Small field of view imaging using wavelet encoding with 2 dimensional RF pulses and gradient echo: phantom results

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Abstract

Object The objective of this work is to propose an imaging sequence based upon the wavelet encoding approach to provide MRI images free from folding artifacts, in the small field of view (FOV) regime, such as dynamic magnetic resonance imaging (MRI) studies.

Materials and methods The method consists of using a 2D spatially selective RF excitation pulse inserted into a gradient-echo pulse sequence to excite spins within a determined plane where wavelet encoding is achieved in one direction and slice selection is performed in the second direction. Wavelet encoding allows for spatially localized excitation and consequently restricts the spins excited within a reduced FOV. It consists of varying, according to a predetermined scheme, the width and position of the profile of the so-called fast RF pulse of the 2D RF excitation pulse, to obey wavelet encoding translation and dilation conditions. This sequence is implemented on a 3 Tesla whole body Siemens scanner.

Results Compared to Fourier encoding, the proposed technique tested on phantoms with different shapes and structures, is able to provide gradient-echo reduced FOV images free from aliased signals.

Conclusion Wavelet encoding is suitable for small FOV imaging in dynamic MRI studies.

Keywords Wavelet encoding · Small FOV imaging · Spatially selective 2D RF excitation · Dynamic MRI

Introduction

Several magnetic resonance imaging (MRI) applications, such as cardiac imaging, interventional, and functional MRI, utilize small field of view (FOV) imaging to perform dynamic MR studies [1]. In cardiac imaging, the entire chest is typically within the FOV while the heart occupies a small part of the FOV. In MR temperature mapping monitoring procedures, such as focused ultrasound ablation of tissue, only the therapy volume, which occupies a small portion of the FOV, is of special interest. In functional MRI of pre-surgical planning, the region surrounding the tumor may be the only part of the FOV that has clinical value. In studies such as these, a reduction of the size of the FOV covering with sufficient resolution the region of interest (ROI) is required; otherwise the resolution of the organ occupying a relatively small part of the imaged FOV is not sufficient. However, reducing the imaging FOV with Fourier encoding results in aliased images in the phase encoding direction originating from the “wraparound” or folding artifacts [2]. In addition to the FOV reduction, the region of interest might be smaller than the imaged organ where only a portion of encoding steps is updated.

A number of solutions have been proposed to solve the folding problem, such as reduced field-of-view methods [3], and the UNFOLD technique [4]. There is, however, a simpler approach that consists of avoiding this problem altogether by only exciting the signal inside the ROI using different encoding techniques. In this scope, the use of a 2D excitation RF pulse is preferred since it simultaneously excites spins within a selected column. Finsterbusch et al. proposed the use of a 2D RF pulse excitation with line scanning in functional neuro-imaging of the human motor cortex [5]. Zhao et al. combined the 2D RF pulse excitation with the UNFOLD approach to suppress the residual artifacts in MRI-based...
temperature mapping studies [6]. Both propositions allow for a better temporal resolution than conventional gradient-echo imaging by restricting the FOV, while maintaining high spatial resolution. Wavelet encoding is another alternative, since it localizes regions of interest to be excited and consequently allows for FOV reduction without folding. Wavelet encoding is derived from wavelet transform which uses prototype functions called wavelets, seen as filters with variable spatial width and position, to divide a given input spatial function into a set of predetermined sub-spaces. This operation is a linear transformation from the input spatial domain to the wavelet domain [14]. The variations of the position and the spatial width of the filters are determined through translation and dilation of the wavelet functions, respectively. In MR, wavelet encoding is performed through RF pulse manipulations, which play the role of the wavelet functions. Wavelet translation and dilation are performed by shifting the frequency of the RF pulse and varying the strength of the corresponding localization gradient, respectively. Most of the proposed wavelet encoding sequences relies on spin-echo–based sequences [7,8], where the excitation RF pulse is used to achieve wavelet encoding, which replaces the phase encoding, and the refocusing RF pulse is used for slice selection. However, using spin-echo sequences is a limiting factor in high speed imaging where gradient-echo–based sequences are preferred especially at high $B_0$ field [9]. One possible solution to this limitation is to use a 2D spatially selective RF excitation pulse to allow for column selection [10]. The first dimension is attributed to FOV reduction selection with wavelet encoding and the second dimension is used for slice selection.

Several K-space trajectories are available to use [11]. The blipped echo planar imaging (EPI) trajectory is chosen for our 2D RF pulse since it allows for a straightforward wavelet encoding implementation. The so-called fast RF pulses of the 2D RF pulse along with the corresponding zig-zag gradient are used for wavelet encoding, and the slow RF pulse of the 2D RF pulse is left for slice selection. As for the wavelet functions, we chose Haar wavelets, due to their simplicity of implementation. Their shapes resemble the profiles of the sinc RF pulses [12].

Following the two dimensional RF pulse, a gradient-echo signal is acquired by activating a standard readout gradient applied in the remaining orthogonal direction. Wavelet encoding provides images with low signal-to-noise ratio (SNR) when compared to Fourier encoding [13]. However, it provides images with better SNR than line scanning techniques [14] and does not rely on aliasing correction methods, as for the combined 2D RF pulse with UNFOLD method, where restrictions are placed on the profile of the main excitation lobe of the 2D RF pulse to avoid aliasing from the side lobes [15]. It remains that side lobes in the slice-select direction are a potential source of undesired aliasing in the proposed encoding method and need to be saturated before encoding. This is performed by using spatial saturation RF pulses on the two sides of the main lobe in the slice direction. The proposed gradient-echo wavelet encoding technique (GE-WE) using a 2D RF excitation pulse is successfully implemented on a 3 Tesla Siemens scanner and phantom tests are reported. Alias-free small FOV images that are suitable for MRI-based dynamic imaging studies are obtained and compared to the standard gradient-echo images.

### Theory

Wavelet encoding has been first proposed by Weaver and Healy as an alternative to phase encoding technique in a spin-echo MR sequence to reduce acquisition time and motion artifacts [16]. In their method, phase encoding is replaced by wavelet encoding, where the excitation RF pulses are manipulated to play the role of the Haar functions to achieve the encoding. This method has been implemented by Panych et al. using different wavelet functions [17]. Since then, the method has not seen widespread application, mainly due to the low SNR of the wavelet encoding images compared to the regular Fourier encoding methods. It has shown usefulness in multi-slice imaging where an improvement of SNR is obtained [18]. In addition to imaging, wavelet encoding has been proposed in magnetic resonance spectroscopic imaging (MRSI) to reduce acquisition time and voxel contamination [12,19]. Here, we propose wavelet encoding as a technique for low resolution images in the small FOV regime. The theory behind the development and implementation of wavelet encoding in MR, briefly summarized here, is discussed in detail in previous works [12,16,19].

Wavelet encoding is based upon the discrete wavelet transform. A linear transformation from the space domain to the wavelet domain is performed using dilated and translated scaling and wavelet functions. This transform achieves a division of an input finite space function to a set of output sub-spaces with different sizes and locations [20]. The wavelet dilation determines the size of the sub-space, while the translation localizes its position [12,16]. The number of wavelet dilations, which sets the number of translations, is determined by the desired spatial resolution. Similar to the Fourier synthesis, which performs an inverse Fourier transform on the acquired K-space data (Fourier coefficients) to obtain the spatial image, an inverse wavelet transform is performed on the acquired sub-spaces (wavelet coefficients) data to perform the same task [20]. The wavelet dilations and translations are achieved by changing the localization $B_0$ field gradient strength and by shifting the frequency of the selective RF pulse, respectively [12,19].

The small tip-angle excitation approach developed by Pauly et al. [21] is briefly summarized here, is used...