

Analysis of 3D IR-UTE for imaging femur head necrosis: signal behavior and optimized soft tissue suppression in dependence of varying relaxation times

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Introduction: Avascular necrosis (AVN) of the femoral head is an increasingly common cause of musculoskeletal disability and poses a major diagnostic and therapeutic challenge. Although patients are initially asymptomatic, AVN of the femoral head usually progresses to joint destruction, requiring total hip replacement. MRI is the most sensitive imaging technique for evaluating and diagnosis of AVN. In early stages AVN appear as marrow edema. In an advanced stage areas of sclerosis separated from normal bone by a sclerotic border are visible. Due to the short T_2 sclerotic tissue appears with low intensity in T_1 - and T_2 -weighted standard sequences. For monitoring therapy or development of necrosis a robust method for visualization of short T_2 components is highly desirable. 3D IR- prepared Ultrashort TE (UTE) [1] can provide direct signal of short- T_2 components such as observed in sclerotic and bone tissue and in the same time efficient suppression of fat and water signal. However, since T_1 and T_2 can change during disease progression IR-3D UTE may fail to provide sufficient short T_2 -contrast due to inefficient magnetization preparation.

The aim of this study is to investigate the behavior of the magnetization preparation in 3D IR-UTE in dependence of T_1 and T_2 in order to evaluate the sequence with respect to therapy monitoring and disease progression. To this end we simulated the magnetization trajectory of 3D IR-UTE for various T_1 and T_2 in a wide range. Additionally, *in vitro* experiments of a human necrotic femur are shown demonstrating the ability of 3D IR-UTE to visualize sclerotic tissue in the presence of necrosis.

Materials and Methods: 3D IR-UTE sequence consists of a long adiabatic inversion pulse followed by UTE acquisition after time delay T_I . Numerical simulations of the magnetization trajectory were performed taking effects of transverse in-pulse relaxation into account. The transverse magnetization M_{xy} at time point TE after excitation was evaluated in dependence of T_1 and T_2 in the steady state (after at least 100 excitation cycles). Relaxation times were varied between $T_1 = 50\text{ms}$ and 2500ms and $T_2 = 0.1\text{ms}$ and 100ms in intervals of 50ms and 0.2ms at a set of constant parameters ($T_{RF,prep} = 12\text{ms}$, $T_{RF,ex} = 50\mu\text{s}$, $FA_{ex} = 25$ degrees, $T_I = 15\text{ms}$, $TE = 70\mu\text{s}$, $TR = 40\text{ms}$). TR and T_I were chosen according to analytical simulations assuming rectangular rf-pulses [2]. TR s longer than 50ms have shown to fail the simultaneous suppression of both short and long T_1 species at a constant T_I while towards shorter TR s the suppression efficiency is increased. We found $TR = 40$ and $T_I = 15$ a good compromise between suppression efficiency and SNR of the short- T_2 components.

Images of necrotic human femoral head were acquired *in vitro*. The images were acquired with identical parameters used in the simulations: $FoV = 128 \times 128 \times 128 \text{mm}^3$, isotropic resolution of 1mm , readout bandwidth = 1200Hz/pixel , 38000 projections and two averages yielding an acquisition time of $TA = 51$ minutes. For signal reception an 8 channel receive only coil (Noras, Germany) was used. In order to compensate for gradient delays and imperfections of the gradient waveforms especially during ramp sampling, trajectory measurements were performed for each physical gradient axis according to the method proposed by Duyn et al [3]. Image reconstruction was done offline using the Matlab (The Mathworks, R2012a) programming environment and nufft-based gridding algorithm by Fessler [4].

Results: In Figure 1 simulations from transverse magnetization M_{xy} at TE are plotted over T_1 and T_2 . Following our simulations simultaneous nulling of long- T_2 components is possible for a wide range of T_1 relaxation times. As can be seen, short- T_2 components can't be inverted by the inversion pulse and thus are not suppressed. Figure 3 shows images of the necrotic femoral head. The first image was acquired without magnetization preparation and contains signal from all tissue components. With magnetization preparation only the short- T_2 components are visible and the sclerotic area of the necrosis is shown in improved contrast.

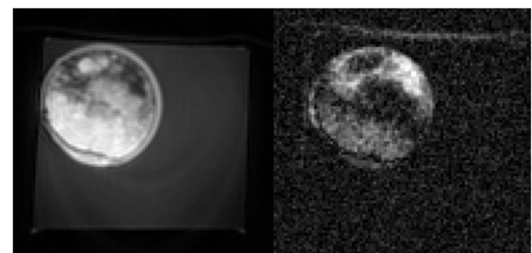
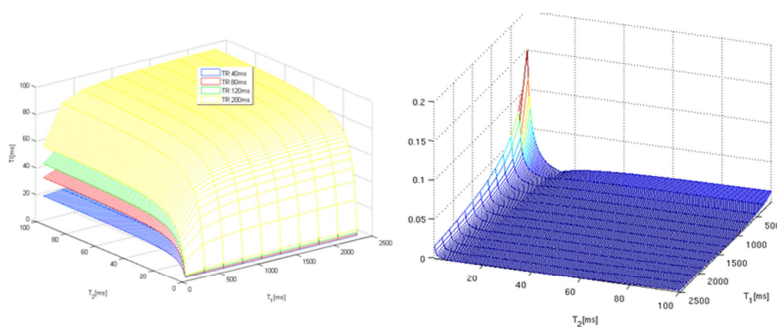


Fig 1 Calculated T_I in dependence of T_1 and T_2 for different TR s. T_I differs less enough to achieve simultaneous suppression of tissue with different T_1 for small TR .

Fig 2 Transversal magnetization M_{xy} at time point TE vs. T_1 and T_2 . Simultaneous suppression of long T_2 -components over a wide range of relaxation times is achieved.

Fig 3 3D UTE Images of necrotic femur head without magnetization preparation (left) and with IR-preparation (right). With magnetization preparation the necrotic region is shown in improved contrast.

Conclusion: In this work we investigated the contrast behavior of 3D IR-UTE when relaxation times change during therapy or disease progression of AVN. Results show that the sequence allows for efficient soft-tissue suppression even when relaxation times change. Thus 3D IR-UTE can be useful to visualize and characterize necrosis in different stages.

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References: [1] Li C, et al., MRM 2011; 000:000-000. [2] Springer et al., JMR 2010; 206: 88-96. [3] Duyn et al., JMR 1998;132(1):150-153. [4] Fessler, JMR 2007;188: 191-195