Ergonomic Flexible Drivers for Hepatic MR Elastography

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Introduction:
Normal liver tissue is soft when assessed by palpation, whereas cirrhotic livers are typically very hard [1]. Liver stiffness is a very sensitive and specific biomarker for staging liver fibrosis in chronic liver disease patients, which has been proved by a number of elastographic techniques such as ultrasound elasticity imaging and Magnetic Resonance Elastography (MRE) [2-6]. Emerging data further suggest that increased liver stiffness occurs even before collagen deposition takes place[7], implying that tissue stiffness change is a prerequisite for injury responses such as stellate cell activation [8], therefore presymptomatic diagnosis of fibrosis could be possible. At our institution, an average of 2-3 hepatic MRE scans are prescribed every day for evaluating liver fibrosis in patients. This allows for a systematic approach to determine which patients would benefit most from liver biopsy referral [8]. To measure liver stiffness, MRE uses a mechanical transducer called a driver to send low-frequency mechanical waves into the liver from the body wall. The resulting propagation of the waves within the liver is imaged by an MRE sequence. Based on different assumptions about the tissue properties, MRE inversion algorithms are applied to the wave images to estimate liver stiffness [9]. Electromechanical drivers [5, 6] and pneumatic drivers [4] are widely used for *in vivo* human hepatic MRE. Mechanical drivers are usually small and rigid, therefore the human-driver mechanical coupling is not optimal since human bodies are soft, large and contoured; they have the potential of causing discomfort to patients. Our pneumatic driver system [4] uses the air in a flexible PVC tube to transmit acoustic energy from an active driver to a passive driver, which is coupled to the anterior chest wall close to the liver via an elastic strap around the patient. The current hepatic passive driver is 19 cm in diameter, has a rigid structure and therefore has the similar limitations, especially for female patients. Our goals were 1) to design an ergonomic flexible passive driver to improve human-driver mechanical coupling and patient comfort; and 2) to compare the flexible driver with the rigid driver on volunteers and patients.

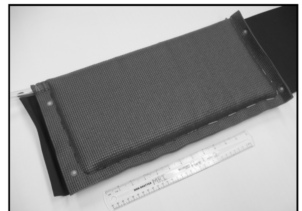

Fig.1. Flexible hepatic MRE

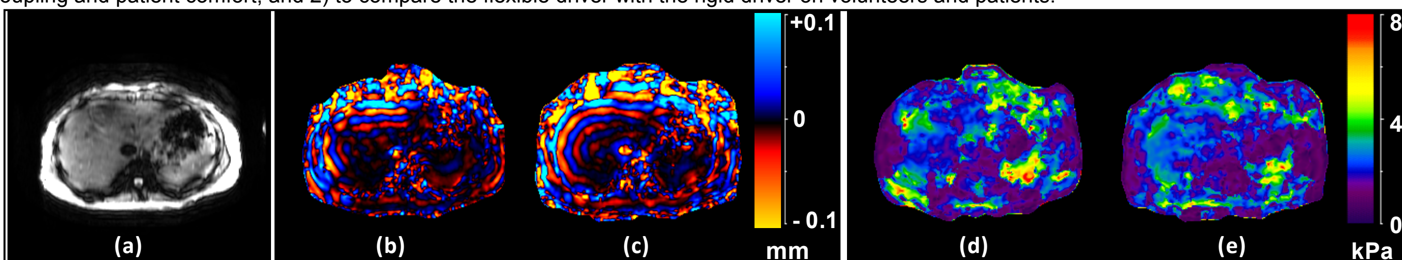

Fig.2. Example MRE scans with both rigid and flexible drivers. magnitude image (a), liver wave images with the rigid (b) and flexible (c) drivers, liver elastograms with the rigid (d) and flexible (e) drivers. Liver stiffness: 2.26 ± 0.08 kPa (rigid) and 2.74 ± 0.23 kPa (flexible).

Methods: The ergonomic flexible driver designed is a large, soft and pillow-like mechanical transducer (Fig.1). It can conform to and cover most of the chest wall (posterior, right and anterior sides) in the vicinity of liver with a 20 cm width elastic band wrapped around the human body, so that the human-driver mechanical coupling is optimized, even for female subjects without causing discomfort to the breasts. The flexible driver has two components: a flexible rectangular bag (20 cm X 40 cm) and a 3-dimensional structure filling material. The bag has a built-in mesh in the material to prevent stretching. The filling material is springy and porous so that it can store vibration energy and let air flow through freely; it occupies the whole cavity of the bag to separate and support the two large vibrating surfaces of the bag effectively. The flexible driver is engineered to be airtight with a 60-cm long, 1.75-cm diameter anti-kink supply tube which connects to the pneumatic active driver. An institutional review board approved study was performed to compare the performance of the flexible driver and the rigid driver. Informed consent was obtained from10 volunteers and 7 patients for the study. The MRE sequence and pneumatic driver system used here were described in the literature [4]. All of the volunteers were scanned at a 3T scanner (MR750, GE, Wisconsin, USA), while all of the patients were scanned at several 1.5T scanners (Signa HDx, GE, Wisconsin, USA) in our institution. MRE parameters used here are: mechanical frequency=60Hz; phase offsets=4; MENC (1.5T) = 32 μm/π-rad; MENC (3T) = 17 μm/π-rad; imaging plane=axial; motion-sensitizing direction=SI; FOV=34-42cm; matrix=256X64; fractional phase FOV=1; flip angle=30^o; NEX=1; bandwidth=31.25 kHz; TE/TR (1.5T)=24.5/50 msec; TE/TR (3T)=20.3/50 msec; slice thickness/spacing=10/0mm; number of slices=2-4; slices positioned at the level of the largest hepatic cross-section; patient position=supine. Regions of interest (ROI) were drawn on the elastograms where liver is located and the wave SNR was high, avoiding regions of blood vessel and severe wave interferences. Liver stiffness (mean, standard deviation) was reported for each subject. JMP8 (SAS, Cary, NC) was used to generate Bland-Altman plots for comparing the liver stiffness measured using the two drivers.

Results and Discussions: None of 17 subjects was uncomfortable with the rigid driver, but all of them felt flexible driver was more comfortable than the rigid driver. Fig. 2 shows examples of MRE scans of one patient with both drivers. The wave images show that the flexible driver generates a more parallel shear wave field in the liver (Fig. 2c), while wave interferences are more significant in the field generated by the rigid driver (Fig. 2b). Severe wave interferences have the potential of causing artifacts in the elastograms, such as the hotspot in the anterior-right part of the liver in Fig. 2d. Therefore, extra effort of the reader is needed to identify such artifacts in the elastogram and to exclude them when drawing ROI for measuring liver stiffness. In the other volunteer and patient data of this study, we observed a higher prevalence of parallel-wave excitations generated by the flexible driver compared to the rigid driver, suggesting the optimized human-driver mechanical coupling of the flexible driver may be more evenly distributing and transmitting mechanical energy to the liver via the large contact area around the anterior, right and posterior chest wall. The Bland-Altman plots [10] shows that the mean difference of the liver stiffness measurements between the rigid and flexible drivers is 0.0061kPa, and the 95% CI of the difference is [-0.1451, 0.1328] kPa (Fig. 3). Therefore, no systemic difference between the flexible and rigid drivers was found in terms of the liver stiffness measurement. The trade-off with the current flexible driver design is that 2-3 times more active driver power was used in this study to overcome its decreased efficiency due to its increased volume and acoustic energy absorption. Future studies will focus on increasing the efficiency of the flexible drivers and testing them on a larger number of patients from the full range of liver fibrosis stages.

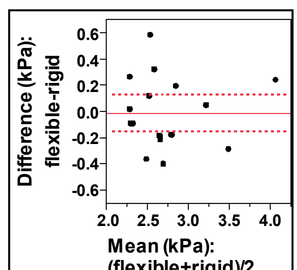

Fig.3. Bland-Altman plot of stiffness difference vs. mean stiffness using the two drivers.

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