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Comparison of breath-hold, respiratory navigated and free-breathing MR elastography of the liver

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ABSTRACT

Purpose: Hepatic magnetic resonance elastography (MRE) is currently a breath-hold imaging technique. Patients with chronic liver disease can have comorbidities that limit their ability to breath-hold (BH) for the required acquisition time. Our aim was to evaluate whether stiffness measurements obtained from a navigator-triggered MRE acquisition are comparable to standard expiratory breath-hold, inspiratory breath-hold or free-breathing in healthy participants.
Materials and methods: Twelve healthy participants were imaged using the four methods on a clinical 1.5 T MR system equipped with a product MRE system. Mean liver stiffness, and measurable area of stiffness (with a confidence threshold >95%) were compared between sequences using the concordance correlation coefficient. Repeatability of each sequence between two acquisitions was also assessed.
Results: The standard BH expiratory technique had high concordance with the navigated technique ($r = 0.716$), and low concordance with the BH inspiration ($r = 0.165$) and free-breathing ($r = 0.105$) techniques. The navigator-triggered technique showed no statistical difference in measurable area of liver or in repeatability compared with the standard expiratory acquisition ($p = 0.997$ and $p = 0.407$ respectively). The free-breathing technique produced less measurable liver area and was less repeatable than the alternative techniques. The increase in acquisition time for navigator techniques was 3 min 6 s compared to standard expiratory breath-hold.
Conclusion: Navigator-based hepatic MRE measurements are comparable to the reference standard expiratory breath-hold acquisition in healthy participants.

1. Introduction

Liver biopsy remains the gold standard for assessment of liver parenchyma, but is an invasive technique and uncomfortable for patients [1]. The risk of a significant hemorrhage requiring transfusion or intervention due to the procedure is estimated in the literature at approximately 1 in 200 [1–3]. Mortality, though rare, is a recognized complication. An investigation that could obviate these risks would be clinically advantageous. There is increasing evidence for the use of magnetic resonance elastography (MRE) in the diagnosis of liver fibrosis [4–6]. Fibrotic livers have, among other factors, a higher collagen content which results in an increase in stiffness that can be quantified by MRE [7,8].

Standard MRE techniques are phase-based and are therefore sensitive to motion artifact from respiration and blood flow [9]. Hepatic MRE is currently performed at end-expiration, and typically requires four breath holds in order to replicate the position of the liver and four slices in four breath holds to get a large sample of liver [10–12]. Breathing has been shown to affect liver stiffness measurements. Horster et al. reported that Valsalva maneuver resulted in falsely elevated measurements of liver stiffness [13]. Sequential breath holds may result in slightly differing diaphragmatic positions and different position of the liver and other viscera, which may result in misregistration effects [14]. In addition, some patients may not be able to manage the breath-holds. Respiratory triggering, using navigator echo diaphragm tracking, is an alternative method to breath-hold acquisitions [15] but is not currently supported in product MRE sequences.

The aims of this study are to 1) evaluate whether a navigated MRE sequence produces equivalent stiffness values compared to

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standard BH end-expiration (BHE), and evaluate the utility of the currently alternatives: BH inspiration (BHI) and free-breathing (FB); and 2) to assess and compare the relative repeatability of each technique.

2. Methods

2.1. Study cohort

Ethical approval was provided for the study and all participants gave informed written consent. The studies were carried out on 12 healthy participants, with no known history of hepatobiliary or cardiovascular disease, who fasted for at least 6 h prior to the scan. There were eight male and four female participants, with a mean age of 30 years, range [24–42 years].

2.2. Image acquisition

Examinations were performed on a 1.5 T whole-body MRI scanner (MR450, GE Healthcare, Waukesha, WI) using an eight-channel receive array coil.

For the MRE acquisition a passive 18.5-cm-diameter pneumatic driver was placed anteriorly over the right lower ribs superficial to the right lobe of the liver. The passive driver was connected to an active drive unit producing shear waves at 60 Hz. The product gradient-echo based MRE sequence was modified to incorporate a 2D cylindrical-excitation navigator tracking acquisition. Sequence parameters were TE/TR =22/50 ms, matrix 256 × 64, field of view =40 × 36 cm, section thickness = 8 mm, gap =5 mm, bandwidth = ±31.25 kHz, and flip angle =30°. A parallel imaging (ASSET) acceleration factor of 1.5 was used. Four slices were acquired with four phase offsets (0°, 90°, 180°, 270°). In the breath-hold acquisitions each offset was acquired in a separate 17-s breath-hold. MRE shear modulus-based stiffness and wave confidence interval (CI) maps were subsequently computed.

Each participant was imaged using the free-breathing, breath-hold and navigator-triggered methods, with each acquisition performed twice without subject repositioning. The order in which the sequences were acquired was randomized. BHE images were acquired following two automated instructed deep breaths, followed by an additional deep inspiration for BHI. Each breath hold was followed by free breathing for approximately 9 s, then BH instructions were repeated.

2.3. Image analysis

Image analysis was performed on OsiriX (version 4.1.2, Pixmeo, SARL, Switzerland). Regions of interest (ROIs) were defined using the boundary of the liver on each of the four slices on the magnitude images and then mapped onto the same spatial locations of the corresponding stiffness maps using copy-and-paste functionality. Approximately 1 cm of liver parenchyma closest to the liver capsule was excluded as this has been shown on previous studies to contain a higher collagen content [16,17]. The area within this where the CI was higher than 95% was then mapped. The mean stiffness and the percentage of analyzable liver area were calculated at a per subject level across all 4 slices (Fig. 1).

Comparisons between the respective methods were assessed using the mean stiffness measurements obtained during repeat scan 1. The relative repeatability of each technique was determined by computing the absolute difference in mean liver stiffness between repeat scans 1 and 2.

The regions of interest were defined by a radiologist with 7 years' experience (IM).

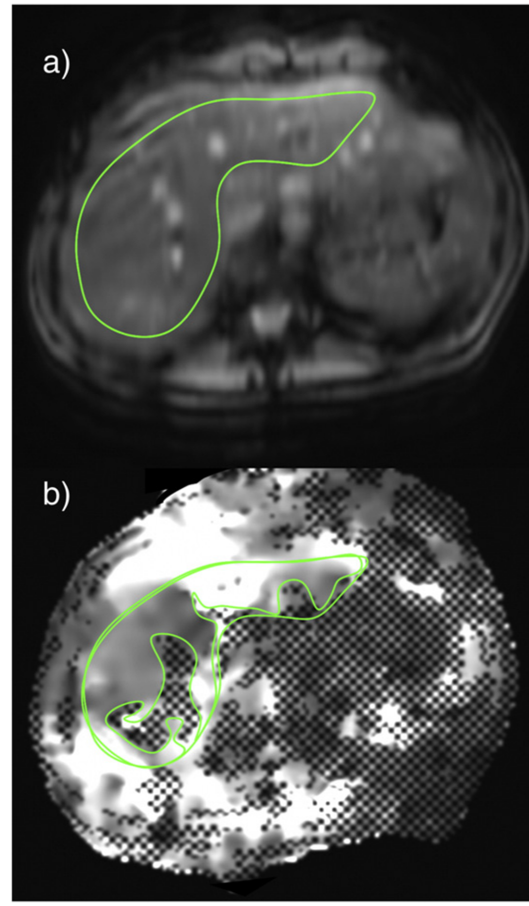

Fig. 1. Example MRE images obtained using the navigator-triggered method. Fig. 1 (a) magnitude scan and (b) shear modulus-based stiffness maps, with areas with CI <95% cross-hatched. The ROIs show the outline of the liver (a) and the outline of the analyzable area in (b). The analyzable percentage of liver (CI > 95%) was 48%. The mean liver stiffness was measured at 2.2 kPa +/− 0.45.

2.4. Statistical analysis

Normality assumptions were formally assessed using the Shapiro–Wilk's test. Agreement between BHE and each alternative method was assessed using the concordance correlation coefficient. A one-way ANOVA was performed to assess if there was an overall difference between each acquisition strategy; to compare the percentage areas of analyzable liver and to evaluate the absolute differences in the repeated measurements. Pairwise comparisons were performed using the paired Student's T-test. A p-value <0.05 was defined as statistically significant. The statistical analysis was performed using the R programming language (version 3.2.1, The R foundation for Statistical Computing, Vienna, Austria).

3. Results

The percentage mean area of liver where the stiffness was quantifiable (CI >95%) and mean stiffness values are summarized in Table 1.

3.1. Mean liver stiffness

The highest agreement was noted between the standard BHE method and the navigated sequence (r = 0.716). The concordance between BHE and the currently available alternative acquisition strategies was markedly lower (BHI: r = 0.165, and FB: r = 0.105).

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