Improved cortical bone segmentation using a spectral-spatial selective pulse to reduce water/fat in-phase echo time

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TARGET AUDIENCE Researchers and medical physicist interested in segmenting bone structures from MRI data and/or in pseudo-CT generation for Radiation Therapy Planning (RTP) and/or MR-based attenuation correction for MR/PET.

PURPOSE MR-bone imaging is valuable for many applications, such as MR-based RTP. For this application a complete segmentation of bone is required together with a Digitally Reconstructed Radiography (DRR) to enable 2D position verification of the patient just prior to radiation delivery. Recently, promising results were obtained in the pelvic area with T_1-Dixon sequences [1,2]. Nevertheless, they suffer from false positive depictions due to misclassification of bone structures in areas characterized by short T_2(*) as occur e.g. in the bowel regions due to the presence of air gaps. Some methods have been proposed to solve the misclassification errors like, for example, the use of a probabilistic atlas [1] that requires prior knowledge of the anatomical area.

This work aims at reducing the in-phase time point for water and fat, by use of a spectral-spatial selective excitation pulse. In particular the use of a reduced echo time reduces signal voids due to T_2* dephasing. We demonstrate here that the shorter T_E in combination with a novel image processing approach leads to more specific black bone imaging by preventing misclassification of regions presenting with low T_2* at a conventional in-phase echo time.

METHODS *Subjects*: The data of two healthy volunteers were acquired on a Philips Achieva 1.5T using a 16-element Torso XL coil with SENSE factor 1.

Pulse: The scanner software was modified to allow the use of a spectral-spatial selective excitation pulse (the end of this pulse is the start of the T_E for the scanner). The RF pulse was designed using a binomial composition as introduced in [3]. The RF pulse length was 1.46 ms (*Fig. 1*) and has to be included when calculating the effective T_E. The first peak of the pulse corresponds to the magnetic moment. Whereas normal excitation pulses provide the same phase for both water and fat, the proposed pulse design enables excitation of water and fat with a relative phase difference. In the current study, the pulse was designed in such a way that at the effective T_E, water and fat was either in-phase, or out-of-phase.

Imaging parameters: Cartesian 3D spoiled GRE imaging parameters were as follow: T_E/T_R=0.86/3.82 ms, flip angle 7°, FOV 12.9x26.4x40 cm³, acquisition matrix 43x132x200, pixel bandwidth of 1.79 kHz and 21.3 s scan-time. The effective T_E corresponds to 2.3 ms.

In-Phase (IP) and Out-of-Phase (OP) images (*Fig. 2* left) were obtained with the aforementioned imaging scan parameter in two separated acquisitions by designing two RF pulses. The two pulses did not need to be designed repeatedly for different subjects.

Two cartesian 3D spoiled GRE images were also acquired as references (*Fig. 2* right). The imaging parameters were (if not specified they remained the same) T_E/T_R=2.3/3.6 ms, 19.7 s scan-time for the OP Ref image, and T_E/T_R=4.6/5.8 ms, 32.6 s acquisition time for the IP Ref image respectively. The pixel bandwidth was for both 1.67 kHz.

All the four sequences were acquired consecutively and the total acquisition time was within approximately 1.5 min (see in *Fig. 1* the exact acquisition timing) to minimize the probability of varying bowel filling between scans.

Imaging processing: Body masks of every transverse slice were obtained using an automatic 3 classes threshold Otsu algorithm [4] on the IP images and excluding the pixel below the first threshold. Two bone masks (*Fig. 3*) were generated applying a 3 classes k-mean clustering algorithm [5] based on Euclidean distance on the 2D topological space defined by all the correspondent pixels in every transverse slice of the IP and the OP images. Bone-only DRRs were reconstructed from the binary bone masks (*Fig. 4*).

RESULTS & DISCUSSION Even though the images are acquired with different sequences the total acquisition time is short enough not to expect considerable variation in the internal anatomy of the volunteers. The two OP images demonstrate very comparable contrast (*Fig. 2* bottom) as can be expected from similar effective echo times equal to 2.3 ms. Signal voids are present at water/fat interfaces and the bony structure results in black region (low magnitude) in the same anatomical area.

On the contrary, the two IP images (*Fig. 2* top) present differences localized in the central region that corresponds to the bowel: the Ref image depicts signal voids not visible in the image acquired with the proposed pulse. The bowel signal voids in the Ref image suggest that the bowel filling consists of a mixture of liquid and gas that causes intra-voxel dephasing for longer T_E. In this way the shortening of the T_E produces less signal voids by reducing the T_2* dephasing effects. This result is exploited in the image processing obtaining a reduction of false positive in the bone mask, as also visible in the bone-only DRRs in *Fig. 4*.

CONCLUSION Cartesian 3D spoiled GRE in-phase and out-phase images with reduced time point (2.3 ms) acquired with a spectral-spatial selective pulse resulted in good segmentation of cortical bones in the pelvis and in bone-only DRRs.

The main innovation is in the increased bone specificity related to improved discrimination between bone and short T_2* regions, such as air/fluid mixtures in the bowel region.

Furthermore the image processing proposed is fast and utilizes algorithms that are standard and easily implementable in a clinical department. Future work could focus on the development of a multi-echo acquisition in order to acquire in-phase and out-of-phase in a single sequence. The use of 2-point Dixon reconstruction based on the in-phase/out-phase could also allow a complete generation of Electron Density map valuable for RTP.

REFERENCES

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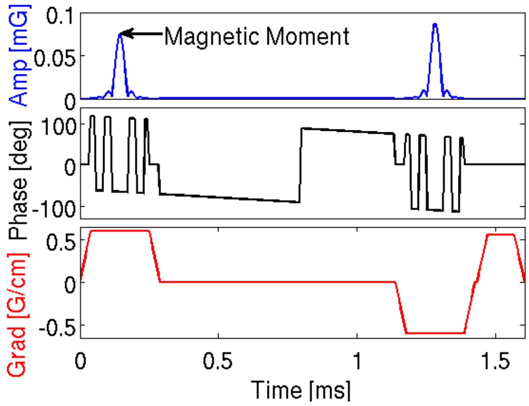

Fig. 1: *RF amplitude, phase and gradient waveform for the IP spectral-spatial selective Pulse.*

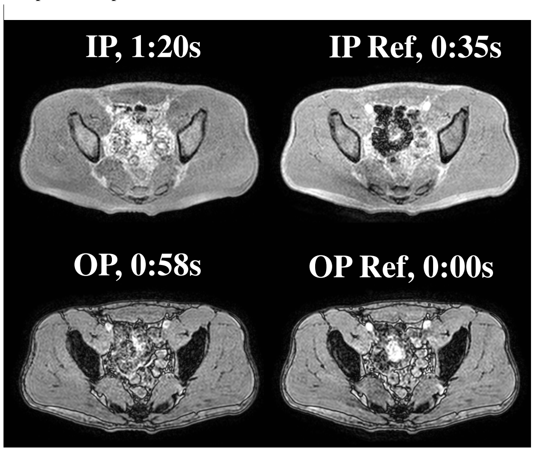

Fig. 2: *In-Phase (IP) and Out-of-Phase (OP) images acquired with the custom pulse (left) and as reference (right). All the images have the same window level. The times are the relative start time from the beginning of the acquisition.*

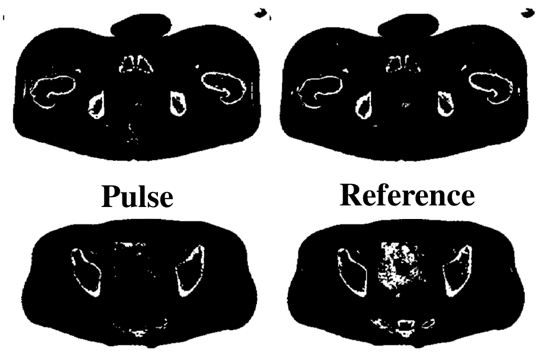

Fig. 3: *Body and Bone masks of the Pulse images (left) and of the Reference ones (right) for two transverse slices: 17 (top) and 39 (bottom).*

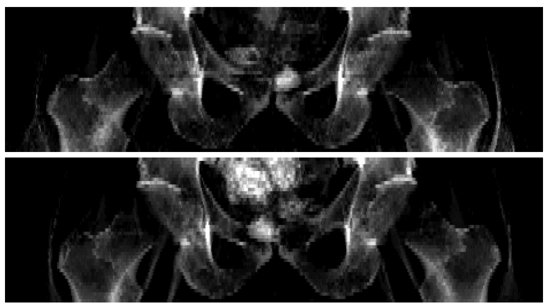

Fig. 4: *Bone-only DRR from the Pulse images (top) and References ones (bottom).*