the phantom. As compared to the volume coil, the SNR gain obtained with the form-fitted MTLR is about 8 at 1mm, 7.5 at 2 mm and 1.6 at 6 mm inside the phantom. As compared to the flattened MTLR, the form-fitted MTLR achieved a substantial SNR gain as displayed figure 4 and exhibited a slower decrease in sensitivity over the first 5 millimeters.

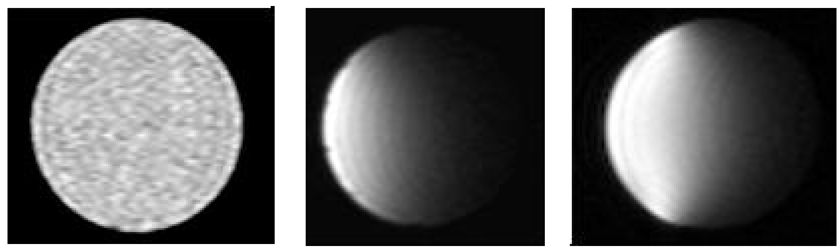

Fig 2 : Phantom images acquired with : a) volume coil, b) flattened MTLR, c) form-fitted MTLR

At a distance of 7 mm, a SNR gain of about 1.8 was obtained. SNR achieved with the flattened and the form-fitted MTLR became comparable above 10 mm.

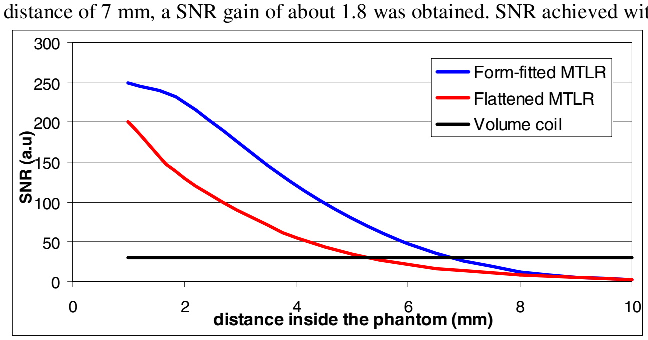

Figure 3 : SNR variation as a function of the distance inside the phantom.

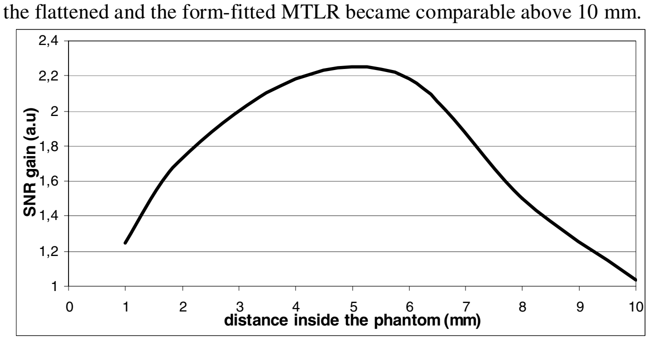

Figure 4: SNR gain variation with the distance inside the sample.

The form-fitted MTLR was finally used to acquire an in-vivo image of a subcutaneous model tumor induced in a mouse (fig 5). The tumor was imaged using a 3D gradient echo sequence and acquisition parameter TR/TE=200/2.6 ms, slice thickness 1 mm, in plane resolution 150×78 μm^2 and Tacq=17 min. This image exhibits an average SNR of 45 at 1 mm inside the tumor and 35 at the center of the tumor. The improved and extended sensitivity allows to image the whole tumor with a good SNR even at the tumor rim opposite to the coil (SNR=22)

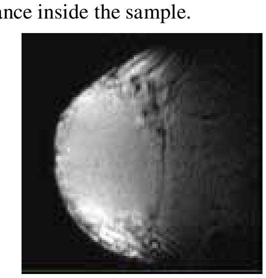

Fig 5 : mouse tumor model image acquired in vivo with the form-fitting MTLR

4. Conclusions.

A form-fitting MTLR was developed and significant SNR gain was observed on phantom images as compared to an identical but flattened MTLR. In case of half-pipe form-fitted MTLR as used in this work, the coil homogeneity was also improved over the observed region. In-vivo image of a subcutaneous model tumor induced in a mouse was performed at microscopic resolution (voxels of 117.10^{-4} mm^3) with a SNR of about 35. The fabrication of MTLR on flexible substrate using microtechnological processes offers new opportunities to develop miniature coils with variable shape that can be matched to not readily accessible or non-planar areas, the improved magnetic coupling between sample and coil providing a significant SNR gain. Flexible MTLR can be of great interest for some biomedical applications involving small or superficial regions of interest, such as the mouse knee, to study articular pathologies, or human nose wings or palpebra for facial skin tumor investigations. The use of flexible MTLR may also be advantageous to design implanted RF coils minimally constraining the tissues, or catheteric RF coils enrolled on catheter extremity [5].

References :[1] Hoult, D. et al, JMR 1979, 34: 425-433; [2] Poirier-Quinot, M. et al. Proc. ISMRM 2003: 2389 ; [3] Serfaty, S. et al, Magn. Reson. Med, 1997, 38:687-689; [4] Coutrot, A-L. et al. Sensors and Actuators A, 2002, 99: 49-54; [5] Tetsuji, D. et al. Proc. Transducers 2005: 4C3.4.