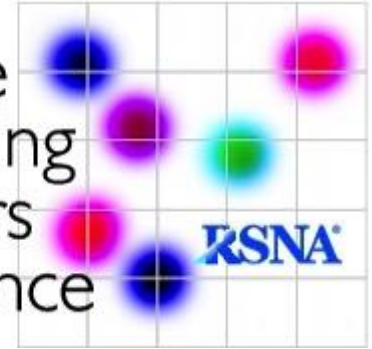


Quantitative  
Imaging  
Biomarkers  
Alliance



QIBA Profile:

# Magnetic Resonance Elastography of the Liver

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Stage 3: Technically Confirmed Profile.  
February 14, 2022

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When referencing this document, please use the following format:

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## 1. Executive Summary

45 The goal of a QIBA Profile is to help achieve a useful level of performance for a given biomarker.

The **Claim** (Section 2) describes the biomarker performance.

The **Activities** (Section 3) contribute to generating the biomarker. Requirements are placed on the **Actors** that participate in those activities as necessary to achieve the Claim.

**Assessment Procedures** (Section 4) for evaluating specific requirements are defined as needed.

50 This QIBA Profile (**Magnetic Resonance Elastography of the Liver**) addresses the application of Magnetic Resonance Elastography (MRE) for the quantification of liver stiffness, which is often used as a **biomarker of liver fibrosis**. It places requirements on **Acquisition Devices, Technologists, Radiologists, Reconstruction Software and Image Analysis Tools** involved in **Subject Handling, Image Data Acquisition, Image Data Reconstruction, Image QA and Image Analysis**.

55 The requirements are focused on achieving sufficient accuracy and avoiding unnecessary variability of the measurement of hepatic stiffness.

The clinical performance target is **to achieve a 95% confidence interval for a true change in stiffness has occurred when there is a measured change in hepatic stiffness of 19% or larger**.

60 This document is intended to help clinicians basing decisions on this biomarker, imaging staff generating this biomarker, vendor staff developing related products, purchasers of such products and investigators designing trials with imaging endpoints.

Note that this document only states requirements to achieve the claim, not “requirements on standard of care.” Conformance to this Profile is secondary to properly caring for the patient.

65 QIBA Profiles addressing other imaging biomarkers using CT, MRI, PET and Ultrasound can be found at [qibawiki.rsna.org](http://qibawiki.rsna.org).

## 2. Clinical Context and Claims

### Clinical Context

70 Chronic liver disease (CLD) is a major health burden in the United States. CLD, regardless of etiology, when untreated may lead to liver fibrosis and if progressive to cirrhosis and its complications. Effective treatment methods for some forms of CLD are available and can prevent progression, or even result in regression, of fibrosis [1,2]. A reliable non-invasive technique is needed for detection, staging and assessment of treatment response in liver fibrosis. Measurement of *liver stiffness* (defined in this document as the magnitude of the complex shear modulus) with MR Elastography (MRE) has been shown to be useful for non-invasive detection and staging of liver fibrosis [3,4]. Published evidence has established that MRE is an accurate and reproducible technique and promising for use in clinical trials [5-7].

Conformance to this Profile by all relevant staff and equipment supports the following claim(s):

80 **Claim: A measured change in hepatic stiffness of 19% or larger indicates that a true change in stiffness has occurred with 95% confidence.**

### Discussion

85 This claim is based on the normal liver stiffness within-subject coefficient of variation (wCV) which we have estimated as 7% [8]. The Repeatability Coefficient is then  $2.77 \times \text{wCV}$ , or 19%. If Y1 and Y2 are the stiffness values (in kPa) at the two time points, then the 95% confidence interval for the true change is  $(Y2-Y1) \pm 1.96 \times \text{sqrt}([Y1 \times 0.07]^2 + [Y2 \times 0.07]^2)$  kPa.

Clinical interpretation with respect to the magnitude of true stiffness change:

90 The magnitude of the true change is defined by the measured change and the error bars. For example, if 3.5 kPa and 2.5 kPa are the stiffness values at time points 1 and 2, respectively, then  $(3.5-2.5)/3.5$  represents a 40% decrease. Since  $40\% > 19\%$ , we are 95% confident that a true change in hepatic stiffness has occurred. The 95% confidence interval for the true change is  $1.0 \pm 0.49$  kPa.

95 Multiple studies have demonstrated good agreement in mechanical stiffness of phantom materials assessed using MRE, and of the same phantom materials assessed using dynamic mechanical analyzer (DMA) instruments [9-11]. These studies provide confidence in the validity of MRE-based stiffness measurements. However, routine comparisons of MRE and DMA measurements for tissue and tissue-like materials are of limited use for MRE QA due to the technical limitations of DMA testing, including the difficulty of defining the geometry of semi-solid test specimens.

100

### 3. Profile Activities

The Profile is documented in terms of “Actors” performing “Activities”. Equipment, software, staff or sites may claim conformance to this Profile as one or more of the “Actors” in the following table.

Conformant Actors shall support the listed Activities by conforming to all requirements in the referenced Section.

110

**Table 1: Actors and Required Activities**

Actor	Activity	Section
Physicist	Installation and Periodic QA	3.3.
Technologist	Subject Handling	3.5.
	Image Data Acquisition	3.6.
	Image Data Reconstruction	3.7.
Radiologist	Image QA	3.8.
	Image Analysis	3.10.
	Image Interpretation	3.11

This Profile does not require an imaging site or vendor to directly demonstrate that they have achieved the performance stated in the Claim. Section 4.2: Assessment Procedure: Liver Stiffness Repeatability is provided, however, for any sites or vendors that wish to perform such an assessment. To confirm the Claim performance, a minimum of N=40 normal subjects should be imaged and the resulting RC should be 19% or less. It would be appropriate for a vendor introducing a new version of MRE to perform such an assessment.

115

The requirements in this Profile do not codify a Standard of Care; they only provide guidance intended to achieve the stated Claim. Failing to conform to a “shall” in this Profile is a protocol deviation. Although deviations invalidate the Profile Claim, such deviations may be reasonable and unavoidable and the radiologist or supervising physician is expected to do so when required by the best interest of the patient or research subject. How study sponsors and others decide to handle deviations for their own purposes is entirely up to them.

120

125

### 3.3. Installation and Periodic QA

Measurements of liver stiffness (magnitude of the complex shear modulus) obtained with MRE depends on the spatial fidelity of the acquired phase images.

130 While other instrumental causes of drift in stiffness measurements have not been documented in the literature, technical failures such as faulty synchronization of the driver system or incorrect driver frequency settings can cause incorrect measurements.

135 Image analysis software for liver MRE is standardized across vendors. Therefore, the quantitative elastograms or stiffness maps are highly reproducible across sites and vendors. For the determination of ROIs, training and procedures should be followed as outlined in Section 3.10.

The software version of the scanner, however, should be identified and tracked across time.

140 There are currently no consensus recommendations for the frequency of phantom testing. Optional QA can be performed using the protocol recommended by the phantom manufacturer. Appendix B describes a sample protocol. The phantom consists of a uniform, tissue-simulating material with known stability over time and storage conditions.

Parameter	Actor	Requirement
Installation	Physicist	Shall perform installation and initial functional validation of the MRI Scanner and MRE driver system according to manufacturer-defined procedures and specifications.
Required QA	Physicist	Shall assess and confirm the validity of the field of view and image linearity on an ongoing basis, using manufacturer-recommended procedures.
	Physicist	Shall confirm correct driver frequency settings as outlined in Appendix D.

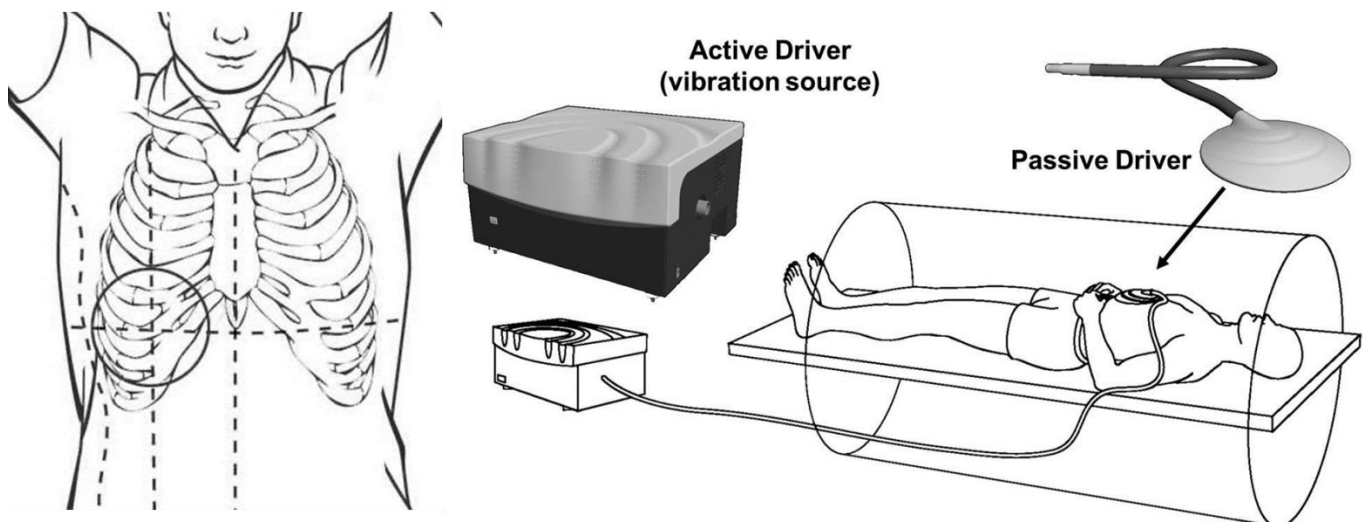
### 3.5. Subject Handling

#### 3.5.1 Subject preparation and positioning

Parameter	Actor	Requirement
Fasting state	Technologist	Shall confirm that the subject has fasted for at least 4 hours before the time of imaging [12,13].
MR scanner and MRE device selection	Technologist	Shall confirm for follow up exams that the subject is scanned on the same MRI scanner and passive driver hardware as the baseline exam.

Parameter	Actor	Requirement
Subject positioning	Technologist	Shall scan the subject in supine position.
	Technologist	Shall place the passive driver over the right lower chest wall at the level of xiphisternum in midclavicular line (Figure 1). Can be placed in the right mid-axillary line if colon is present between the anterior body wall and the liver [14,15].
	Technologist	Shall ensure the passive driver is held in firm contact with the body wall using an elastic band.
	Technologist	Shall ensure connection of the plastic tube between the passive & active driver, which is located outside the scan room.

145



150 **Figure 1:** Place the passive driver over the right lower anterior chest wall at the level of the xiphisternum, centered on the mid-clavicular line, ensuring the belt is firmly tightened around the body (see 3.5.1).

### 3.6. Image Data Acquisition

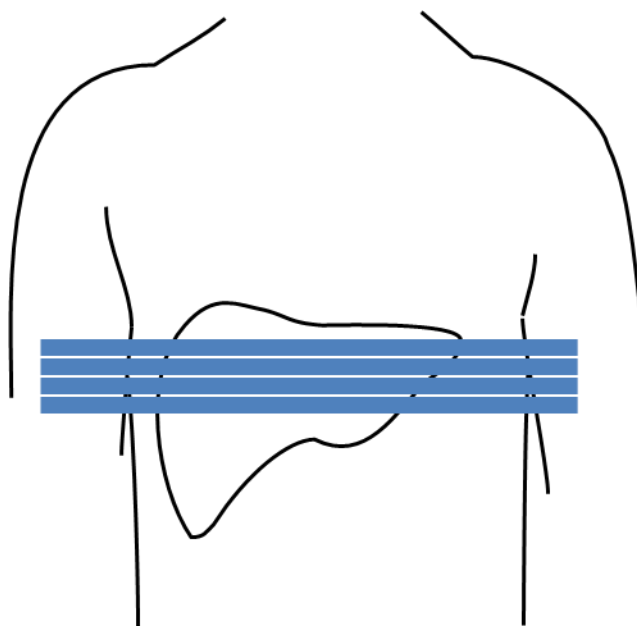
155 EPI-MRE sequence at 3T are specified due to the higher technical success rate. GRE MRE sequences are susceptible to T2\* effects resulting in poor SNR or failures in tissue with short T2\* relaxation times, particularly at 3T. [16]

**3.6.1 MRE Sequence (GRE and EPI)**

Parameter	Actor	Requirement
Image Acquisition	Technologist	Shall acquire image data during suspended expiration in a natural end-expiratory position.
Slice Selection	Technologist	Shall acquire axial sections for MRE positioned at the level of the widest transverse extent of the liver, avoiding the lungs, liver dome and inferior tip of the right lobe (Figure 2)
Image Acquisition	Technologist	Shall use an EPI-MRE sequence at 3T, if available (GRE-MRE if not available).
Image acquisition	Technologist	Shall confirm that subjects are scanned with the same parameters and software during follow up exams as the baseline liver MRE.
Image Acquisition	Technologist	Shall confirm that the magnitude images show signal loss in the subcutaneous fat just below the passive driver placement, confirming that mechanical waves are being applied.
Technical success	Technologist	Shall confirm the phase images (also known as wave images) demonstrate shear waves in the liver. (Figures 3-7)
Technical success	Technologist	Shall review the post-processed elastograms (with or without confidence map, as available) to confirm technical success of the exam.
Technical success	Technologist	Shall re-acquire the exam if possible if the above technical success criteria are not met.

Sequences discussed are commercially available 2D MRE acquisition techniques. See Appendix D for detailed vendor specific and scanner specific protocol parameters.

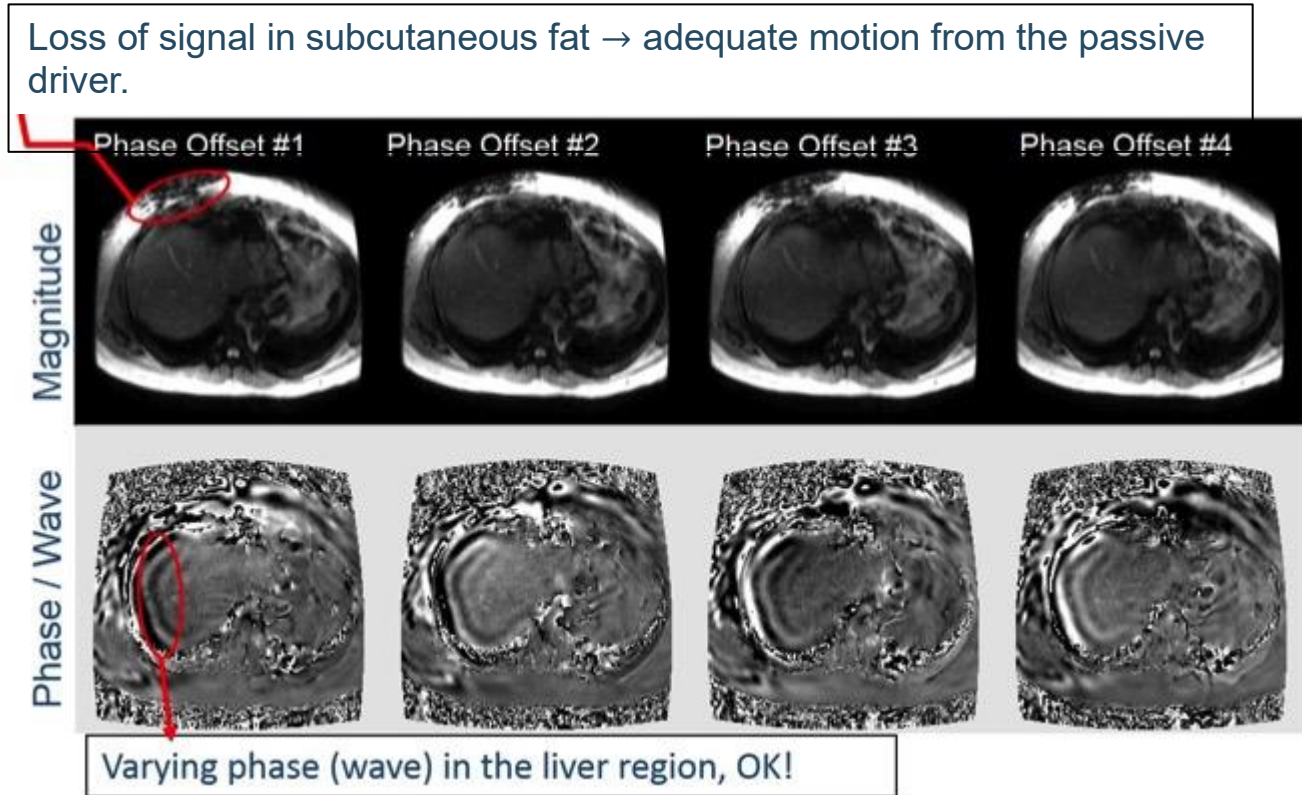
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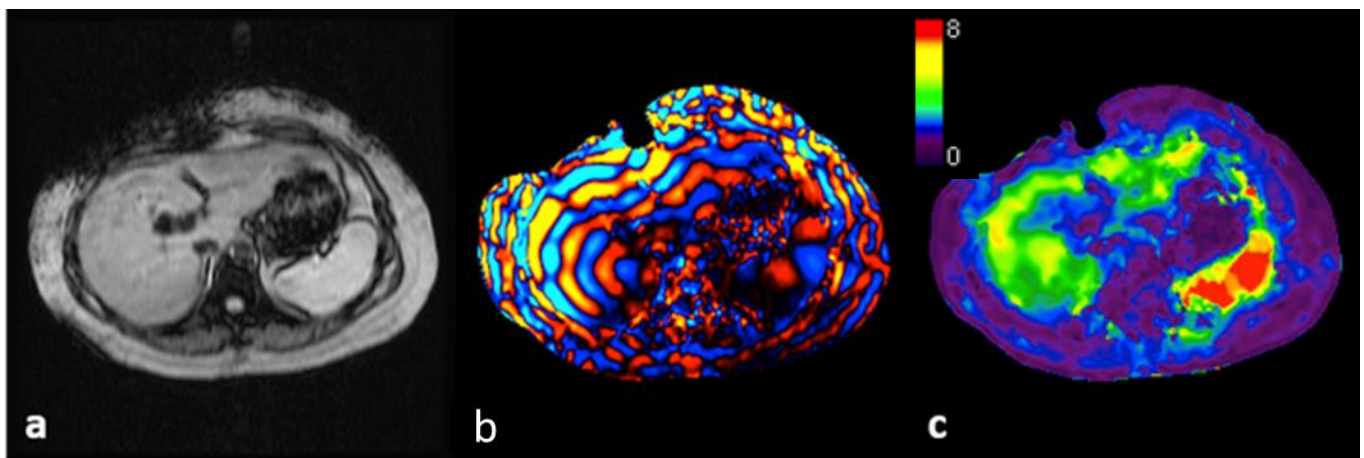


**Figure 2:** Position sections for MRE at the level of the widest transverse extent of the liver, avoiding the lung, liver dome and inferior tip of the right lobe.

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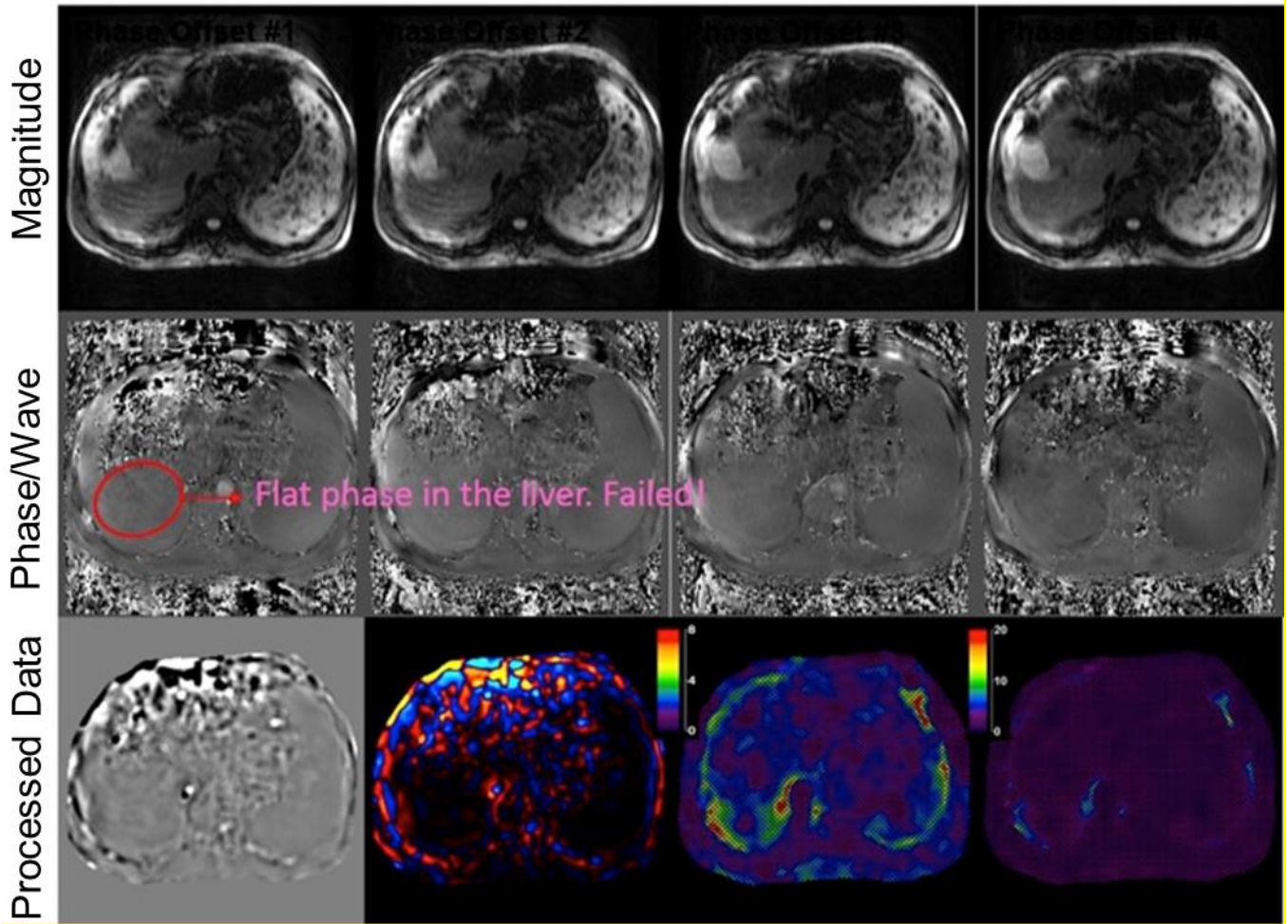
**Figure 3:** Valid MRE. Top row shows the magnitude images of four time offsets and bottom row shows the phase (wave) images. The four time offsets belong to a single slice location.



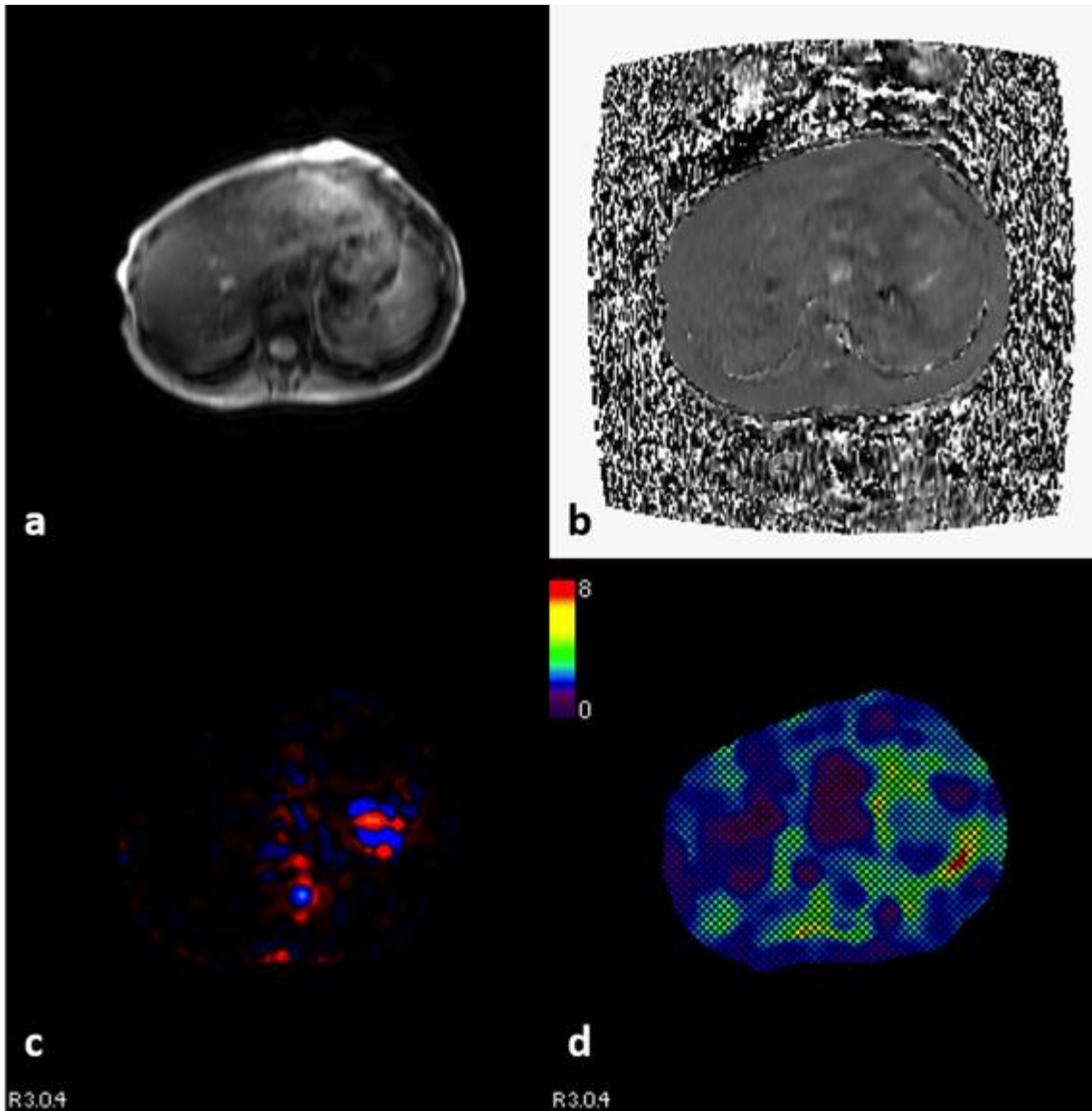
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**Figure 4:** Magnitude (a) and color-coded wave (b) images of a successful MRE showing excellent illumination of waves through the liver. Stiffness map (c) shows elevated liver stiffness consistent with

significant fibrosis.

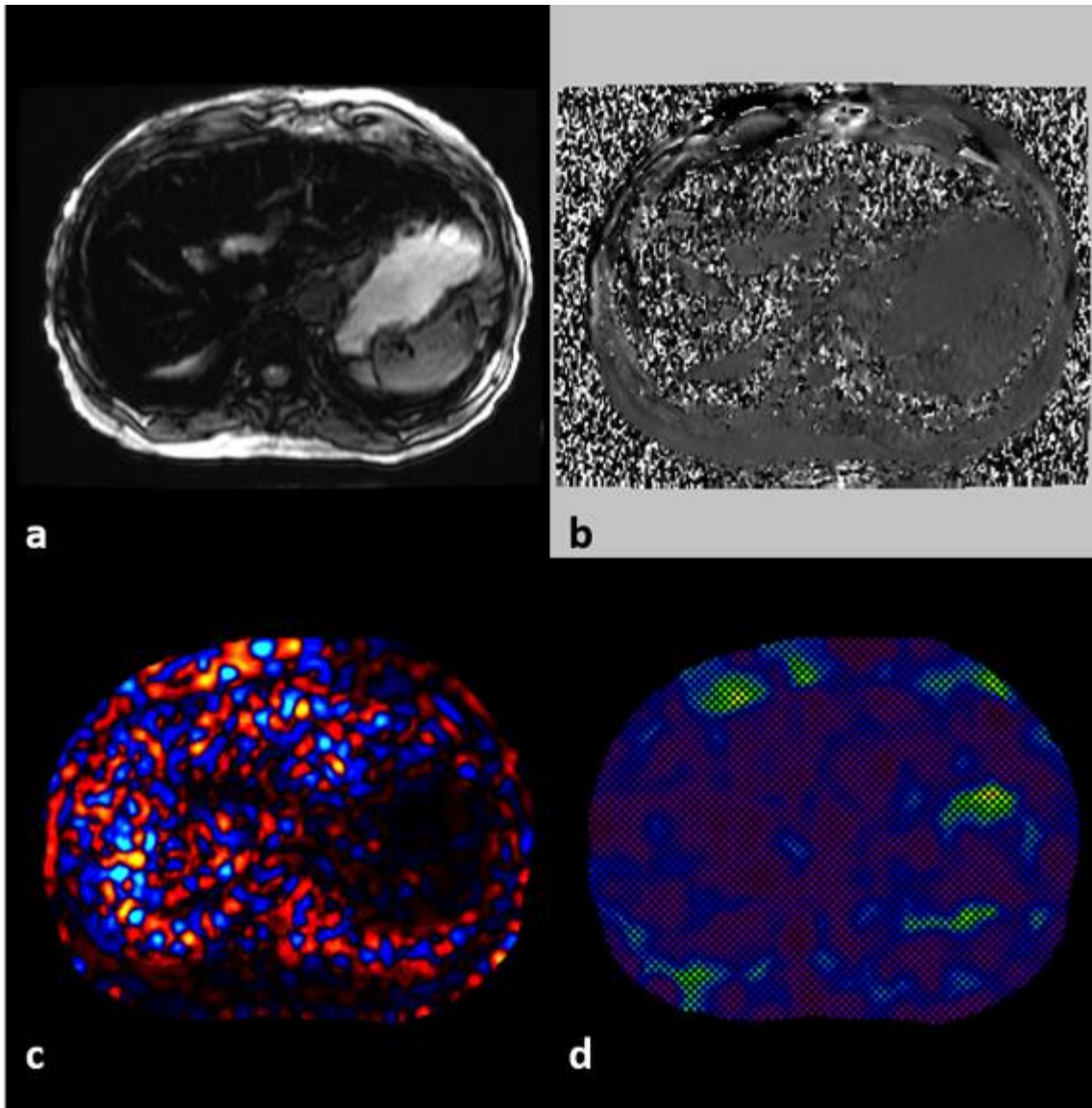


175 **Figure 5:** Failed MRE exam – Representative images of failed MRE exam due to colonic interposition between the passive driver and the liver.



180 **Figure 6:** Failed MRE exam – Representative images of failed MRE exam due to a disconnection of the plastic tube between the passive and active drivers. Magnitude (a), phase (b), and color-coded wave (c) images show no waves traversing the liver. Stiffness map (d) has no valid data.





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**Figure 7:** Failed MRE exam – Representative images of failed MRE exam due to hepatic iron overload. Magnitude (a) shows a lack of liver signal while the phase (b) and color-coded wave (c) images show no waves traversing the liver. Stiffness map (d) has no valid data (represented with the hashed-out area). Lack of signal in the liver from T2\* effects confound the MRE processing.

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### 3.7. Image Data Reconstruction

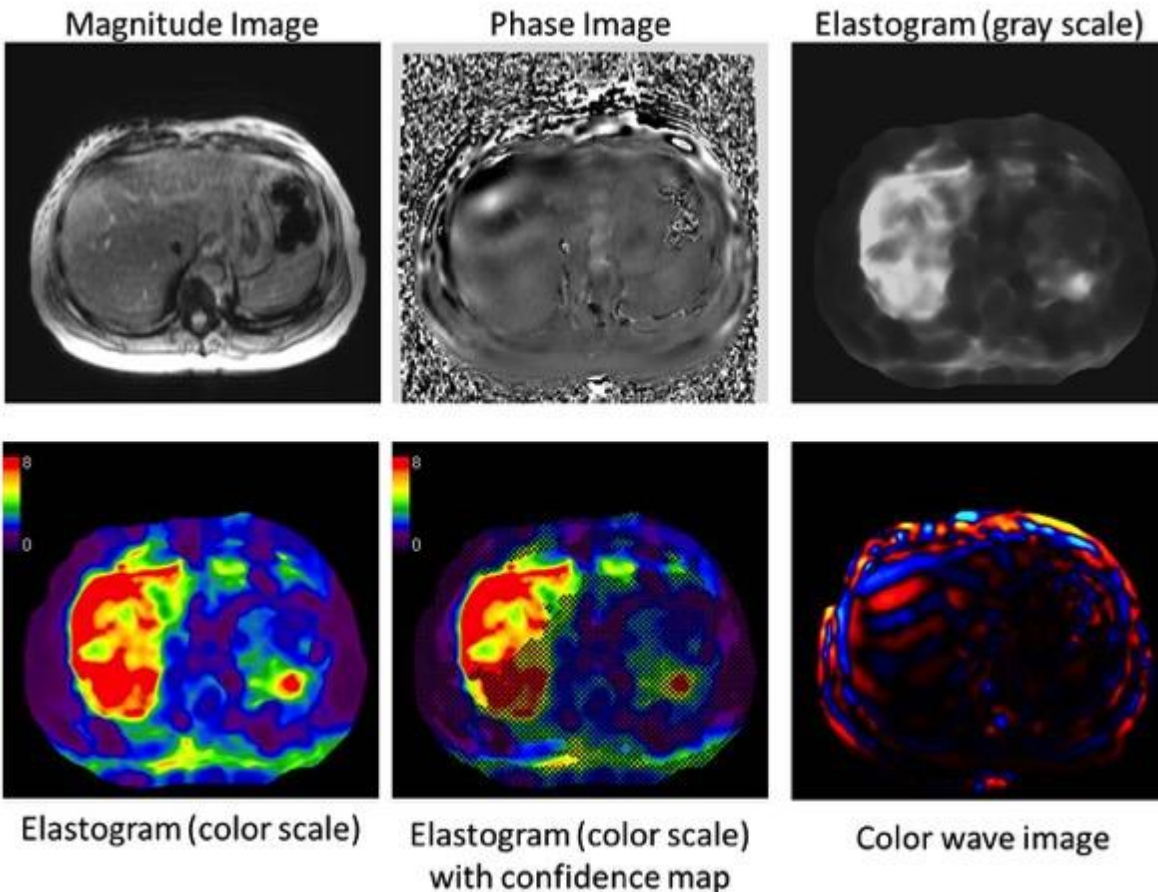
#### 3.7.1 DISCUSSION

Post-processing of the acquired magnitude and phase (wave) images is performed to create quantitative maps of liver stiffness, or elastograms. This post-processing technique is standardized across vendors.

195 **3.7.2 SPECIFICATION**

Parameter	Actor	Requirement
Image Reconstruction	Technologist	Shall confirm that the following images have been generated: quantitative stiffness maps (grayscale), confidence maps, and unwrapped wave images. (Figure 8)

1. Quantitative stiffness maps (elastograms), depicting the magnitude of the complex shear modulus in a gray or color scale. The most appropriate default scale is 0-8 kPa.
2. Confidence maps: quantitative elastograms in which areas where the estimated stiffness values have reduced reliability due to low wave amplitude are indicated with cross-hatching or other means.
3. Unwrapped wave images, providing a clear depiction of the observed waves. Phase wrapping occurs when the shear wave motion is large. Since MRE is a phase-based technique, the displacement data typically must be unwrapped before subsequent processing is performed.



**Figure 8:** Representation of images generated in an MRE study. Additional post-processed images may be available depending on the software version installed on the scanner.

### 3.8. Image QA

- 210 The quantitative elastograms of successful exams should demonstrate areas of valid stiffness data within the liver in the confidence maps (see Figures 3 to 8 as representative examples of a successful and failed MRE studies).

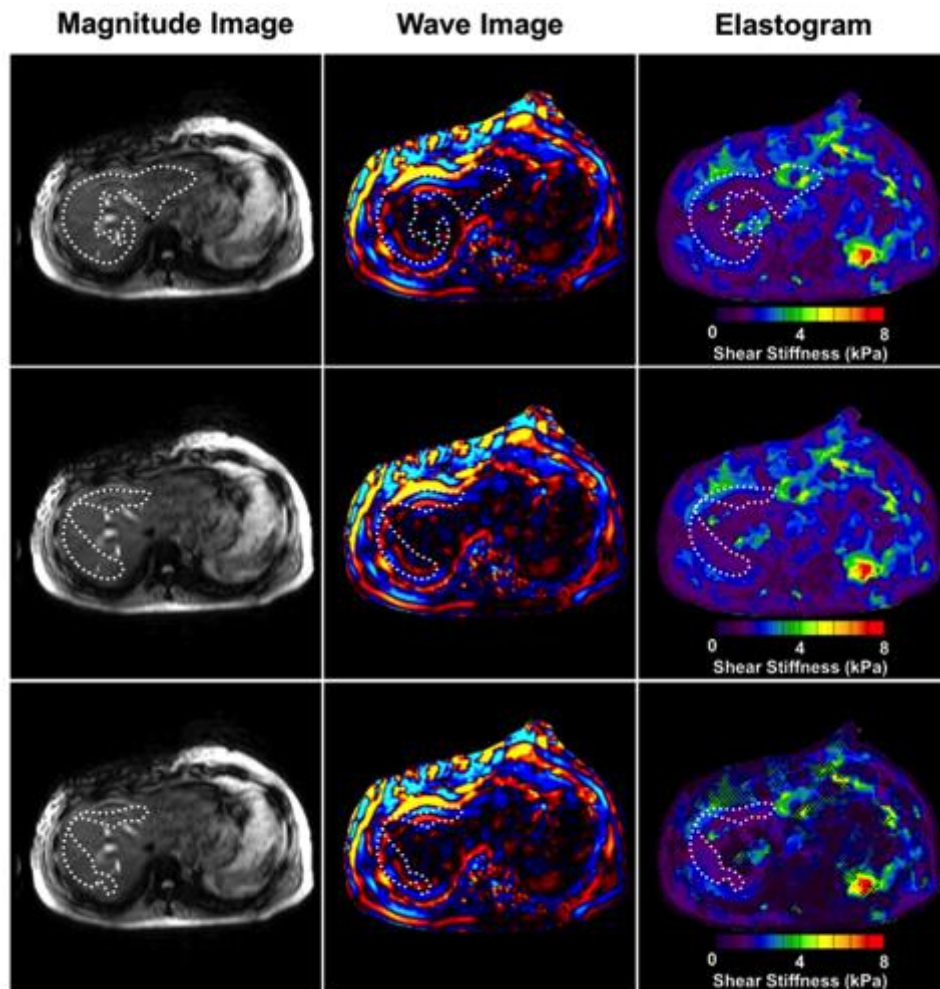
Parameter	Actor	Requirement
Image QA	Radiologist	Shall check the suitability of the data by confirming the presence of signal loss in subcutaneous fat under the driver in the magnitude images, and the presence of visible waves in the liver in the phase and wave images (Figure 3).

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### 3.10. Image Analysis

Parameter	Actor	Requirement
Mean shear stiffness of the liver	Radiologist	Shall reference the magnitude image to draw ROIs in the largest possible area of liver parenchyma, staying ~1 cm inside the liver boundary, avoiding the area directly underneath the passive driver, and excluding major blood vessels seen on the MRE magnitude images. (Figure 9)
	Radiologist	Shall use the phase or wave images to avoid areas of incoherent waves (due to wave interference from waves propagating through the region from different directions or due to other disruptions to the wave field such as those caused by adjacent blood vessels, fissures, and other organs) (Figure 9)
	Radiologist	Shall place ROIs in individual slices and in the right lobe whenever possible. (Figure 9)
	Radiologist	Shall exclude areas of low confidence, as seen by the checkerboard pattern in the masked elastogram images (Figure 9).
	Radiologist	Shall calculate mean shear stiffness of the liver using manually specified regions of interest (ROIs) containing a minimum of 500 pixels for an acquisition with a 420 mm FOV and reconstruction matrix of 256x256 total, corresponding to approximately 12.8 cm <sup>3</sup> [17,3,18].
	Radiologist	Shall reject the elastography if the acquisition failed due to hepatic iron

Parameter	Actor	Requirement
		overload, colonic interposition, or other cause of inadequate waves and the scan repeated. (Figure 5, 7)



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**Figure 9:** Regions of interest (ROIs) should be drawn with reference to the magnitude, wave, and elastogram images. The ROI should be within the contour of the liver, excluding areas near the margins and major vessels (top row). The ROI should be modified to exclude areas with low wave amplitude as well as incoherent waves (due to wave interference from waves propagating through the region from different directions or due to other disruptions to the wave field such as those caused by adjacent blood vessels, fissures, and other organs), as observed in the wave images (middle row). The ROI should also exclude areas of low confidence, as seen by the checkerboard pattern in the masked elastogram images (lower row). In practice, the ROIs may be drawn in a single step, keeping these principles in mind. Generally the ROI should be confined to the right lobe of the liver.

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### 3.11. Image Interpretation

Parameter	Actor	Requirement
Liver stiffness	Radiologist	Shall report overall mean stiffness by calculating the mean stiffness value of each ROI and then reporting the mean value across all slices.

Example: Slice 1: mean liver stiffness = 2.32 kPa ; Slice 2: mean liver stiffness = 2.25 kPa; Slice 3: mean liver stiffness = 2.52 kPa; and Slice 4: mean liver stiffness = 2.22 kPa; then the overall mean =  $(2.32+2.25+2.52 + 2.22)/(4) = 2.33$  kPa.

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## 4. Assessment Procedures

To conform to this Profile, participating staff (“Actors”) and equipment shall support each activity assigned to them in Table 1.

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To support an activity, the actor shall conform to the requirements (indicated by “shall language”) listed in the specifications table of the activity subsection in Section 3.

Although most of the requirements described in Section 3 can be assessed for conformance by direct observation, some of the performance-oriented requirements cannot, in which case the requirement will reference an assessment procedure in a subsection here in Section 4.

245

Formal claims of conformance by the organization responsible for an Actor shall be in the form of a published QIBA Conformance Statement. Vendors publishing a QIBA Conformance Statement shall provide a set of “Model-specific Parameters” (as shown in Appendix D) describing how their product was configured to achieve conformance. Vendors shall also provide access or describe the characteristics of the test set used for conformance testing.

### 4.1. Assessment Procedure: Liver Stiffness Repeatability

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This procedure can be used by a vendor or an imaging site to assess the repeatability of liver stiffness measurements using MRE. Repeatability is assessed in terms of a percent Repeatability Coefficient (RC) which is based on the within-subject coefficient of variation (wCV) during a test-retest study.

The test-retest repeatability study may be performed in a group of healthy volunteer subjects.

The Assessor shall:

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- Image each subject twice on the same day (and additionally, image some subjects a third time within one week).
- Use the same scanner, driver hardware, parameters, and software
- Follow the guidelines outlined in Section 3.5 for subject preparation and positioning.
- Ask subjects to stand following the liver MRE acquisition and reposition them for the second MRE exam.
- Perform a third MRE exam within 7 days.
- Reconstruct and analyze the data as described in Section 3.7 and 3.10 respectively.

260



Let  $Y_{i1}$  denote the liver stiffness measurement for the  $i$ -th subject from the first scan,  $Y_{i2}$  denote the liver stiffness measurement from the second scan, and, as available,  $Y_{i3}$  denote the liver stiffness measurement from the third scan. For each subject, calculate the mean of the  $J$  measurements (where  $J=2$  or  $3$ ) and the  $wSD$ :

$$\bar{Y}_i = \sum(Y_{ij})/J \text{ and } wSD_i^2 = \sum(Y_{ij} - \bar{Y}_i)^2 / (J - 1).$$

Then estimate the  $wCV$  for the  $N$  subjects:

$$wCV = \sqrt{\sum_{i=1}^N (wSD_i^2 / \bar{Y}_i^2) / N}.$$

The percent repeatability coefficient is then calculated as:  $\%RC = 1.96 \times \sqrt{2 \times \%wCV^2}$ .

275

To demonstrate conformance with the profile claim, this estimated  $\%RC$  from the test-retest study must be  $\leq 19\%$ .

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## Appendices

### 330 Appendix A: Acknowledgements and Attributions

This document is proffered by the Radiological Society of North America (RSNA) Quantitative Imaging Biomarker Alliance (QIBA) MR Elastography Biomarker Committee. The MR Elastography Biomarker Committee is composed of physicians, scientists, engineers and statisticians representing academic institutions, professional societies, developers, imaging device manufacturers, biopharmaceutical companies, government research organizations and regulatory agencies that utilize MRE.

335

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Gudrun Zahlmann, PhD	Independent Consultant

## Appendix B: Background Information

340 A number of publications report the repeatability of liver stiffness measurements with MRE. Ten articles were included based on fulfillment of four or more categories of the QUADAS-2 tool (Quality Assessment of Diagnostic Accuracy Studies). For the purpose of this profile, 10 studies were included in the RC calculation of RC=18.4% with 95% CI of [14.2, 22.2]. Table 1 lists the publications used for the determination of the claim.

345 **Table 1: Selected repeatability parameters extracted from literature publications.**

Publication	Sample Size	Field Strength (T)	Freq (Hz)	Time Interval	CV Reported (%)	RC (%)	RC 95% CI

Wang 2011 [1]	5	1.5	60	2 weeks	9-12	23	14.3, 56.4
Venkatesh 2014 [2]	41	1.5	60	4-6 weeks	8.4	18.8	13.5, 31.0
Shire 2011 [3]	9	1.5	60	1-2 weeks	6-11	17	12.2, 28.0
Shinagawa 2014 [4]	10	3.0	60	1 week	NA	10	7.0, 17.5
Shin 2014 [5]	15	1.5	60	2 weeks	NA	14	10.3, 21.7
Shi 2014 [6]	22	3.0	60	1 week	5.75	15.9	12.7, 21.4
Lee 2014 [7]	47	1.5	60	8-10 mins	13	25.3	21.0, 31.7
Jajamovich 2014 [8]	30	3.0	60	20 mins	3.8	10.5	8.6, 13.4
Bohte 2013 [9]	30	3.0	50	1-4 weeks	10.1	22.2	17.7, 29.7
Trout 2016 [10]	24	1.5, 3.0	60	same day	10.7	16.6	13.3, 23.1

Note, CV = coefficient of variation, NA = not applicable, RC = repeatability coefficient, CI = confidence interval. All publications reported values for the complex shear modulus ( $G^*$ ).

### References for Appendix B

- 350 [1] Wang Y, Ganger DR, Levitsky J, et al. Assessment of chronic hepatitis and fibrosis: comparison of MR elastography and diffusion-weighted imaging. *AJR Am J Roentgenol* 2011; 196(3):553-561.
- [2] Venkatesh SK, Wang G, Teo LL, Ang BW. Magnetic resonance elastography of liver in healthy Asians: normal liver stiffness quantification and reproducibility assessment. *J Magn Reson Imaging* 2014; 39(1):1-8.
- 355 [3] Shire NJ, Yin M, Chen J, et al. Test-retest repeatability of MR elastography for noninvasive liver fibrosis assessment in hepatitis C. *J Magn Reson Imaging* 2011; 34(4):947-955.
- [4] Shinagawa Y, Mitsufuji T, Morimoto S, et al. Optimization of scanning parameters for MR elastography at 3.0 T clinical unit: volunteer study. *Jpn J Radiol* 2014; 32(7):441-446.
- [5] Shin SU, Lee JM, Yu MH, et al. Prediction of esophageal varices in patients with cirrhosis: usefulness of three-dimensional MR elastography with echo-planar imaging technique. *Radiology* 2014; 360 272(1):143-153.
- [6] Shi Y, Guo Q, Xia F, Sun J, Gao Y. Short- and midterm repeatability of magnetic resonance elastography in healthy volunteers at 3.0 T. *Magn Reson Imaging* 2014; 32(6):665-670.
- 365 [7] Lee YJ, Lee JM, Lee JE, et al. MR elastography for noninvasive assessment of hepatic fibrosis: reproducibility of the examination and reproducibility and repeatability of the liver stiffness value measurement. *J Magn Reson Imaging* 2014; 39(2):326-331.

- [8] Jajamovich GII, Dyvorne II, Donnerhack C, Taouli B. Quantitative liver MRI combining phase contrast imaging, elastography, and DWI: assessment of reproducibility and postprandial effect at 3.0 T. PLoS One 2014; 9(5):e97355.
- [9] Bohte AE, Garteiser P, De Niet A, et al. MR elastography of the liver: defining thresholds for detecting viscoelastic changes. Radiology 2013;269(3):768-776.
- [10] Trout AT, Serai S, Mahley AD, et al. Liver stiffness measurements with MR elastography: agreement and repeatability across imaging systems, field strengths, and pulse sequences. Radiology 2016; 281(3):793-804.

## Appendix C: Conventions and Definitions

### *Definitions/Abbreviations*

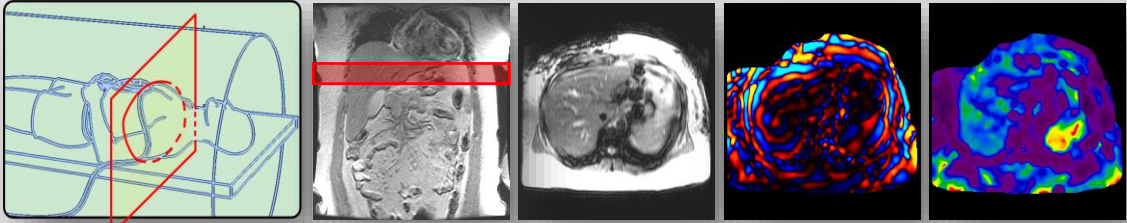
- DMA: dynamic mechanical analyzer
- CLD: chronic liver disease
- CT: computed tomography
- MRE: magnetic resonance elastography
- MRI: magnetic resonance imaging
- PET: positron emission tomography
- QA: quality assurance
- QIBA: Quantitative Imaging Biomarkers Alliance
- RC: repeatability coefficient
- ROI: region of interest
- RSNA: Radiological Society of North America
- wCV: within-subject coefficient of variation
- wSD: within-subject standard deviation

## Appendix D: Detailed MRE Protocols

For acquisition modalities, reconstruction software and software analysis tools, profile conformance requires meeting the activity specifications above in Sections 2, 3, and 4.

This Appendix provides, as an informative tool, some specific acquisition parameters, reconstruction parameters and analysis software parameters that are expected to be compatible with meeting the profile requirements.

### GE 1.5T - Hepatic MRE Protocols - June 2020

<b>Scanners and Sequences</b>	Scanner	Artist, Creator, Explorer, HDx, Optima MR450w, Voyager		
	Software versions	HD16 and ≥DV22.1	HD16 and ≥DV22.1	≥DV22.1
	Pulse sequence	<b>fgremre (Resoundant-GE)</b>	<b>epimre (Resoundant-GE)</b>	<b>MR-Touch (GRE)</b>
	Mode	2D, zoom gradient	2D, zoom gradient	2D
	Options	Fast, ASSET, MultiPhase	FC, ASSET, MultiPhase	Fast, ASSET, MultiPhase
<b>Patient Cooperation</b>	<p>(1) Patients shall fast at least 4hours prior to the exams                  (2) Patients hold their breath at the end of expiration during all MRE scans, as well as during the scout scans and parallel imaging calibration scans.                  (3) Make sure the elastic belt is tightly secured on the driver and the patient for optimized energy transfer, while patient can breathe comfortably. For patients with thick subcutaneous fat, this is very important.</p>			
<b>Slice Positioning</b>	 <p style="text-align: center;">Place 4 axial slices at the largest portion of the liver in coronal view avoiding the heart, the liver dome and the liver bottom tip.</p>			
<b>Patient Information Input</b>	Position	feet-first, supine	feet-first, supine	feet-first, supine
	Weight	Actual Weight	Actual Weight	Actual Weight
	Height			
<b>Coil (note 1)</b>	Coil	Torso	Torso	Torso
<b>Imaging Parameters</b>	Imaging Plane	Axial	Axial	Axial
	No. of slices	4	4	4

**GE 1.5T - Hepatic MRE Protocols - June 2020**

Slice thickness (mm)/gap	10 mm / 0 mm	8 mm / 2 mm	10 mm / 0 mm
FOV (mm) / Phase FOV (100%)	420(required)x420(or less) (note 4)	420(required)x(420 or less) (note 4)	420(required) x 420 (or less) (note 4)
Matrix	256 x 64	80 x 80	256 x 64
TE (msec)	in-phase TE (about 18.2)	min full (around 55.4) (note 1)	min TE (type a value close to 18.2 if possible)
TR (msec)	50	1000	50
Flip Angle (degree)	25	default (90)	25
NEX, EPI shots	1	1, 1shot	1
Bandwidth (kHz)	31.25	250 (hard coded)	31.25
Freq Encoding Dir	right - left	right - left	right - left
Phases per Location	4	3	
Phase Acq. Order	Interleaved	Interleaved	
Delay After Acq.	Minimum	Minimum	
Acceleration	ASSET (Note 1)	ASSET (Note 1)	ASSET (Note 1)
Acceleration factor	2	2	2
No. of breath holds	4 (note 2)	1	4 (note 2)
Shimming Volume	Cover the whole body	Cover the whole body	Cover the whole body
Spectrum Peaks	Water Peak	Water Peak	Water Peak
Saturation Band	SI	SI	SI



<b>GE 1.5T - Hepatic MRE Protocols - June 2020</b>				
	scan time	55 s (note 2)	11 sec	55 sec (note 2)
<b>Driver Parameters (Generic) (note 5)</b>	Driver Power (%)	50	50	50
	Driver frequency (Hz)	60	60	60
	Driver cycles/ trigger (Duration)	3 (auto-calculated)	Auto-calculated	Auto-calculated
<b>Motion Encoding Gradients (Generic) (note 5)</b>	MEG frequency (Hz) (or Period Mismatch)	75 Hz (0.8)	80	75
	MENC (1/motion sensitivity)	~30 $\mu\text{m}$ / ( $\pi$ radian) (note 3)	~30 $\mu\text{m}$ / ( $\pi$ radian) (note 3)	~30 $\mu\text{m}$ / ( $\pi$ radian)
	Axis of MEG	4 (Z)	4 (Z)	4 (Z)
<b>User CV or Advanced Table (Specific: epimre - DV16 and DV24) (note 5)</b>	CV0 -Ramp Sampling (1=on, 0=off)		1	
	CV5 -Scale for RF2 Crusher Area		1	
	CV6 -Split MEG (0=L, 1/2/3 = L-R in/half/min)		2	
	CV7 -Flow Comp. Type for MEG		0	
	CV8 -Driver Frequency Percent Increase		0	
	CV9 -Time from Start of MEG1 to MEG2 (-1 = opt, 0=min)		0	
	CV10 -Number of Gradient Pairs		1	
	CV11 -Soft-start Ramp-up Time (sec)		0	
	CV12 -Fraction of Max Gradient Amplitude		1	
	CV13 -Desired MEG Frequency (Hz)		80	
	CV14 -Driver Amp. % (-1 = not V3)		50	

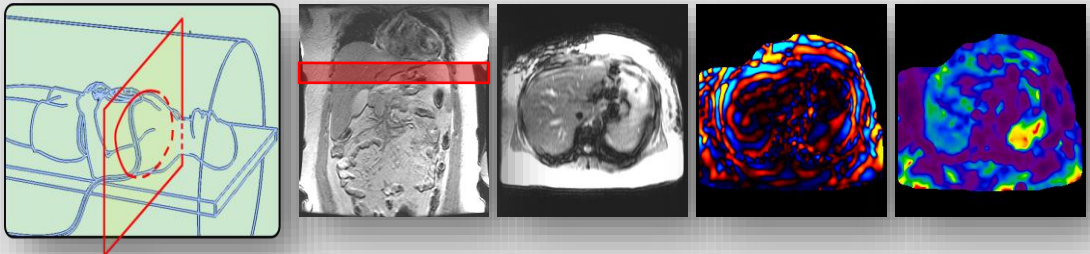
<b>GE 1.5T - Hepatic MRE Protocols - June 2020</b>				
	CV15 -Recon (Def-1912;3D ver =1914;Brain=1915;2D MMDI = 1916)		1916	
	CV16 -Trigger Loc # of Cycles Pre-MEG		4	
	CV17 -MEG Direction (F/P/S=1/2/4, Tetra=8)		4	
	CV18 -Vibration Mode (0=Burst, 1 or 2 = Contin.)		1	
	CV19 - MENC (um per radians)		Don't edit	
	CV20 -# of Motion Periods for Offsets		1	
	CV21 -Frequency of Applied Motion (Hz)		60	
	CV23 -Burst Mode Burst Count		1	
	CV24 -Do High-Resolution Recon.?		1	
<b>User CV (Specific: fgremre - DV16) (note 5)</b>	CV 12 -use version3 driver	1		
	CV 13 -Motion Encoding Gradient (MEG) pairs	1		
	CV 14 Motion Frequency - Hz	60		
	CV 15 Scale Max Gradient Amplitude	0.75		
	CV 17 freq=1, phase=2, slice=4	4		
	CV 21 period mismatch	0.8		
	CV 24 driver amplitude	50		
<b>MR-Touch Tab</b>	Temporal Phases	4		

## GE 1.5T - Hepatic MRE Protocols - June 2020

<b>(Specific fgremre-DV22.1, DV24) (note 5)</b>	MEG Frequency (Hz)	75		
	Driver Amplitude (%) (note 6)	50		
	Driver Cycle Per Trigger	3		
	MEG Direction	4 (Z)		
<b>Advanced Tab (Specific fgremre-DV22.1, DV24) (note 5)</b>	CV12 use Resoundant	1.00		
<b>MR-Touch Tab (Specific MR-Touch sequence - DV22.1, DV24) (note 5)</b>	Temporal Phases			4
	MEG Frequency (Hz)			75
	Driver Amplitude (%) (note 6)			50
	Driver Cycle Per Trigger			3
	MEG Direction			4 (Z)

NOTE: (1) Use the body coil instead of the torso if the patient cannot fit into the bore with the torso coil; if the body coil is used then the ASSET is turned off automatically, increasing the scan time (gre) or TE (epi). (2) For GREMRE, scan time can vary depending on the FOV (in phase dir) - decreasing the phase FOV can slightly decrease the scan time and breath-hold time. (3) Depending on your gradient hardware performance, the absolute gradient strength could be different. (4) FOV is recommended to be a fixed value (420 mm) for consistency, even for small patients; **if a different FOV is prescribed for a study, it is recommended that the same FOV is applied to every patient and every time point.** (5) The specific tab and parameters can be different for different software versions and MRE sequences; the generic MRE parameters for driver and motion encoding gradients are the guideline to those specific tab and parameters (MRE-related); overall, this recommendation is conservative so that it can be successfully performed at all software versions and scanners. (6) Driver Frequency is 60Hz (default).

### GE 3T - Hepatic MRE Protocols - June 2020

<b>Scanners and Sequences</b>	Scanner	Architect, Discovery MR750w, PET/MR, Pioneer, Premier		
	Software versions	HD16 and ≥DV22.1	HD16 and ≥DV22.1	≥DV22.1
	Pulse sequence	<b>fgremre (Resoundant-GE)</b>	<b>epimre (Resoundant-GE)</b>	<b>MR-Touch (EPI)</b>
	Mode	2D, zoom gradient	2D, zoom gradient	2D
	Options	Fast, ASSET, MultiPhase	FC, ASSET, MultiPhase	FC, ASSET, MultiPhase
<b>Patient Cooperation</b>	<p>(1) Patients shall fast at least 4 hours prior to the exams</p> <p>(2) Patients hold their breath at the end of expiration during all MRE scans, as well as during the scout scans and parallel imaging calibration scans.</p> <p>(3) Make sure the elastic belt is tightly secured on the driver and the patient for optimized energy transfer, while patient can breathe comfortably. For patients with thick subcutaneous fat, this is very important.</p>			
<b>Slice Positioning</b>	 <p>Place 4 axial slices at the largest portion of the liver in coronal view, and avoid the heart, the liver dome and the liver bottom tip.</p>			
<b>Patient Information Input</b>	Position	feet-first, supine	feet-first, supine	feet-first, supine
	Weight	Actual Weight	Actual Weight	Actual Weight
	Height			
<b>Coil (note 1)</b>	Coil	Torso	Torso	Torso
<b>Imaging Parameters</b>	Imaging Plane	Axial	Axial	Axial
	No. of slices	4	4	4
	Slice thickness (mm)/gap	10 mm / 0 mm	8 mm / 2 mm	8 mm / 2 mm

**GE 3T - Hepatic MRE Protocols - June 2020**

FOV (mm) / Phase FOV (100%)	420(required)x420( or less) (note 4)	420(required)x420( or less) (note 4)	420(required)x420( or less) (note 4)
Matrix	256 x 64	96 x 96	96 x 96
TE (msec)	min full (around 15.9, this is close to in-phase TE)	min full( around 55.4) (note 1)	min full( around 55.4) (note 1)
TR (msec)	50	1000	1000
Flip Angle (degree)	20	default (90)	default (90)
NEX, EPI shots	1	1, 1shot	1, 1shot
Bandwidth (kHz)	31.25	250 (hard coded)	250 (hard coded)
Freq Encoding Dir	right - left	right - left	right - left
Phases per Location	4	3	
Phase Acq. Order	Interleaved	Interleaved	
Delay After Acq.	Minimum	Minimum	
Acceleration	ASSET (Note 1)	ASSET (Note 1)	ASSET (Note 1)
Acceleration factor	2	2	2
No. of breath holds	4 (note 2)	1	1
Shimming Volume	Cover the whole body	Cover the whole body	Cover the whole body
Spectrum Peaks	Water Peak	Water Peak	Water Peak
Saturation Band	SI	SI	SI
scan time (note 7)	about 55 s (note 2)	about 11 sec	about 16 sec

<b>GE 3T - Hepatic MRE Protocols - June 2020</b>				
<b>Driver Parameters (Generic) (note 5)</b>	Driver Power (%)		50	50
	Driver frequency (Hz)	60	60	60
	Driver cycles/trigger (Duration)	3 (auto-calculated)	Auto-calculated	Auto-calculated
<b>Motion Encoding Gradients (Generic) (note 5)</b>	MEG frequency (Hz) (or Period Mismatch)	80 Hz (0.75)	80	80
	<b>MENC (1/motion sensitivity)</b>	~30 $\mu\text{m}/(\pi \text{ radian})$ (note 3)	~30 $\mu\text{m}/(\pi \text{ radian})$ (note 3)	~30 $\mu\text{m}/(\pi \text{ radian})$ (note 3)
	Axis of MEG	4 (Z)	4 (Z)	4 (Z)
<b>User CV or Advanced Table (Specific: epimre - HD16 and <math>\geq</math>DV24) (note 5)</b>	CV0 -Ramp Sampling (1=on, 0=off)		1	
	CV5 -Scale for RF2 Crusher Area		1	
	CV6 -Split MEG (0=L, 1/2/3 = L-R in/half/min)		2	
	CV7 -Flow Comp. Type for MEG		0	
	CV8 -Driver Frequency Percent Increase		0.5	
	CV9 -Time from Start of MEG1 to MEG2 (-1 = opt, 0=min)		0	
	CV10 -Number of Gradient Pairs		1	
	CV11 -Soft-start Ramp-up Time (sec)		0	
	CV12 -Fraction of Max Gradient Amplitude		1	
	CV13 -Desired MEG Frequency (Hz)		80	
	CV14 -Driver Amp. % (-1 = not V3)		50	

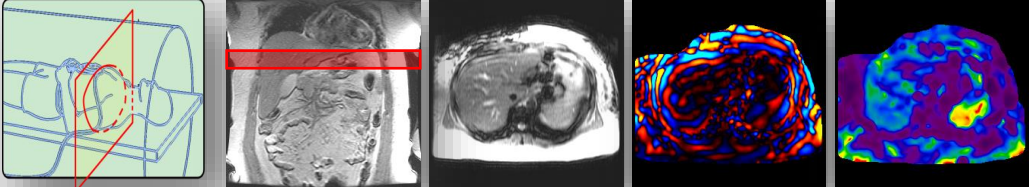
<b>GE 3T - Hepatic MRE Protocols - June 2020</b>				
	CV15 -Recon (Def-1912;3D ver =1914;Brain=1915; 2D MMDI = 1916)		1916	
	CV16 -Trigger Loc # of Cycles Pre-MEG		4	
	CV17 -MEG Direction (F/P/S=1/2/4, Tetra=8)		4	
	CV18 -Vibration Mode (0=Burst, 1 or 2 = Contin.)		1	
	CV19 - MENC (um per radians)		Don't edit	
	CV20 -# of Motion Periods for Offsets		1	
	CV21 -Frequency of Applied Motion (Hz)		60	
	CV23 -Burst Mode Burst Count		1	
	CV24 -Do High-Resolution Recon.?		1	
<b>User CV (Specific: fgremre - HD16) (note 5)</b>	CV 12 -use version3 driver	1		
	CV 13 -Motion Encoding Gradient (MEG) pairs	1		
	CV 14 Motion Frequency - Hz	60		
	CV 15 Scale Max Gradient Amplitude	0.75		
	CV 17 freq=1, phase=2, slice=4	4		
	CV 21 period mismatch	0.75		
	CV 24 driver amplitude	50		
<b>MR-Touch Tab</b>	Temporal Phases	4		

<b>GE 3T - Hepatic MRE Protocols - June 2020</b>				
<b>(Specific fgremre- ≥DV22.1)(note 5)</b>	MEG Frequency (Hz)	80		
	Driver Amplitude (%) (note 6)	50		
	Driver Cycle Per Trigger	3		
	MEG Direction	4 (Z)		
<b>Advanced Tab (Specific fgremre- ≥DV22.1) (note 5)</b>	CV12 use Resoundant	1.00		
<b>MR-Touch Tab (Specific MR-Touch sequence - ≥DV22.1) (note 5)</b>	Temporal Phases			4
	MEG Frequency (Hz)			90
	Driver frequency (Hz)			60
	Driver Amplitude (%)			50
	MEG Direction			Z
	Driver Cycle Per Trigger			15 (Not for edit)
	MENC um/rad			28.5 (Not for edit)

NOTE: (1) Use body coil instead of torso if patients cannot fit into the bore with the torso coil; if body coil is used then the ASSET is turned off automatically, scan time is longer (gre) or TE is longer (epi). (2) For GREMRE, scan time can vary depending on the FOV (in phase dir) setup - decreasing phase FOV can slightly decrease scan time and breath-hold time. (3) Depending on your gradient hardware performance, the absolute gradient strength could be different. (4) FOV is recommended to be a fixed value (420 mm), even for small patients for consistency; **if a different FOV is determined for a study, it is recommended the same FOV is applied to every patient and every time point.** (5) The specific tab and parameters can be different for different software versions and MRE sequences; the generic MRE parameters for driver and motion encoding gradients are the guideline to those specific tab and parameters (MRE-related); overall, this recommendation is conservative so that it can be successfully performed at all software versions and scanners. (6) Driver Frequency is 60Hz (default). (7) scan time can be slightly different for different scanners



## Siemens 1.5T - Hepatic MRE Protocols - June 2020

<b>Scanners and Sequences</b>	Scanner	MAGNETOM Tim 3G or Tim 4G	
	Software versions	N4 VE11C SP01 and above	
	Pulse sequence	<b>greMRE</b>	<b>epseMRE (WIP)</b>
	Mode	2D	2D
<b>Patient Cooperation</b>	<p>(1) Patients shall fast at least 4 hours prior to the exams</p> <p>(2) Patients hold their breath at the end of expiration during all MRE scans, as well as during the scout scans and parallel imaging calibration scans.</p> <p>(3) Make sure the elastic belt is tightly secured on the driver and the patient for optimized energy transfer, while patient can breathe comfortably. For patients with thick subcutaneous fat, this is very important.</p>		
<b>Slice Positioning</b>	 <p>Place 4 axial slices at the largest portion of the liver in coronal view, and avoid the heart, the liver dome and the liver bottom tip.</p>		
<b>Patient Information Input</b>	Position	head-first, supine	head-first, supine
	Weight	Actual Weight	Actual Weight
	Height	Actual Height	Actual Height
<b>Coil (note 1)</b>	Coil	Torso	Torso
<b>Imaging Parameters</b>	Imaging Plane	Axial	Axial
	No. of slices	4	4
	Slice thickness (mm)/dist. Factor	10 mm / 0% (0)	8 mm / 25% (2mm)
	FOV (mm) / Phase FOV (100%)	420/1 (note 4)	420/1 (note 4)

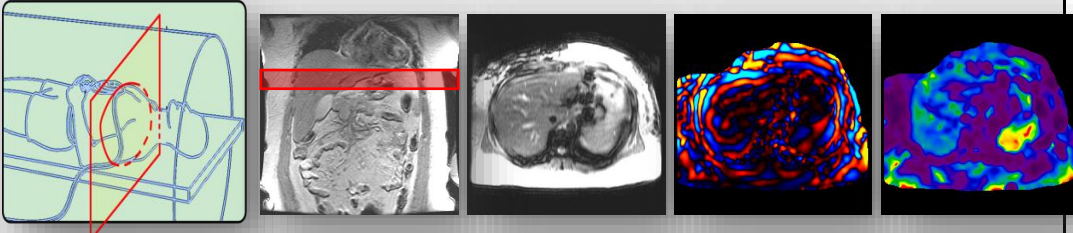
## Siemens 1.5T - Hepatic MRE Protocols - June 2020

	Matrix (Base x Phase)	256 x 25% (64)	98 x 100% (128)
	TE (msec)	min (about ~20 with flow comp off)	min (about 40 with flow comp on)
	TR (msec)	50	1000
	Flip Angle (degree)	20	default (90)
	NEX, EPI shots	1	1, 1shot
	Bandwidth (Hz/Pixel)	260 Hz/pixel	2000 Hz/pixel
	Phase enc.dir.	Anterior-Posterior	Anterior-Posterior
	Acceleration	GRAPPA (note 1)	GRAPPA (note 1)
	Acceleration factor	2	2
	No. of breath holds	4 (each 17sec) (note 2)	1 (each 11 sec)
	Shimming Volume	auto	auto
	Spectrum Peaks	Water Peak	Water Peak
	Saturation Band	SI	SI
	Fat Suppression		SPAIR
	Fat Sat. mode		Strong
	scan time	4 x 17 sec	11 sec
<b>Driver Parameters (Generic) (note 5)</b>	Driver Power (%)	50 (default) (note 6)	50 (default) (note 6)
	Driver frequency (Hz)	60 (default) (note 6)	60 (default) (note 6)

## Siemens 1.5T - Hepatic MRE Protocols - June 2020

	Driver cycles/ trigger (Duration)	3 (default) (note 6)	3 (default) (note 6)
<b>Motion Encoding Gradients (Generic) (note 5)</b>	MEG fractional encoding	85%	80%
	MEG frequency (Hz)	60 Hz (Hard Coded)	60 Hz (Hard Coded)
	MEG Amplitude	(Hard coded)	30 mT/m (Hard coded)
	Axis of MEG	Slice (Hard Coded)	Slice
	Number of phase	4 (Hard coded)	3
<b>Specific Parameters (note 5)</b>	Sequence - Part 1 - Flow Comp	NO	YES
	Sequence - Special - MEG Amplitude (mT/m)	Not available	30
	Sequence - Special - MEG Frequency (mT/m)	Not available	60.0
	Sequence - Special - MEG Waveform	Not available	1-2-1
	Sequence - Special - MEG Direction	Not available	Slice
	System - Tx/Rx - Img. Scale Cor.	2	2
	Resolution - Filter Image - Prescan Normalize	Check	Check

NOTE: (1) Use body coil instead of torso if patients cannot fit into the bore with the torso coil; if body coil is used then the ASSET is turned off automatically, scan time is longer. (2) For GREMRE, scan time can vary depending on the FOV (in phase dir) setup - decreasing phase FOV can slightly decrease scan time and breath-hold time. (3) Depending on your gradient hardware performance, the absolute gradient strength could be different. (4) FOV is recommended to be a fixed value (420 mm), even for small patients for consistency; **if a different FOV is determined for a study, it is recommended the same FOV is applied to every patient and every time point.** (5) The specific tab and parameters can be different for different software versions and MRE sequences; the generic MRE parameters for driver and motion encoding gradients are the guideline to those specific tab and parameters (MRE-related); overall, this recommendation is conservative so that it can be successfully performed at all software versions and scanners. (6) The current implementation of Siemens MRE does not access the active driver, those values are default values and can be changed by using a separate web connection to the active driver (Syngo or Laptop); epseMRE sequences delivers one trigger every 50ms.

<b>Siemens 3T - Hepatic MRE Protocols - June 2020</b>			
<b>Scanners and Sequences</b>	Scanner	MAGNETOM Tim 3G or Tim 4G	
	Software versions	N4 VE11C SP01 and above	
	Pulse sequence	<b>greMRE</b>	<b>epseMRE</b>
	Mode	2D	2D
<b>Patient Cooperation</b>	<p>(1) Patients shall fast at least 4 hours prior to the exams</p> <p>(2) Patients hold their breath at the end of expiration during all MRE scans, as well as during the scout scans and parallel imaging calibration scans.</p> <p>(3) Make sure the elastic belt is tightly secured on the driver and the patient for optimized energy transfer, while patient can breathe comfortably. For patients with thick subcutaneous fat, this is very important.</p>		
<b>Slice Positioning</b>	 <p>Place 4 axial slices at the largest portion of the liver in coronal view, and avoid the heart, the liver dome and the liver bottom tip.</p>		
<b>Patient Information Input</b>	Position	head-first, supine	head-first, supine
	Weight	Actual Weight	Actual Weight
	Height	Actual Height	Actual Height
<b>Coil (note 1)</b>	Coil	Torso	Torso
<b>Imaging Parameters</b>	Imaging Plane	Axial	Axial
	No. of slices	4	4
	Slice thickness (mm)/dist. Factor	10 mm / 0% (0)	8 mm / 25% (2mm)

### Siemens 3T - Hepatic MRE Protocols - June 2020

	FOV (mm) / Phase FOV (100%)	420/1 (note 4)	420/1 (note 4)
	Matrix (Base x Phase)	256 x 25%(64)	98 x 100%(128)
	TE (msec)	min (about 20 with flow comp off)	min (about 40 with flow comp on)
	TR (msec)	50	1000
	Flip Angle (degree)	20	default (90)
	NEX, EPI shots	1	1, 1shot
	Bandwidth (Hz/Pixel)	260 Hz/pixel	2380 Hz/pixel
	Phase enc.dir.	Anterior-Posterior	Anterior-Posterior
	Acceleration	GRAPPA (note 1)	GRAPPA (note 1)
	Acceleration factor	2	2
	No. of breath holds	4 (each ~17sec) (note 2)	1 (each ~11 sec)
	Shimming Volume	auto	auto
	Spectrum Peaks	Water Peak	Water Peak
	Saturation Band	SI	SI
	scan time	4 x 17 sec	11 sec
<b>Driver Parameters (note 5&amp;6)</b>	Driver Power (%)	50 (default)	50 (default)
	Driver frequency (Hz)	60	60
	Sequence - Part 1 - Flow Comp	NO	YES

### Siemens 3T - Hepatic MRE Protocols - June 2020

<b>Specific Parameters (note 5)</b>	Sequence - Special - MEG Amplitude (mT/m)	Not available	30
	Sequence - Special - MEG Frequency (mT/m)	Not available	60.0
	Sequence - Special - MEG Waveform	Not available	1-2-1
	Sequence - Special - MEG Direction	Not available	Slice
	System - Tx/Rx - Img. Scale Cor.	2	2
	Resolution - Filter Image - Prescan Normalize	Check	Check

NOTE: (1) Use body coil instead of torso if patients cannot fit into the bore with the torso coil; if body coil is used then the ASSET is turned off automatically, scan time is longer. (2) For GREMRE, scan time can vary depending on the FOV (in phase dir) setup - decreasing phase FOV can slightly decrease scan time and breath-hold time. (3) Depending on your gradient hardware performance, the absolute gradient strength could be different. (4) FOV is recommended to be a fixed value (420 mm), even for small patients for consistency; if a different FOV is determined for a study, it is recommended the same FOV is applied to every patient and every time point. (5) The specific tab and parameters can be different for different software versions and MRE sequences; the generic MRE parameters for driver and motion encoding gradients are the guideline to those specific tab and parameters (MRE-related); overall, this recommendation is conservative so that it can be successfully performed at all software versions and scanners. (6) The current implementation of Siemens MRE does not access active driver, those values are default values and can be changed by using a separate web connection to the active driver (Syngo or Laptop); epseMRE sequences delivers one trigger every 50ms.

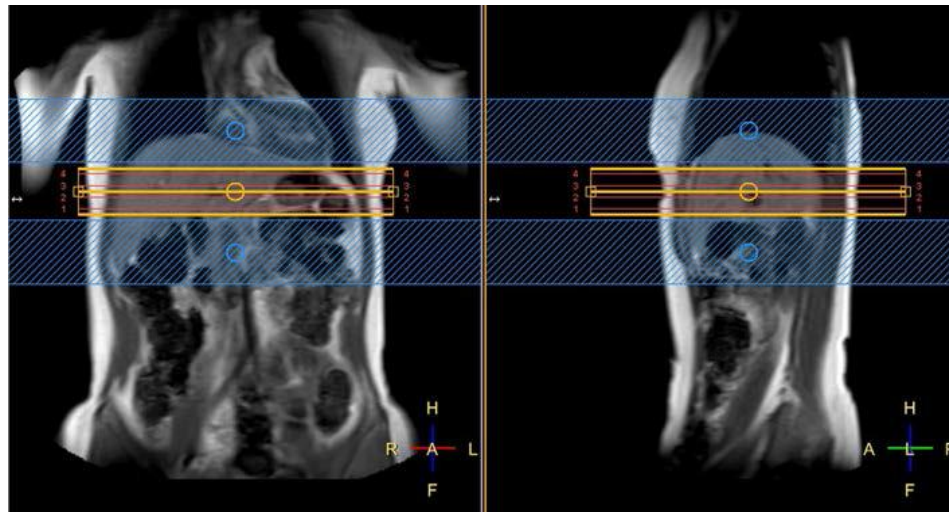
### Philips 1.5T - Hepatic MRE Protocols – June 2020

<b>Scanners and Sequences</b>	Scanner	Achieva, Ambition, Ingenia	
	Software versions	MR R5.1.7 SP2 (or later)	
	Pulse sequence	<b>FFE MRE</b>	<b>SE-EPI MRE</b>
	Mode	2D	2D
<b>Patient Cooperation</b>	(1) Patients shall fast at least 4 hours prior to the exams		

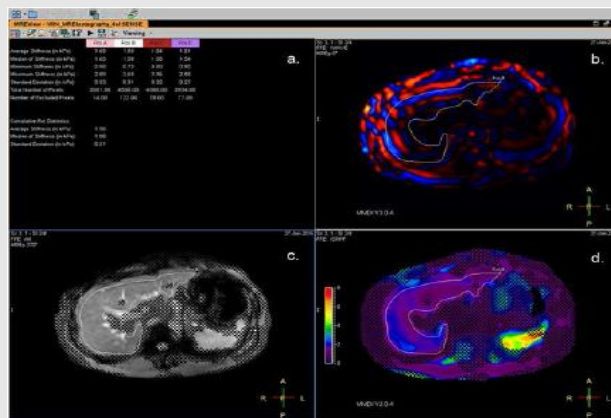
## Philips 1.5T - Hepatic MRE Protocols – June 2020

- (2) Patients hold their breath at the end of expiration during all MRE scans, as well as during the scout scans and parallel imaging calibration scans.
- (3) Make sure the elastic belt is tightly secured on the driver and the patient for optimized energy transfer, while patient can breathe comfortably. For patients with thick subcutaneous fat, this is very important.

**Slice Positioning**



Place 4 axial slices at the largest portion of the liver in coronal view, and avoid the heart, the liver dome and the liver bottom tip.



<b>Patient Information Input</b>	Position	head-first, supine	head-first, supine
	Weight	Actual Weight	Actual Weight
	Height		

## Philips 1.5T - Hepatic MRE Protocols – June 2020

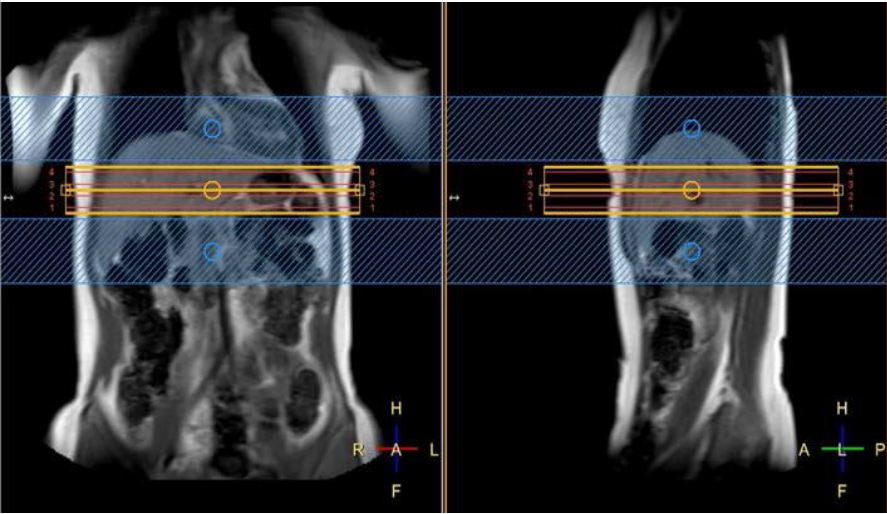
Coil	Coil	Torso	Torso
<b>Imaging Parameters</b>	Imaging Plane	Transverse	Transverse
	No. of slices	4	4
	Slice thickness (mm)/gap	10 mm / 1 mm	10 mm / 1 mm “default”
	FOV (mm) / Phase FOV (mm)	450(required)x403(or less) (Note 2)	400(required)x400(or less) (Note 2)
	Matrix	300 × 86	100 x 100
	TE (msec)	20 (“shortest”)	58 “shortest”
	TR (msec)	50	1000
	Flip Angle (degree)	20	90
	NSA, EPI shots	1	1, 1shot
	Bandwidth (Hz/Pixel)	~288 Hz/pixel	~2000 Hz/pixel
	Freq Encoding Dir	right - left	right - left
	Acceleration	SENSE	SENSE
	Acceleration factor	2	2
	No. of breath holds	4	1
	Shimming Volume	Auto	Auto
REST slabs	2 parallel	2 parallel	
scan time	71 s (~17 s breathholds) (note 1)	~13 s	
<b>Driver Parameters</b>	Driver Power	Moderate (50%)	Low (25%) (note 4)
	Driver frequency (Hz)	60	60



## Philips 1.5T - Hepatic MRE Protocols – June 2020

<b>Motion Encoding Gradients</b>	MEG frequency (Hz) (or Period Mismatch)	60 Hz (note3)	60 Hz (note3) (note 4)
	Axis of MEG	FH	FH
<b>Specific Parameters (To be specified)</b>	Patient experience scan	“yes”	“yes”
	Flow compensation	No	No
	Fat suppression	No	“SPAIR” Suppression level: strong

NOTE: (1) For FFE MRE, scan time can vary depending on the FOV (in phase dir) setup - decreasing phase FOV can slightly decrease scan time and breath-hold time. (2) FOV is recommended to be a fixed value (450 mm), even for small patients for consistency; if a different FOV is determined for a study, it is recommended the same FOV is applied to every patient and every time point. (3) In current sequences, MEG frequency is the same as the driver frequency; in future versions, there will be a separate MEG frequency input, the recommended value is higher than 60Hz, usually 70Hz (period fraction 85%), or 75Hz (period fraction 80%). (4) future SE EPI version will have flexible MEG number, as well as fractional MEGs so the TE can be reduced, which is important for liver applications and future SE EPI version will have option of one MEG instead of current two MEGs, as well as fractional MEGs so the TE can be reduced, which is important for liver applications; because the motion sensitivity will be lower by a factor of two, the driver power should be at 50% instead of 25%. (5) The patient experience scan will give an additional breath-hold, so the subject can experience the vibrations for a full breath hold before the data is acquired. Can turn this off if not the first MRE exam performed or to save time.

<b>Philips 3T - Hepatic MRE Protocols - June 2020</b>			
<b>Scanners and Sequences</b>	Scanner	Achieva, Elition, Ingenia	
	Software versions	MR R5.1.7 SP2	
	Pulse sequence	<b>FFE MRE</b>	<b>SE-EPI MRE</b>
	Mode	2D	2D
<b>Patient Cooperation</b>	<p>(1) Patients shall fast at least 4 hours prior to the exams</p> <p>(2) Patients hold their breath at the end of expiration during all MRE scans, as well as during the scout scans and parallel imaging calibration scans.</p> <p>(3) Make sure the elastic belt is tightly secured on the driver and the patient for optimized energy transfer, while patient can breathe comfortably. For patients with thick subcutaneous fat, this is very important.</p>		
<b>Slice Positioning</b>	<div style="display: flex; justify-content: space-around;">  </div> <p>Place 4 axial slices at the largest portion of the liver in coronal view, and avoid the heart, the liver dome and the liver bottom tip.</p>		
	Position	head-first, supine	head-first, supine

<b>Philips 3T - Hepatic MRE Protocols - June 2020</b>			
<b>Patient Information Input</b>	Weight	Actual Weight	Actual Weight
	Height		
<b>Coil</b>	Coil	Torso	Torso
<b>Imaging Parameters</b>	Imaging Plane	Transverse	Transverse
	No. of slices	4	4
	Slice thickness (mm)/gap	10 mm / 1 mm	10 mm / 1 mm
	FOV (mm) / Phase FOV (mm)	450(required)x403(or less) (Note 2)	400(required)x400 (or less) (Note 2)
	Matrix	300 × 86	100 x 100
	TE (msec)	20 “shortest”	58 (note 4) “shortest”
	TR (msec)	50	1000
	Flip Angle (degree)	30	90
	NSA, EPI shots	1	1, 1shot
	Bandwidth (Hz/Pixel)	~288 Hz/pixel	~2000 Hz/pixel
	Freq Encoding Dir	right - left	right - left
	Acceleration	SENSE	SENSE
	Acceleration factor	2	2
	No. of breath holds	4	1
	Shimming Volume	Auto	Auto
REST slabs	2 parallel	2 parallel	

### Philips 3T - Hepatic MRE Protocols - June 2020

	scan time	71 s (~17 s breathholds) (note 1)	9 sec
<b>Driver Parameters (Generic)</b>	Driver Power	Moderate (50%)	Low (25%) (note 4)
	Driver frequency (Hz)	60	60
<b>Motion Encoding Gradients (Generic)</b>	MEG frequency (Hz) (or Period Mismatch)	60 Hz (note 3)	60 Hz (note 3) (note 4)
<b>Specific Parameters (To be specified)</b>	Patient experience scan	“yes” (note 5)	“yes” (note 5)
	Flow compensation	No	No
	Fat suppression	No	“SPAIR” Suppression level: strong

NOTE: (1) For FFE MRE, scan time can vary depending on the FOV (in phase dir) setup - decreasing phase FOV can slightly decrease scan time and breath-hold time. (2) FOV is recommended to be a fixed value (450 mm), even for small patients for consistency; if a different FOV is determined for a study, it is recommended the same FOV is applied to every patient and every time point. (3) In current sequences, MEG frequency is same as the driver frequency; with research patches, there would be separate MEG frequency input, the recommended value is higher than 60Hz, usually 70Hz (period fraction 85%), or 75Hz (period fraction 80%).(4) future SE EPI research patch will have option of one MEG instead of current two MEGs, as well as fractional MEGs so the TE can be reduced, which is important for liver applications; because the motion sensitivity will be twice lower, the driver power should be at 50% instead of 25%. (5) The patient experience scan will give an additional breath-hold, so the subject can experience the vibrations for a full breath hold before the data is acquired. Can turn this off if not the first MRE exam performed or to save time.

415 **Appendix E: Phantom Parameter Recommendations**

GE 1.5T - Phantom 2DMRE Parameter Recommendations - June 2020				
Scanners and Sequences	Scanner	HDx	HDx	MR450w (Tentative)
	Software versions	DV16 and DV22.1 and 24	DV16 and DV22.1 and 24	DV22.1 and 24
	Pulse sequence	<b>fgmre (Resoundant-GE)</b>	<b>epimre (Resoundant-GE)</b>	<b>MR-Touch (GRE)</b>
	Mode	2D, zoom gradient	2D, zoom gradient	2D
	Options	Fast, ASSET, MultiPhase	ASSET, MultiPhase	Fast, ASSET, MultiPhase
Phantom Setup	Place the 16-cm diameter cylinder phantom vertically in the torso coil, place the liver driver (facing down) on the top of the phantom and secure them with the liver MRE elastic belt tightly.			
Slice Positioning	Place one coronal slice at the center of the height of the phantom, with a fixed squared FOV (200 mm). 			
Information Input (Pretest Patient)	Position	feet-first, supine	feet-first, supine	feet-first, supine
	Weight	150 Lbs	150 Lbs	150 Lbs
	Height			
Coil (note 1)	Coil	Torso	Torso	Torso
Imaging Parameters	Imaging Plane	coronal	coronal	coronal
	No. of slices	4	4	4
	Slice thickness (mm)/gap	10 mm / 0 mm	8 mm / 2 mm	10 mm / 0 mm
	FOV (mm) / Phase FOV (100%)	20cm/1 (note 4)	20cm/1 (note 4)	20cm/1 (note 4)
	Matrix	256 x 64	64 x 64	256 x 64
	TE (msec)	in-phase TE (about 18.2) (note 7)	min full TE (note 1)	min full TE (type a value close to 18.2 if possible)
	TR (msec)	50	250	50
	Flip Angle (degree)	25	default (90)	25
	NEX, EPI shots	1	8, 4shot	1
	Bandwidth (kHz)	31.25	250 (hard coded)	31.25
	Freq Encoding Dir	Superior-Inferior	Superior-Inferior	Superior-Inferior
	Phases per Location	4	4	
	Phase Acq. Order	Interleaved	Interleaved	
Delay After Acq.	Minimum	Minimum		

**GE 1.5T - Phantom 2DMRE Parameter Recommendations - June 2020**

	Acceleration	ASSET (Note 1)	ASSET (Note 1)	ASSET (Note 1)
	Acceleration factor	1	1	1
	No. of breath holds			
	Shimming Volume	Cover the whole phantom	Cover the whole phantom	Cover the whole phantom
	Spectrum Peaks	Peak with middle freq (there are 3 peaks)	Peak with middle freq (there are 3 peaks)	Peak with middle freq (there are 3 peaks)
	Saturation Band	SI	SI	SI
	scan time	about 28 s (note 2)	about 1 min 13 sec	about 28 sec (note 2)
<b>Driver Parameters (Generic) (note 5)</b>	Driver Power (%)	10	10	10
	Driver frequency (Hz)	60	60	60
<b>Motion Encoding Gradients (Generic) (note 5)</b>	Driver cycles/ trigger (Duration)	3 (auto-caculated)	Auto-calculated	Auto-caculated
	MEG frequency (Hz) (or Period Mismatch)	75 Hz (0.8)	155	75
	MEG Amplitude (G/cm)	About 3 G/cm with Zoom gradient (75%) (note 3)	Full Scale (note 3)	
	Axis of MEG	4 (Z)	4 (Z)	4 (Z)
<b>User CV or Advanced Table (Specific: epimre -DV16 and DV24) (note 5)</b>	CV0 -Ramp Sampling (1=on, 0=off)		1	
	CV1			
	CV2			
	CV3			
	CV4			
	CV5 -Scale for RF2 Crusher Area		1	
	CV6 -Split MEG (0=L, 1/2/3 = L-R in/half/min)		2	
	CV7 -Flow Comp. Type for MEG		0	
	CV8 -Driver Frequency Percent Increase		0.5	
	CV9 -Time from Start of MEG1 to MEG2 (-1 = opt, 0=min)		0	
	CV10 -Number of Gradient Pairs		1	
	CV11 -Soft-start Ramp-up Time (sec)		0	
	CV12 -Fraction of Max Gradient Amplitude		1	
	CV13 -Desired MEG Frequency (Hz)		155	
	CV14 -Driver Amp. % (-1 = not V3)		10	
	CV15 -Recon (Def=1912;3D ver =1914;Brain=1915;2D MMDI = 1916)		1916	
CV16 -Trigger Loc # of Cycles Pre-MEG		4		

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**GE 1.5T - Phantom 2DMRE Parameter Recommendations - June 2020**

	CV17 -MEG Direction (F/P/S=1/2/4, Tetra=8)		4	
	CV18 -Vibration Mode (0=Burst, 1 or 2 = Contin.)		2	
	CV19 - MENC (um per radians)		Don't edit	
	CV20 -# of Motion Periods for Offsets		1	
	CV21 -Frequency of Applied Motion (Hz)		60	
	CV22			
	CV23 -Burst Mode Burst Count		1	
	CV24 -Do High-Resolution Recon.?		1	
	CV 12 -use version3 driver	1		
	CV 13 -Motion Encoding Gradient (MEG) pairs	1		
	CV 14 Motion Frequency - Hz	60		
<b>User CV (Specific: fgremre DV16) (note 5)</b>	CV 15 Scale Max Gradient Amplitude	0.75		
	CV 17 freq=1, phase=2, slice=4	4		
	CV 21 period mismatch	0.8		
	CV 24 driver amplitude	10		
<b>MR-Touch Tab (Specific fgremre-DV22.1, DV24) (note 5)</b>	Temporal Phases	4		
	MEG Frequency (Hz)	75		
	Driver Amplitude (%) (note 6)	10		
	Driver Cycle Per Trigger	3		
	MEG Direction	4 (Z)		
<b>Advanced Tab (Specific fgremre-DV22.1, DV24) (note 5)</b>	CV12 use resoundant	1.00		
<b>MR-Touch Tab (Specific MR-Touch sequence -DV22.1, DV24) (note 5)</b>	Temporal Phases			4
	MEG Frequency (Hz)			75
	Driver Amplitude (%) (note 6)			10
	Driver Cycle Per Trigger			3
	MEG Direction			4 (Z)

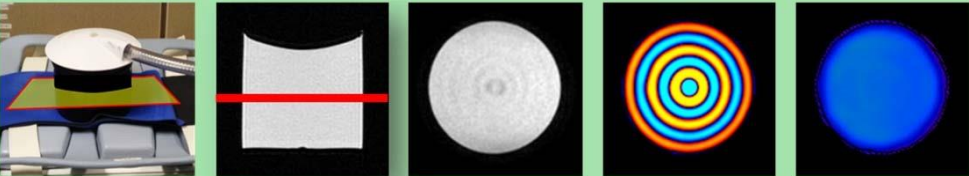
NOTE: (1) Always use torso coil (multi-channel), add pads around the phantom to support the top part of the torso coil, which should not contact the phantom; if other coils that do not support parallel imaging is used, then the ASSET is turned off automatically, scan time is longer. (2) For GREMRE, scan time can vary depending on the FOV (in phase dir) setup - decreasing phase FOV can slightly decrease scan time; however, do not do this for the phantom. (3) Depending on your gradient hardware performance, the absolute gradient strength could be different. (4) FOV is recommended to be a fixed value (200 mm), even for this 16-cm diameter cylinder phantom. (5) The specific tab and parameters can be different for different software versions and MRE sequences; the generic parameters for driver and motion encoding gradients are the guideline to those specific tab and parameters; overall, this recommendation is conservative so that it can be successfully performed at all software versions and scanners.(6) Driver Frequency is 60Hz (default). (7) FC is not supported with F/W in phase TE, FC should be turned off; if this causes trouble, then Try min full TE.

GE 3T - Phantom 2DMRE Parameter Recommendations – June 2020					
<b>Scanners and Sequences</b>	Scanner	HDx	HDx	MR750w	3T (MR750W)
	Software versions	DV16 and DV22.1 and 24	DV16 and DV22.1 and 24	DV22.1 and 24	DV22.1 and 24
	Pulse sequence	<b>fgremre (Resoundant-GE)</b>	<b>epimre (Resoundant-GE)</b>	<b>MR-Touch (EPI) - Clinical Mode</b>	<b>MR-Touch (EPI) - Research Mode</b>
	Mode	2D, zoom gradient	2D, zoom gradient	2D	2D
	Options	Fast, ASSET, MultiPhase	ASSET, MultiPhase	ASSET, FC	ASSET, FC
<b>Phantom Setup</b>	Place the 16-cm diameter cylinder phantom vertically in the torso coil, place the liver driver (facing down) on the top of the phantom and secure them with the liver MRE elastic belt tightly.				
<b>Slice Positioning</b>	Place one coronal slice at the center of the height of the phantom, with a fixed squared FOV (200 mm). 				
<b>Information Input (Pretent Patient)</b>	Position	feet-first, supine	feet-first, supine	feet-first, supine	feet-first, supine
	Weight	150 Lbs	150 Lbs	150 Lbs	150 Lbs
	Height				
<b>Coil (note 1)</b>	Coil	Torso	Torso	Torso	Torso
<b>Imaging Parameters</b>	Imaging Plane	coronal	coronal	coronal	coronal
	No. of slices	4	4	4	4
	Slice thickness (mm)/gap	10 mm / 0 mm	8 mm / 2 mm	8 mm / 2 mm	8 mm / 2 mm
	FOV (cm) / Phase FOV (100%)	20cm/1 (note 4)	20cm/1 (note 4)	20cm/1 (note 4)	20cm/1 (note 4)
	Matrix	256 x 64	96 x 96	96 x 96	96 x 96
	TE (msec)	min full (around 15.9, this is close to inphase TE)	min full( around 31 msec) (note 1)	min full( around 57.6 msec) (note 1)	min full (note 1)
	TR (msec)	50	250	250	248 (display CV -> act_tr = 248000)
	Flip Angle (degree)	20	default (90)	default (90)	default (90)
	NEX, EPI shots	1	8, 4shot	1, 1shot	1, 8-shot (display CV -> touch_maxshots = 8))
	Bandwidth (kHz)	31.25	250 (hard coded)	250 (hard coded)	250 (hard coded)
	Freq Encoding Dir	Superior-Inferior	Superior-Inferior	Superior-Inferior	Superior-Inferior
	Phases per Location	4	4		
	Phase Acq. Order	Interleaved	Interleaved		
	Delay After Acq.	Minimum	Minimum		
	Acceleration	ASSET (Note 1)	ASSET (Note 1)	ASSET (Note 1) (Note 2)	ASSET
	Acceleration factor	1	1	2	1
	No. of breath holds				
Shimming Volume	Cover the whole phantom	Cover the whole phantom	Cover the whole phantom	Cover the whole phantom	
Spectrum Peaks	Peak with middle freq (there are 3 peaks)	Peak with middle freq (there are 3 peaks)	Peak with middle freq (there are 3 peaks)	Peak with middle freq (there are 3 peaks)	
Saturation Band					



GE 3T - Phantom 2DMRE Parameter Recommendations – June 2020					
	scan time	28 s (note 2)	1 min 13 sec	10 sec	24 sec
<b>Driver Parameters (Generic) (note 5)</b>	Driver Power (%)	10	10	10	10
	Driver frequency (Hz)	60	60	60	60
	Driver cycles/ trigger (Duration)	3 (auto-calculated)	Auto-calculated	Auto-calculated	Auto-calculated
<b>Motion Encoding Gradients (Generic) (note 5)</b>	MEG frequency (Hz) (or Period Mismatch)	80 Hz (0.75)	155	90	90
	MEG Amplitude (G/cm)	About 1.7 G/cm with whole gradient (75%) (note 3)	Full Scale (note 3)		
	Axis of MEG	4 (Z)	4 (Z)	4 (Z)	4 (Z)
<b>User CV or Advanced Table (Specific: epimre –DV1 and DV24) (note 5)</b>	CV0 -Ramp Sampling (1=on, 0=off)		1		
	CV1				
	CV2				
	CV3				
	CV4				
	CV5 – Scale for RF2 Crusher Area		1		
	CV6 – Split MEG (0=L, 1/2/3 = L-R in/half/min)		2		
	CV7 – Flow Comp. Type for MEG		0		
	CV8 – Driver Frequency Percent Increase		0.5		
	CV9 – Time from Start of MEG to MEG2 (-1 = opt, 0 = min)		0		
	CV10 – Number of gradient pairs		1		
	CV11 – Soft start Ramp-up time (sec)		0		
	CV12 – Fraction of Max Gradient Amplitude		1		
	CV13 – Desired MEG Frequency (Hz)		155		
	CV14 – Driver Amp %(-1 = not V3)		10		
	CV15 = Recon (Def – 1912; 3D ver = 1914; Brain = 1915; 2D MMDI = 1916)		1916		
	CV16 – Trigger Loc # of Cycles Pre-MEG		4		
	CV17 – MEG Direction (F/P/S = 1/2/4, Tetra = 8)		4		
	CV18 – Vibration Mode (0 = Burst, 1 or 2 = Continuous)		2		
	CV19 – MENC (um per radians)		Don't edit		
	CV20 - # of Motion Periods for Offsets		1		
	CV21 – Frequency of Applied Motion (Hz)		60		
	CV22				
	CV23 – Burst Mode Count		1		
CV24 – Do High Resolution Recon?		1			
<b>User CV (Specific: fgremre – DV16) (note 5)</b>	CV 12 – use version 3 driver	1			
	CV 13 – Motion Encoding Gradient (MEG) pairs	1			

GE 3T - Phantom 2DMRE Parameter Recommendations – June 2020					
	CV 14 Motion Frequency (Hz)	60			
	CV 15 Scale Max Gradient Amplitude	0.75			
	CV 17 freq = 1, phase = 2, slice = 4	4			
	CV 21 period mismatch	0.75			
	CV24 driver amplitude	10			
<b>MR-Touch Tab</b> (Specific fgremre – DV22.1, DV24) (note 5)	Temporal phase	4			
	MEG Frequency (Hz)	80			
	Driver Amplitude (%) (note 6)	10			
	Driver cycle per trigger	3			
	MEG Direction	4 (Z)			
<b>Advanced Tab</b> (Specific fgremre – DV22.1, DV24) (note 5)	CV12 use resoundant	1.00			
<b>MR-Touch Tab</b> (Specific MR-Touch sequence – DV22.1, DV24) (note 5)	MEG Frequency (Hz)			90	90
	Driver frequency (Hz)			60	60
	Driver amplitude (%)			10	10
	MEG Direction			Z	Z
	Driver Cycle per Trigger			15 (not for edit)	15 (not for edit)
	MENC um/rad			28.5 (not for edit)	28.5 (not for edit)
<p>NOTE: (1) Always use torso coil (multi-channel), add pads around the phantom to support the top part of the torso coil, which should not contact the phantom; if other coils that do not support parallel imaging is used, then the ASSET is turned off automatically, scan time is longer. (2) For GREMRE, scan time can vary depending on the FOV (in phase dir) setup – decreasing phase FOV can slightly decrease scan time; however do not do this for the phantom. (3) Depending on your gradient hardware performance, the absolute gradient strength could be different. (4) FOV is recommended to be a fixed value (200 mm), even for this 16-cm diameter cylinder phantom. (5) The specific tab and parameters can be different for different software versions and MRE sequences; the generic parameters for driver and motion-encoding gradients are the guideline to those specific tab and parameters; overall, this recommendation is conservative so that it can be successfully performed at all software versions and scanners. (6) Driver Frequency is 60 Hz (default).</p>					

Siemens 1.5T - Phantom 2DMRE Parameter Recommendations – June 2020			
Scanners and Sequences	Scanner	MAGNETOM (Tim 3G, Tim 4G)	
	Software versions	N4 VE11C SP01 and above	
	Pulse sequence	greMRE	epseMRE
	Mode	2D	2D
Phantom Setup	Place the 16-cm diameter cylinder phantom vertically in the torso coil, place the liver driver (facing down) on the top of the phantom and secure them with the liver MRE elastic belt tightly.		
Slice Positioning	Place one coronal slice at the center of the height of the phantom, with a fixed squared FOV (200 mm). 		
Information Input	Position	head-first, supine	head-first, supine
	Weight	150 Lbs	150 Lbs
	Height	5 ft	5 ft
Coil (note 1)	Coil	Torso	Torso
Imaging Parameters	Imaging Plane	Coronal	Coronal
	No. of slices	4	4
	Slice thickness (mm)/dist. Factor	10 mm / 0% (0)	8 mm / 25% (2mm)
	FOV (mm) / Phase FOV (100%)	200mm/1 (note 4)	200mm/1 (note 4)
	Matrix (Base x Phase)	256 x 25%(64)	128 x 100%(128)
	TE (msec)	min (about ~20 with flow comp off)	min

	TR (msec)	50	1000
	Flip Angle (degree)	25	default (90)
	NEX, EPI shots	1	1, 1shot
	Bandwidth (Hz/Pixel)	260 Hz/pixel	1502 Hz/pixel
	Phase enc.dir.	Right-Left	Right-Left
	Acceleration	GRAPPA (note 1)	GRAPPA (note 1)
	Acceleration factor	1	1
	No. of breath holds	NA	NA

	Shimming Volume	auto	auto
	Spectrum Peaks	Peak with middle freq (there are 3 peaks)	Peak with middle freq (there are 3 peaks)
	Saturation Band		
	scan time	34 sec	11 sec
<b>Driver Parameters (Generic) (note 5)</b>	Driver Power (%)	10 (default) (note 6)	10 (default) (note 6)
	Driver frequency (Hz)	60 (default) (note 6)	60 (default) (note 6)
	Driver cycles/ trigger (Duration)	3 (default) (note 6)	3 (default) (note 6)
<b>Motion Encoding Gradients (Generic) (note 5)</b>	MEG frequency (Hz)	60 Hz (Hard Coded)	60 Hz (Hard Coded)
	MEG Amplitude	(Hard coded)	30 mT/m (Hard coded)
	Axis of MEG	Slice (Hard Coded)	Slice
	Number of phase	4 (Hard coded)	4 (Hard coded)
<b>Specific Parameters (note 5)</b>	Sequence - Part 1 - Flow Comp	NO	YES
	Sequence - Special - MEG Amplitude (mT/m)	Not available	30
	Sequence - Special - MEG Frequency (Hz)	Not available	60.0
	Sequence - Special - MEG Waveform	Not available	1-2-1
	Sequence - Special - MEG Direction	Not available	Slice

	System - Tx/Rx - Img. Scale Cor.	1	1
	Resolution - Filter Image - Prescan Normalize	Check	Check

NOTE: (1) Always use torso coil (multi-channel), add pads around the phantom to support the top part of the torso coil, which should not contact the phantom; if other coils that do not support parallel imaging is used, then the ASSET is turned off automatically, scan time is longer. (2) For GREMRE, scan time can vary depending on the FOV (in phase dir) setup - decreasing phase FOV can slightly decrease scan time; however, do not do this for the phantom. (3) Depending on your gradient hardware performance, the absolute gradient strength could be different. (4) FOV is recommended to be a fixed value (200 mm), even for this 16-cm diameter cylinder phantom. (5) The specific tab and parameters can be different for different software versions and MRE sequences; the generic MRE parameters for driver and motion encoding gradients are the guideline to those specific tab and parameters (MRE-related); overall, this recommendation is conservative so that it can be successfully performed at all software versions and scanners. (6) The current implementation of Siemens MRE does not access active driver, those values are default values and can be changed by using a separate web connection to the active driver (Syngo or Laptop); epseMRE sequences delivers one trigger every 50ms.

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**Siemens 3T - Phantom 2DMRE Parameter Recommendations - June 2020**

<b>Scanners and Sequences</b>	Scanner	MAGNETOM (Tim 3G, Tim 4G)	
	Software versions	N4 VE11C SP01 and above	
	Pulse sequence	greMRE	epseMRE
	Mode	2D	2D
<b>Phantom Setup</b>	Place the 16-cm diameter cylinder phantom vertically in the torso coil, place the liver driver (facing down) on the top of the phantom and secure them with the liver MRE elastic belt tightly.		
<b>Slice Positioning</b>	Place one coronal slice at the center of the height of the phantom, with a fixed squared FOV (200 mm). 		
<b>Information Input (Patient)</b>	Position	head-first, supine	head-first, supine
	Weight	150 Lbs	150 Lbs
	Height	5 ft	5 ft
<b>Coil (note 1)</b>	Coil	Torso	Torso
<b>Imaging Parameters</b>	Imaging Plane	Coronal	Coronal

	No. of slices	4	4
	Slice thickness (mm)/dist. Factor	10 mm / 0% (0)	8 mm / 25% (2mm)
	FOV (mm) / Phase FOV (100%)	200mm/1 (note 4)	200mm/1 (note 4)
	Matrix (Base x Phase)	256 x 25%(64)	128 x 100%(128)
	TE (msec)	min (about ~20 with flow comp off)	min
	TR (msec)	50	1000
	Flip Angle (degree)	20	default (90)
	NEX, EPI shots	1	1, 1shot
	Bandwidth (Hz/Pixel)	260 Hz/pixel	1502 Hz/pixel
	Phase enc.dir.	Right-Left	Right-Left
	Acceleration	GRAPPA (note 1)	GRAPPA (note 1)
	Acceleration factor	1	1
	No. of breath holds	NA	NA

	Shimming Volume	auto	auto
	Spectrum Peaks	Peak with middle freq (there are 3 peaks)	Peak with middle freq (there are 3 peaks)
	Saturation Band		
	scan time	34 sec	11 sec
<b>Driver Parameters (Generic) (note 5)</b>	Driver Power (%)	10 (default) (note 6)	10 (default) (note 6)
	Driver frequency (Hz)	60 (default) (note 6)	60 (default) (note 6)
	Driver cycles/ trigger (Duration)	3 (default) (note 6)	3 (default) (note 6)
<b>Motion Encoding Gradients (Generic) (note 5)</b>	MEG frequency (Hz)	60 Hz (Hard Coded)	60 Hz (Hard Coded)
	MEG Amplitude	(Hard coded)	30 mT/m (Hard coded)
	Axis of MEG	Slice (Hard Coded)	Slice

	Number of phase	4 (Hard coded)	4 (Hard coded)
<b>Specific Parameters (note 5)</b>	Sequence - Part 1 - Flow Comp	NO	YES
	Sequence - Special - MEG Amplitude (mT/m)	Not available	30
	Sequence - Special - MEG Frequency (Hz)	Not available	60.0
	Sequence - Special - MEG Waveform	Not available	1-2-1
	Sequence - Special - MEG Direction	Not available	Slice
	System - Tx/Rx - Img. Scale Cor.	1	1
	Resolution - Filter Image - Prescan Normalize	Check	Check

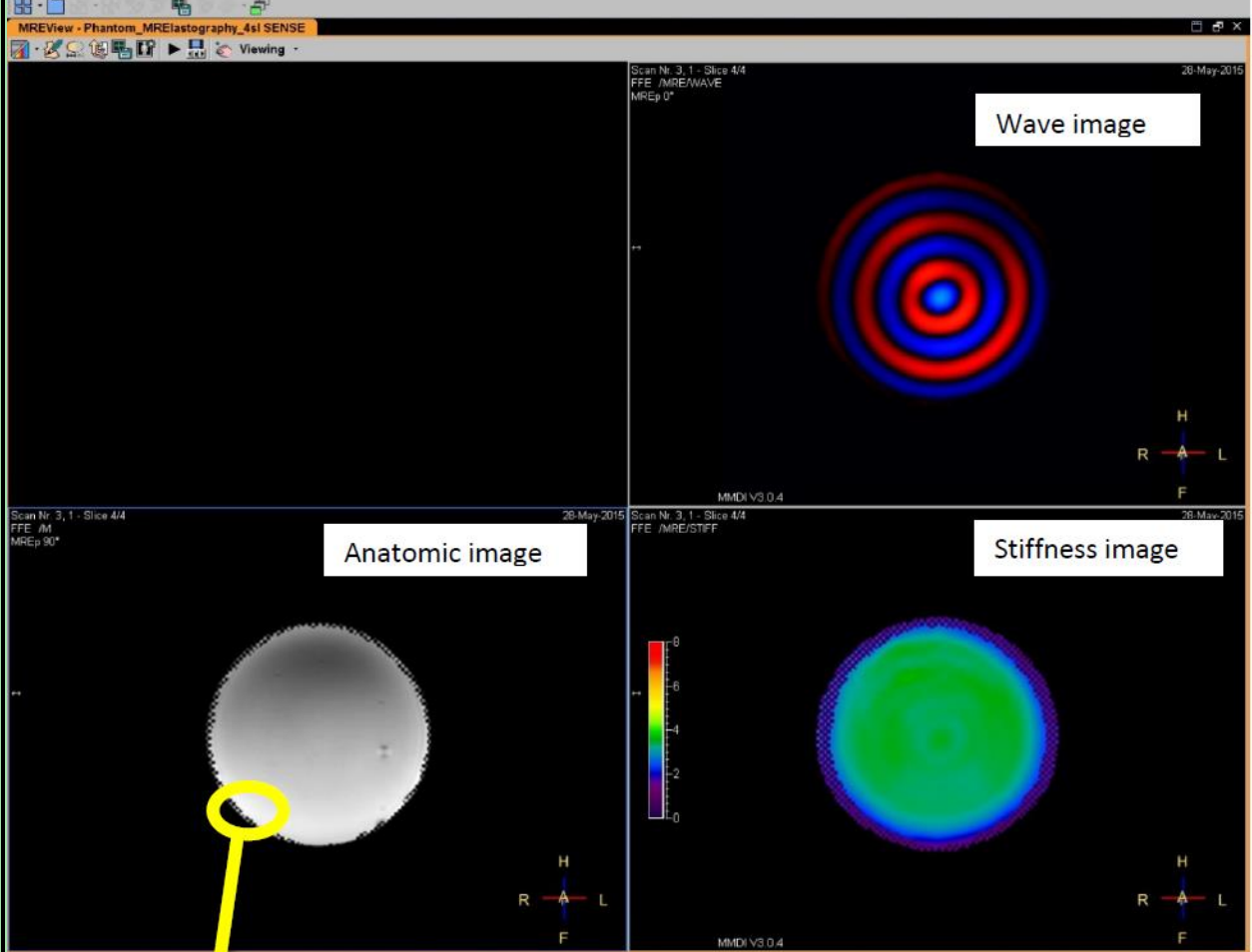
NOTE: (1) Always use torso coil (multi-channel), add pads around the phantom to support the top part of the torso coil, which should not contact the phantom; if other coils that do not support parallel imaging is used, then the ASSET is turned off automatically, scan time is longer. (2) For GREMRE, scan time can vary depending on the FOV (in phase dir) setup - decreasing phase FOV can slightly decrease scan time; however, do not do this for the phantom. (3) Depending on your gradient hardware performance, the absolute gradient strength could be different. (4) FOV is recommended to be a fixed value (200 mm), even for this 16-cm diameter cylinder phantom. (5) The specific tab and parameters can be different for different software versions and MRE sequences; the generic MRE parameters for driver and motion encoding gradients are the guideline to those specific tab and parameters (MRE-related); overall, this recommendation is conservative so that it can be successfully performed at all software versions and scanners. (6) The current implementation of Siemens MRE does not access active driver, those values are default values and can be changed by using a separate web connection to the active driver (Syngo or Laptop); epseMRE sequences delivers one trigger every 50ms.

**Philips 1.5T - Phantom 2DMRE Parameter Recommendations - June 2020**

<b>Scanners and Sequences</b>	Scanner	Achieva, Ambition, Ingenia	
	Software versions	MR R5.1.7 SP2 (or later)	
	Pulse sequence	<b>FFE MRE</b>	<b>2D SE-EPI MRE (WIP)</b>
	Mode	2D	2D
<b>Phantom Setup</b>	Place the 16-cm diameter cylinder phantom vertically in the head coil, place the liver driver (facing down) on the top of the phantom and secure them with the liver MRE elastic belt tightly.		



Place one coronal slice at the center of the height of the phantom, with a fixed squared FOV (200 mm).



Slice  
Positing

Information  
Input  
(Patient)

Position	head-first, supine	head-first, supine
Weight		



	Height		
<b>Coil (note 1)</b>	Coil	Head	Head
<b>Imaging Parameters</b>	Imaging Plane	Coronal	Coronal
	No. of slices	4	4
	Slice thickness (mm)/gap	10 mm / 1 mm	8 mm / 2 mm
	FOV (mm) / Phase FOV (100%)	300/300	300/300
	Matrix	200 x 64	64 x 64
	TE (msec)	min or 20	min or 58
	TR (msec)	50	1000
	Flip Angle (degree)	30	default (90)
	NSA, EPI shots	1	1, 1shot
	Bandwidth (Hz/Pixel)	218 Hz/pixel	88 Hz/pixel
	Freq Encoding Dir	FH	FH
	Acceleration	None	None
	Acceleration factor	1	1
No. of breath holds	0	0	

	Shimming	Auto	Auto
	REST slabs	No	No
	scan time	1:44 (note 2)	19 sec
<b>Driver Parameters (Generic) (note 5)</b>	Driver Power (%)	10	10
	Driver frequency (Hz)	60	60
	Driver cycles/ trigger (Duration)	3 (auto-calculated)	Auto-calculated

<b>Motion Encoding Gradients (Generic) (note 5)</b>	MEG frequency (Hz) (or Period Mismatch)	60 Hz	60 Hz
	MEG Amplitude (G/cm)	18.4	18.4
	Axis of MEG	AP	AP
	Number of phase	4	4
<b>Specific Parameters (To be specified)</b>			

NOTE: (1) Always use head coil ; if other coils that do not support parallel imaging is used. (2) For FFE MRE, scan time can vary depending on the FOV (in phase dir) setup - decreasing phase FOV can slightly decrease scan time; however, do not do this for the phantom. (3) Depending on your gradient hardware performance, the absolute gradient strength could be different. (4) FOV is recommended to be a fixed value (300 mm), even for this 16-cm diameter cylinder phantom. (5) The specific tab and parameters can be different for different software versions and MRE sequences; the generic MRE parameters for driver and motion encoding gradients are the guidelines to those specific tab and parameters (MRE-related); overall, this recommendation is conservative so that it can be successfully performed at all software versions and scanners.

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<b>Philips 3T - Phantom 2DMRE Parameter Recommendations - June 2020</b>			
<b>Scanners and Sequences</b>	Scanner	Achieva, Elition, Ingenia	
	Software versions	MR R5.1.7 SP2	
	Pulse sequence	<b>GRE MRE</b>	<b>2D SE-EPI MRE</b>
	Mode	2D	2D
	Shimming Volume	Auto	Auto
	REST slabs	No	No
	scan time	1:44 s (note 2)	19 sec
<b>Driver Parameters (Generic) (note 5)</b>	Driver Power (%)	10	10
	Driver frequency (Hz)	60	60
<b>Motion Encoding Gradients (Generic) (note 5)</b>	MEG frequency (Hz) (or Period Mismatch)	60 Hz	60 Hz
	MEG Amplitude (G/cm)	18.4	18.4
	Axis of MEG	AP	4AP
	Number of phase	4	4
NOTE: (1) Always use head coil. (2) For FFE MRE, scan time can vary depending on the FOV (in phase dir) setup - decreasing phase FOV can slightly decrease scan time; however, do not do this for the phantom. (3) Depending on your gradient hardware performance, the absolute gradient strength could be different. (4) FOV is recommended to be a fixed value (300 mm), even for this 16-cm diameter cylinder phantom. (5) The specific tab and parameters can be different for different software versions and MRE sequences; the generic MRE parameters for driver and motion encoding gradients are the guidelines to those specific tab and parameters (MRE-related); overall, this recommendation is conservative so that it can be successfully performed at all software versions and scanners.			

### 4.3 Assessment Procedure: Stiffness Measurement Stability

This procedure can be used by a vendor or an imaging site to assess MRE stiffness measurement stability. Stiffness measurement stability is assessed in terms of the Stiffness Measurement Difference between successive MRE QA phantom scans.

#### 4.3.1 MRE QA PHANTOM

The MRE QA phantom is made of Polyvinyl Chloride (PVC) gel in a 12.5cm × 15.5cm cylinder container with a 0.15 cm wall thickness. It should be handled carefully when being transferred from one location to another to avoid dropping.



Figure 1. MRE QA Phantom

#### 4.3.2 PHANTOM SETUP:

The phantom setup uses the patient liver MRE driver (active driver and passive driver components), the patient elastic belt, a phantom specific friction cloth, and the patient torso RF coil. There are 10 steps for a typical phantom setup; the goal of the setup is to make sure the phantom is sitting on the table vertically and stably:

- 1) Position the bottom part of the torso coil on the patient table
- 2) Put the elastic belt on the bottom coil
- 3) Put the phantom on the elastic belt vertically
- 4) Put the friction cloth on the top of the phantom
- 5) Put the passive driver on the friction cloth
- 6) Wrap the phantom, friction cloth and passive driver with the elastic belt tightly
- 7) Put some cushions around the phantom to support the top part of the torso coil, which should not contact the phantom/driver
- 8) Put the top part of the torso coil on the cushions
- 9) Connect the passive driver to the tube of the active driver
- 10) Advance to scan

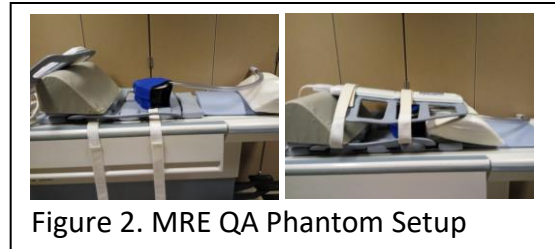


Figure 2. MRE QA Phantom Setup

#### 4.3.3 PHANTOM IMAGING PARAMETERS

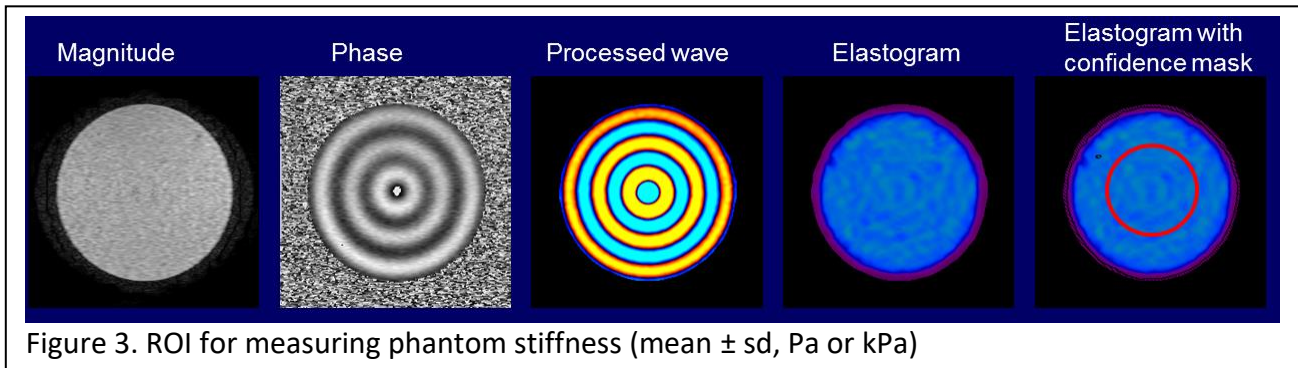
Patient MRE sequences are used for this procedure, but with different imaging parameters. Phantom imaging parameters have been optimized according to its T1 and T2 relaxation time, chemical spectrum and geometry, which are very different from the patients. Detailed parameters for GRE MRE and EPI MRE sequences at both 1.5-T and 3-T platforms of the three vendors (GE, Siemens and Philips can be found in Appendix E).

#### 4.3.4 REGION OF INTEREST (ROI) FOR MEASURING PHANTOM STIFFNESS

Position a circular ROI in the middle of the phantom with half of the phantom diameter on the elastogram (with or without confidence mask). A high quality phantom exam should have the majority of phantom uncovered with the confidence mask. Phantom edges should be avoided from the ROI due to

465 the edge effect.

Compute the mean and standard deviation of the pixel values in the ROI (in units of Pa or kPa).



**4.3.5 QA RECORD**

470 Record the date and the Phantom Mean Stiffness and Phantom SD Stiffness for each assessment in a table such as Table 1.

Compute and record the Stiffness Measurement Difference between the current ( $E_{current}$ ) and previous ( $E_{previous}$ ) measurements as:  $2 \times \text{abs}(E_{current} - E_{previous}) / (E_{current} + E_{previous})$ .

475 **Table 1: MRE QA Record**

Date	Phantom Mean Stiffness (kPa)	Phantom SD Stiffness (kPa)	Stiffness Measurement Difference	Pass Criteria (Expected Stiffness Measurement Difference)
First Scan	E0	SD0	NA	NA
6 months	E1	SD1	$2 \times \text{abs}(E1 - E0) / (E1 + E0)$	$\leq 10\%$
Next 6 months	E2	SD2	$2 \times \text{abs}(E2 - E1) / (E2 + E1)$	$\leq 10\%$
⋮	⋮	⋮	⋮	⋮

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## Appendix F



## QIBA Checklist:

# Magnetic Resonance Elastography of the Liver

### INSTRUCTIONS

This Checklist is organized by "Actor" for convenience. If a QIBA Conformance Statement is already available for an actor (e.g. your analysis software), you may choose to provide a copy of that statement rather than confirming each of the requirements in that Actors checklist yourself.

Within an Actor Checklist the requirements are grouped by the corresponding Activity in the QIBA Profile document. If you are unsure about the meaning or intent of a requirement, additional details may be available in the Discussion section of the corresponding Activity in the Profile.

Site Conformity indicates whether you have performed the requirement and confirmed conformance.

Site Opinion allows you to indicate how the requirement relates to your current, preferred practice. If a requirement is not feasible or not worth it to achieve the Profile Claim, please explain to help us understand why.

Since several of the requirements mandate the use of specific assessment procedures, those are also included at the end to minimize the need of referring to the Profile document.

Feedback on all aspects of the Profile and associated processes is welcomed.

**PHYSICIST CHECKLIST** **PAGE 69**

**RADIOLOGIST CHECKLIST** **PAGE 70**

**TECHNOLOGIST CHECKLIST** **PAGE 71-72**

**PHYSICIST CHECKLIST**

Note: The role of the Physicist actor may be an in-house medical physicist, a physics consultant or other staff (such as a vendor service or specialists) qualified to perform the validations described.

<i>Parameter</i>	<i>Specification</i>
<i>Periodic QA (section 3.3)</i>	
<i>Installation</i>	Shall perform installation and initial functional validation of the MRI Scanner and MRE driver system according to manufacturer-defined procedures and specifications.
Required QA	Shall assess and confirm the validity of the field of view and image linearity on an ongoing basis, using manufacturer-recommended procedures.
	Shall confirm correct driver frequency settings as outlined in Appendix D.
<i>Installation</i>	Shall perform installation and initial functional validation of the MRI Scanner and MRE driver system according to manufacturer-defined procedures and specifications.

**RADIOLOGIST CHECKLIST**

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**Note:** The Radiologist is responsible for image analysis, image QA, and interpretation. The Radiologist is also responsible for ensuring that the protocol has been validated, although the Physicist actor is responsible for performing the validation.

Parameter	Conforms?	Specification
<i>Image QA (section 3.8)</i>		
Image QA	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall check the suitability of the data by confirming the presence of signal loss in subcutaneous fat under the driver in the magnitude images, and the presence of visible waves in the liver in the phase and wave images (Figure 3).
<i>Image Analysis (section 3.10)</i>		
Mean shear stiffness of the liver	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall reference the magnitude image to draw ROIs in the largest possible area of liver parenchyma, staying ~1 cm inside the liver boundary, avoiding the area directly underneath the passive driver, and excluding major blood vessels seen on the MRE magnitude images. (Figure 9)
	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall use the phase or wave images to avoid areas of incoherent waves (due to wave interference from waves propagating through the region from different directions or due to other disruptions to the wave field such as those caused by adjacent blood vessels, fissures, and other organs) (Figure 9)
	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall place ROIs in individual slices and in the right lobe whenever possible. (Figure 9)
	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall exclude areas of low confidence, as seen by the checkerboard pattern in the masked elastogram images (Figure 9).
	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall calculate mean shear stiffness of the liver using manually specified regions of interest (ROIs) containing a minimum of 500 pixels for an acquisition with a 420 mm FOV and reconstruction matrix of 256x256 total, corresponding to approximately 12.8 cm <sup>3</sup> [17,3,18].
		Shall reject the elastography if the acquisition failed due to hepatic iron overload, colonic interposition, or other cause of inadequate waves and the scan repeated. (Figure 5, 7)
<i>Image Interpretation (section 3.11)</i>		
Liver Stiffness	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall report overall mean stiffness by calculating the mean stiffness value of each ROI and then reporting the mean value across all slices.

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**TECHNOLOGIST CHECKLIST**

<i>Parameter</i>	<i>Conforms?</i>	<i>Specification</i>
<i>Subject Handling (section 3.5)</i>		
Fasting state	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall confirm that the subject has fasted for at least 4 hours before the time of imaging [12,13].
MR Scanner and MRE device	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall confirm for follow up exams that the subject is scanned on the same MRI scanner and passive driver hardware as the baseline exam.
Subject positioning	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall scan the subject in supine position.
	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall place the passive driver over the right lower chest wall at the level of xiphisternum in midclavicular line (Figure 1). Can be placed in the right mid-axillary line if colon is present between the anterior body wall and the liver) [14,15].
	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall ensure the passive driver is held in firm contact with the body wall using an elastic band.
	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall ensure connection of the plastic tube between the passive & active driver, which is located outside the scan room.
<i>Image Data Acquisition (section 3.6)</i>		
Image acquisition	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall acquire image data during suspended expiration in a natural end-expiratory position.
Slice selection	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall acquire coronal sections for MRE positioned at the level of the widest transverse extent of the liver, avoiding the lungs, liver dome and inferior tip of the right lobe. (Figure 2)
Image Acquisition	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall use an EPI-MRE sequence at 3T, if available (GRE-MRE if not available).
Image acquisition	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall confirm that subjects are scanned with the same parameters and software during follow up exams as the baseline liver MRE.
Image Acquisition	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall confirm that the magnitude images show signal loss in the subcutaneous fat just below the passive driver placement, confirming that mechanical waves are being applied.
Technical success	<input type="checkbox"/> Yes <input type="checkbox"/> No	Shall confirm the phase images (also known as wave images) demonstrate shear waves in the liver. (Figures 3-7)
		Shall review the post-processed elastograms (with or without confidence map, as available) to confirm technical success of the exam.
		Shall re-acquire the exam if possible if the above technical success criteria are not met.



<i>Parameter</i>	<i>Conforms?</i>	<i>Specification</i>
<i>Image Data Reconstruction (section 3.7)</i>		
<i>Image Reconstruction</i>	<input type="checkbox"/> <i>Yes</i> <input type="checkbox"/> <i>No</i>	Shall confirm that the following images have been generated: quantitative stiffness maps, confidence maps, and unwrapped phase images. (Figure 8)
<i>Parameter</i>	<i>Conforms?</i>	<i>Specification</i>
<i>Subject Handling (section 3.5)</i>		
<i>Fasting state</i>	<input type="checkbox"/> <i>Yes</i> <input type="checkbox"/> <i>No</i>	Shall confirm that the subject has fasted for at least 4 hours before the time of imaging [12,13].
<i>MR Scanner and MRE device</i>	<input type="checkbox"/> <i>Yes</i> <input type="checkbox"/> <i>No</i>	Shall confirm for follow up exams that the subject is scanned on the same MRI scanner and passive driver hardware as the baseline exam.
<i>Subject positioning</i>	<input type="checkbox"/> <i>Yes</i> <input type="checkbox"/> <i>No</i>	Shall scan the subject in supine position.
	<input type="checkbox"/> <i>Yes</i> <input type="checkbox"/> <i>No</i>	Shall place the passive driver over the right lower chest wall at the level of xiphisternum in midclavicular line (Figure 1). Can be placed in the right mid-axillary line if colon is present between the anterior body wall and the liver) [14,15].
	<input type="checkbox"/> <i>Yes</i> <input type="checkbox"/> <i>No</i>	Shall ensure the passive driver is held in firm contact with the body wall using an elastic band.
	<input type="checkbox"/> <i>Yes</i> <input type="checkbox"/> <i>No</i>	Shall ensure connection of the plastic tube between the passive & active driver, which is located outside the scan room.
<i>Image Data Acquisition (section 3.6)</i>		
<i>Image acquisition</i>	<input type="checkbox"/> <i>Yes</i> <input type="checkbox"/> <i>No</i>	Shall acquire image data during suspended expiration in a natural end-expiratory position.
<i>Slice selection</i>	<input type="checkbox"/> <i>Yes</i> <input type="checkbox"/> <i>No</i>	Shall acquire coronal sections for MRE positioned at the level of the widest transverse extent of the liver, avoiding the lungs, liver dome and inferior tip of the right lobe. (Figure 2)
<i>Image Acquisition</i>	<input type="checkbox"/> <i>Yes</i> <input type="checkbox"/> <i>No</i>	Shall use an EPI-MRE sequence at 3T, if available (GRE-MRE if not available).
<i>Image acquisition</i>	<input type="checkbox"/> <i>Yes</i> <input type="checkbox"/> <i>No</i>	Shall confirm that subjects are scanned with the same parameters and software during follow up exams as the baseline liver MRE.
<i>Image Acquisition</i>	<input type="checkbox"/> <i>Yes</i> <input type="checkbox"/> <i>No</i>	Shall confirm that the magnitude images show signal loss in the subcutaneous fat just below the passive driver placement, confirming that mechanical waves are being applied.
<i>Technical success</i>	<input type="checkbox"/> <i>Yes</i> <input type="checkbox"/> <i>No</i>	Shall confirm the phase images (also known as wave images) demonstrate shear waves in the liver. (Figures 3-7)

<i>Parameter</i>	<i>Conforms?</i>	<i>Specification</i>
		Shall review the post-processed elastograms (with or without confidence map, as available) to confirm technical success of the exam.
		Shall re-acquire the exam if possible if the above technical success criteria are not met.
<i>Image Data Reconstruction (section 3.7)</i>		
<i>Image Reconstruction</i>	<input type="checkbox"/> <i>Yes</i> <input type="checkbox"/> <i>No</i>	Shall confirm that the following images have been generated: quantitative stiffness maps, confidence maps, and unwrapped phase images. (Figure 8)