Magnetic Resonance Imaging 32 (2014) 679–683

Contents lists available at ScienceDirect

Magnetic Resonance Imaging

journal homepage: www.mrijournal.com

Rapid acquisition technique for MR elastography of the liver

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ARTICLE INFO

Article history:
Received 28 August 2013
Revised 5 February 2014
Accepted 6 February 2014

Keywords:
MR elastography
MRE
Liver MRE
Liver fibrosis

ABSTRACT

Magnetic resonance elastography (MRE) of the liver is a novel noninvasive clinical diagnostic tool to stage fibrosis based on measured stiffness. The purpose of this study is to design, evaluate and validate a rapid MRE acquisition technique for noninvasively quantitating liver stiffness which reduces by half the scan time, thereby decreasing image registration errors between four MRE phase offsets. *In vivo* liver MRE was performed on 16 healthy volunteers and 14 patients with biopsy-proven liver fibrosis using the standard clinical gradient recalled echo (GRE) MRE sequence (MREs) and a developed rapid GRE MRE sequence (MREr) to obtain the mean stiffness in an axial slice. The mean stiffness values obtained from the entire group using MREs and MREr were 2.72 ± 0.85 kPa and 2.7 ± 0.85 kPa, respectively, representing an insignificant difference. A linear correlation of $R^2 = 0.99$ was determined between stiffness values obtained using MREs and MREr. Therefore, we can conclude that MREr can replace MREs, which reduces the scan time to half of that of the current standard acquisition (MREs), which will facilitate MRE imaging in patients with inability to hold their breath for long periods.

1. Introduction

Hepatic disease is a major cause of mortality worldwide. Chronic liver diseases such as hepatitis B (CHB), hepatitis C (CHC), alcoholic liver disease (ALD) and nonalcoholic fatty liver disease (NAFLD) can lead to hepatocellular carcinoma (HCC) or liver fibrosis [1].

Liver fibrosis is characterized by progressive deposition of excess collagen, proteoglycans, and other macromolecules in the extracellular matrix in response to repetitive liver injury from various chronic liver diseases [2]; it results in increasing stiffness of the hepatic tissues. Potential complications of cirrhosis include liver failure, portal hypertension, varices, HCC, and hepatic encephalopathy.

Originally considered to be irreversible, liver fibrosis is now regarded as a dynamic process with potential for regression [3]. Early detection of liver fibrosis may be helpful in the management of chronic liver diseases [4–7]. Although fibrosis is reversible if detected early, progressive fibrosis initiates the onset of hepatic cirrhosis which is irreversible and lethal in nature.

Currently, liver biopsy is the gold standard for detecting liver fibrosis [8,9]. However, liver biopsy is an invasive, expensive procedure associated with a high risk of complications [10–13]. It is also affected by substantial sampling error, thereby overestimating or underestimating the degree of fibrosis.

Magnetic resonance elastography (MRE) is a novel noninvasive technique to estimate stiffness of soft tissues [8,9,14–23]. MRE involves a three stage process. First, noninvasive vibrations are applied to the area of interest via a driver which transmits waves. Second, a phase-contrast magnetic resonance imaging (MRI) sequence synchronized to the externally-applied vibrations measures the wave displacement field. Finally, the wave images are then mathematically converted to spatial stiffness maps known as inversion, to assess the tissue stiffness.

Currently, MRE is a clinical tool to stage liver fibrosis [8,9,24]. Because, MRE is typically a breathhold technique and current clinical standard MRE sequence requires ~22 sec breathhold to obtain wave images/stiffness map for a single slice, it often becomes difficult for the patient with liver disease comply with needed suspended breathing. The purpose of our study is to design, evaluate, and validate a developed rapid MRE acquisition

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http://dx.doi.org/10.1016/j.mri.2014.02.013
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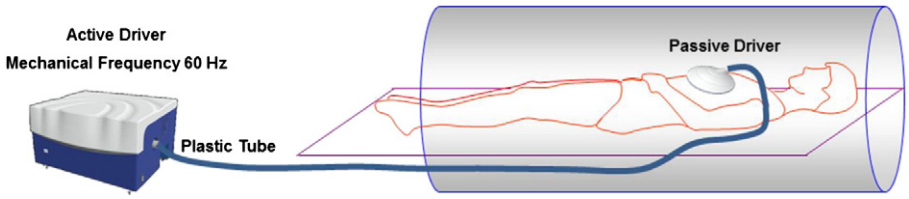

Fig. 1. Experimental setup. A passive driver is placed on the abdomen, on the ROI. Waves are noninvasively transmitted to the passive driver and into the subject. These waves are imaged by the MRI scanner and are used to calculate stiffness.

technique that can markedly reduce the breathhold time in noninvasively quantitating liver stiffness by MRE compared to the clinical standard MRE sequence.

2. Materials and methods

The study protocol was approved by the institutional review board. Written informed consent was obtained and documented for all patients and volunteers. A total of 30 subjects (10 men, 20 women; age range, 20–66 years), including 16 normal healthy individuals, and 14 patients with biopsy-proven liver fibrosis, were included in the study.

2.1. Image acquisition

All imaging was performed on 1.5 T (Avanto, Siemens, Erlangen, Germany; n = 6) or 3 T (TimTrio, Siemens, Erlangen, Germany; n = 24) MR imaging (MRI) scanners. For each examination, the subject was positioned supine.

For MRE in this study, mechanical waves were introduced into the subject's liver by a commercial pneumatic driver system (Resoundant, Mayo Clinic Foundation, Rochester, MN) (Fig. 1). The passive driver was placed anterior on the patient's body close to the liver region (centered at the level of the xiphoid process) and secured with an elastic belt. The passive driver was connected via a polyvinylchloride tube to the active driver which was placed outside the scan room to induce 60 Hz vibrations in to the liver.

A standard gradient recalled echo (GRE) MRE sequence (MREs) [9] and a developed rapid GRE MRE sequence (MREr) were used to acquire an axial slice covering a major portion of the liver. For MREs, bipolar motion encoding gradients (MEGs) shown in Fig. 2a were used to obtain phase contrast MRI images. Bipolar gradients enhance phase contrast by discarding unwanted contributions to the phase caused by system imperfections. Since the magnitude of both the polarities of the bipolar gradients was constant, the phase difference image between the opposite polarities remained zero for static spins and encodes moving spins only. The polarities were swapped every other TR in synchronization with the external vibrations (Fig. 2a). Four sets of wave images spaced equally over a period of the wave motion were obtained by changing the temporal relationship between the motion encoding gradients (MEGs) and the external vibrations. Fig. 2a shows the pulse sequence diagram for MREs

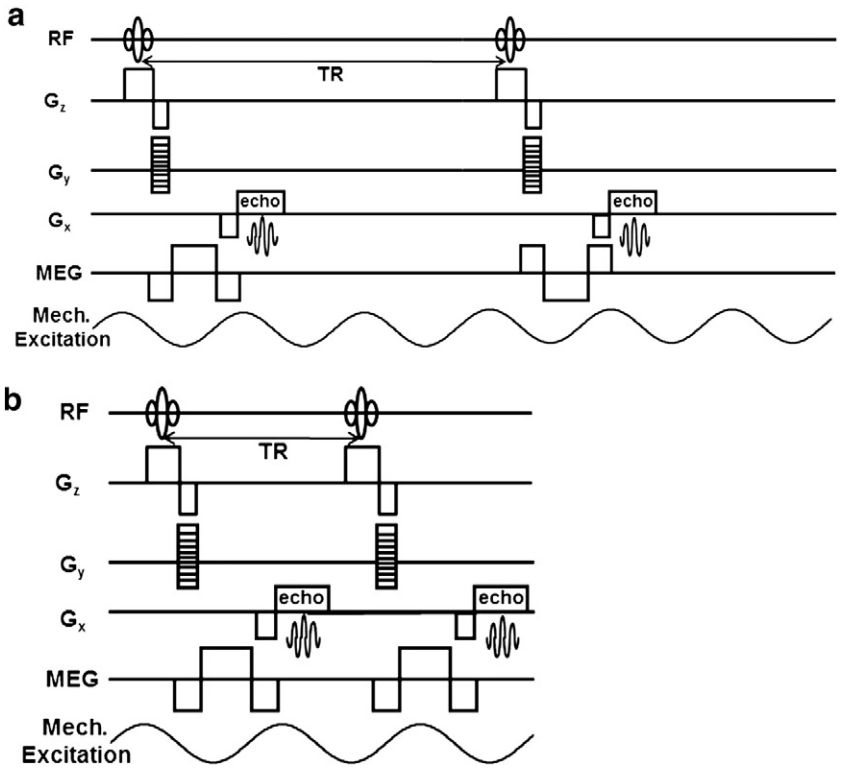

Fig. 2. Pulse sequence diagram. a) shows the GRE based MREs pulse sequence. The polarities of the MEGs are swapped every other TR and the TR equals to 3 cycles of external motion (CEV). b) Shows the GRE based MREr pulse sequence. In MREr the polarities of the MEGs stay the same for all the TR cycles. Every TR is synchronized with 1.5 CEV. For simplicity flow compensating gradients and killer gradients are not shown.