Development and Positive Contrast Imaging of an MR-Visible Mesh-Implant for repair of abdominal hernia

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Objective:

Each year, approximately 1.5 million textile meshes are implantationed worldwide for treatment of abdominal and diaphragmatic hernia [1]. After incorporation, textile meshes change their appearance markedly due to tissue ingrowth and integration into scar tissue. Moreover, in up to 30%, migration, shrinkage, deformation or fistula formation cause severe complications [1]. Consequently a significant number of patients present with mesh related problems. Conventional mesh implants consist of polymers which can not be depicted using X-ray or computed tomography (CT). Using ultrasound, sometimes meshes can be delineated in case of ambient seroma. Magnetic resonance imaging (MRI) does not display the polymer mesh, as the structure itself is very thin (approximately < 0.3 mm) and as T2-relaxation of the polymer is very short. Consequently, conventional polymer meshes remain hidden after implantation and post surgery monitoring of the implant is not feasible. By implementing superparamagnetic nanoparticles in a polymer mesh (NPM), additional susceptibilities are induced and the mesh can be delineated as a hypointense structure. However, as air and scar tissue within the abdomen will present with hypointense signal too, an additional positive contrast presentation of NPM susceptibilities as inversion-recovery with ON-resonant water suppression (IRON) [3] is necessary. The protons next to the NPM precess with different resonant frequencies due to local susceptibilities. By inverting the magnetisation combined with a spectrally-selective on-resonant saturation prepulse, the original signal is suppresse and positive signal can be obtained from off-resonant protons in close proximity to the magnetic structures. Aim of this study is to develop an MR-visible mesh and evaluating its MRI properties ex-vivo.

Methods:

Superparamagnetic nanoparticles of ferrofluids (mean core size 9.4nm) [2] were admixed with a concentration of approximately 1mg per 1g base material of PVDF filament. After extrusion of the PVDF fibre with incorporated superparamagnetic particles (Fig. 1), a textile mesh was assembled (Fig. 3a). To evaluate NPM delineation, MRI was performed in a 1.5 Tesla scanner (Achieva, Philips, The Netherlands) with a multi-channel receiver coil using SSFP sequences (repetition time (TR) 6.26 msec, echo time (TE) 3,13 msec, field of view (FoV) / matrix 200mm / 392, NSA2, flip angle (FA) 80°), T2* weighted sequences (TR 285 msec, TE 23 msec; FoV / matrix 200mm/ 248, NSA2; FA 18°), and IRON gradient echo sequences (TR 200 msec, TE 8 msec, FoV / matrix 200mm/ 185, NSA 3, FA 18°, offset frequency 180s^{-1}). With the NPM placed in an agarose phantom, in a phantom consisting of pieces of meat (Fig. 2), and implantation into the abdominal wall of corps of a rat, a rabbit (Fig. 3) and a pig transverse, sagittal and coronal slices were measured. To avoid artefacts due to air-tissue interfaces, water was injected into the pouch where the mesh was located.

Additionally to MRI, ultrasound (7.5 MHz probe) and CT (64 multi-slice CT; 200 mAs, 120 kV) examinations were performed in order to display the NPM.

Results:

On SSFP and on T2* MRI, the NPM were clearly delineated as hypointense structures (Fig. 2). In the phantoms (Fig. 2b) and within the corps (Fig. 3d), SSFP allowed an exact depiction of the NPM. On T2* sequences, signal voids (Fig 2a) outshined the NPM, however air tissue interfaces also induced susceptibility effects. In the agarose phantom without any tissue interfaces, IRON-sequences perfectly showed the NPM with positive contrast. In the meat phantom (Fig. 2c) the NPM was also clearly visible and had a strong hyperintense signal on IRON-sequences (Fig 2c). In the corps, containing even more different kinds of tissue, the on-resonant suppression was even less distinct (Fig 3e). However, the bright signal indicates the position of the NPM and in combination with the SSFP sequence a precise evaluation in more complex situations becomes feasible. Knowing the exact localization of the NPM, ultrasound presented the subcutaneous mesh as a hyperechogenic reflex (Fig. 3b). In CT, the mesh could not be visualized; the hypodens line (Fig. 3c) corresponds to the instilled water.

Conclusion:

This study demonstrates that with help of an NPM combined with positive contrast imaging techniques, as IRON sequences, delineation of mesh implants is feasible. Moreover, this method might lead to the desired solution for monitoring mesh structures after surgery and reveal mesh related problems in time.

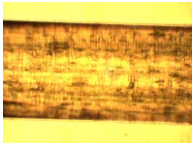

Fig. 1: Polymer-fibre with incorporated superparamagnetic particles.

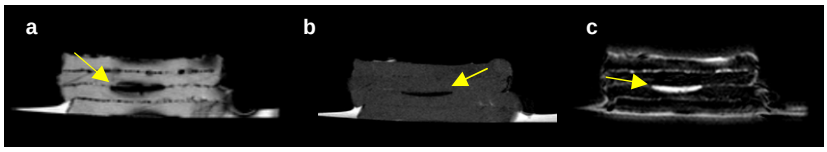

Fig. 2: The NPM (arrows) in the meat-phantom on T2*- (a), SSFP- (b) and IRON-sequences (c).

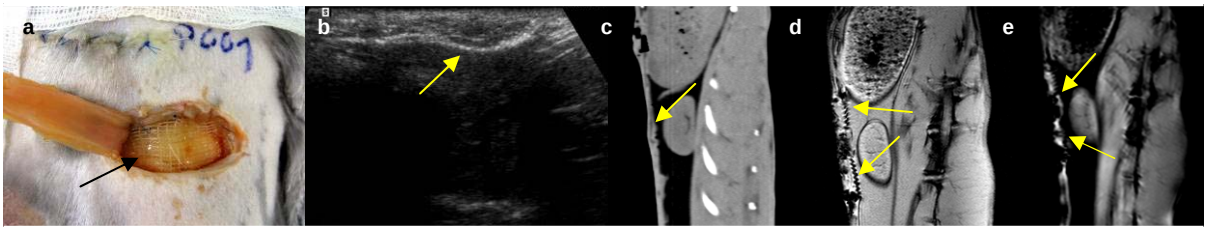

Fig. 3 The NPM (arrows) in the abdominal wall of a rabbit, in-situ (a), in US (b), in CT (c), in MRI using SSFP- (d) and IRON–sequences (e).

References:

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