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Phase preparation in steady-state free precession MR elastography☆

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Abstract

Strain and motion measurements in balanced steady-state free precession (bSSFP) imaging require high magnetic field homogeneity. This requirement is due to the nonlinear signal response to spin phase variations in bSSFP. Here, a technique that utilizes background gradients for preparing strong in-plane spin phase variations is proposed. As a result, periodic patterns of increased motion sensitivity appear, which are interleaved with bands of low phase-to-noise ratio. Spatial filters commonly used in MR elastography (MRE) remove these bands and leave wave images equivalent to a uniform phase response in bSSFP-MRE. Since phase preparation gradients locally enhance motion sensitivity, the technique can be employed for selectively increasing the wave signal amplitude in MRE. The method is applied without the need for previous shimming, which reduces the examination time. In vivo phase prepared bSSFP-MRE is demonstrated in human liver and heart.

Keywords: Magnetic resonance elastography; Balanced SSFP; Nonlinear phase response; Liver; Myocardium

1. Introduction

Palpation is the standard clinical practice for assessing the health of tissue near the body surface. The high sensitivity of the method to pathological changes is based on the direct relationship between the macroscopic viscoelastic properties of tissue and its structural organization on a molecular scale [1]. MR elastography (MRE) [2–4] allows quantifying the viscoelasticity of soft tissue deep inside the body and has the potential to help characterize, for instance, musculoskeletal diseases [5–7], liver fibrosis [8–10] or breast cancer [11–14].

Technically, MRE is based on the application of external vibrations and measuring the bulk tissue response by motion-sensitive MRI. The vibration frequency has to be low (for most in vivo studies, below 100 Hz) in order to mitigate damping of the shear waves due to viscosity. However, since in standard MRE, the duration of bipolar motion encoding gradients (MEGs) matches the mechanical vibration period, low vibration frequencies automatically require long echo times and therefore impose high signal loss due to T2 dephasing. This concept was recently revised using MEGs much shorter than one vibration period [10,15,16]. In this approach, only fractions of one vibration cycle are exploited for motion encoding, resulting in lower motion sensitivity. Nevertheless, the concept of fractional MRE has two advantages: The experiment is accelerated, and shortening TE and TR allows the application of steady-state free precession (SSFP) sequences for encoding shear vibrations with high phase-to-noise ratio (PNR) in soft and viscous materials. This was shown to be beneficial in MRE studies on human liver and heart.

In SSFP-MRE, the harmonic vibration frequency has to be tuned to the sequence TR to avoid signal ghosts [17]. To combine short TR and low vibration frequencies f_v, one has to adjust both so that $n\cdot\mathrm{TR}=1/f_v$, with n being an integer number. In a recently published study, Bieri et al. [18] showed that altering the deflection amplitude of each TR results in two steady states of the magnetization, and thus, two images with inverse motion phase contrast (PC) have to be sampled in an interleaved fashion. In general, k-space must be sampled n times in fractional MRE. Fig. 1 depicts the motion encoding and sampling scheme for n=1, 2 and 4

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