Magnetic Resonance Elastography with an air ball-vibrator

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Introduction

In this work we report on the development of a new technique for powerful compact MR Elastography (MRE) vibrator based upon air ball-vibrator. It is compact vibrator that generated powerful centrifugal force vibration in the high speed revolution of the internal ball by compressed air. This is equipment with easy handling due to the simple principle and structure. Vibration frequency and centrifugal force are freely changeable by operation of air pressure (air flow volume), and replacement of internal ball. In order to achieve a MRI-compatible, all parts were renewed with the nonmagnetic material one. Vibration amplitudes (displacements) were measured optically by laser displacement sensor. From performance test of displacement, even though the vibration frequency increase, the amount of displacement did not decrease. An essential step in MRE is the generation of mechanical waves within tissue via a vibrator, and MRE sequence synchronized to several phase offsets of vibration. In this system, the phase offset was detected by four-channel optical-fiber sensor, it was used MRI trigger signal. From agarose-gel phantom experiment, this vibrator can be used to make MR elastogram. This work shows that the use of ball-vibrator for MRE is feasible and can improve MRE image resolution by maintains adequate amount of displacement with high frequency vibrations.

Materials and methods

Figure 1 shows a picture of a prototype MRI-compatible ball-vibrator. The compressed air flows in through the tube connector [a]. Centrifugal force vibration and vibration frequency change by replacement the internal ball [b], and operation air pressure. An air pressure (air flow volume) was controlled by high-precision regulator. The vibrator body was made from acrylic, and built-in raceway ring [c] was made from polytetrafluoroethylene (PTFE). The four-channel optical-fiber sensor [d] enabled the synchronization of four time vibration phase offsets. Silencer [e] mitigates noise.

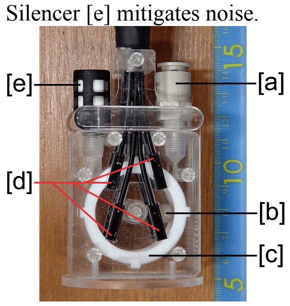

FIG. 1. Ball-vibrator

[a] tube connector
[b] internal ball
[c] raceway ring
[d] 4ch optical-fiber
[e] silencer

A vibration displacement was measured by laser displacement sensor (KEYENCE, Tokyo, Japan); an air flow volume was measured by thermal mass flowmeter (TOKYO KEISO, Tokyo, Japan); a self-made simultaneous measurement system (LabVIEW, National Instruments, TX, USA) was used to record the displacement and the air flow volume.

A centrifugal force of ball vibrator can be calculated with the following equation:

$$F = \frac{W}{g} \times r \times \left(\frac{2\pi \times N}{60} \right)^2 \qquad [1]$$

where F is centrifugal (vibration) force (kgf), W is ball weight (kg), g is gravitational acceleration (9.8m/sec^2), r is rolling radius of internal ball (m), N is revolution (rpm). The relationship between the centrifugal force and internal ball type shows in Fig. 2. Each ball revolution is 6,000 rpm (100Hz).

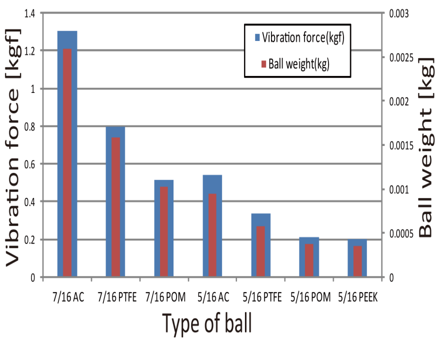

FIG. 2. Vibration force

7/16: 7/16 inch dia.
5/16: 5/16 inch dia.
AC: alumina ceramic
PTFE: polytetrafluoroethylene
POM: polyoxymethylene
PEEK: polyetheretherketone

MRE data were acquired on a 2.0-T animal experiment scanner (BRUKER, Karlsruhe, Germany). A self-modified spin echo (SE) MRE sequence was used for data acquisition. SE-MRE imaging parameters were a coronal imaging plane, 12-cm FOV, 256 × 128 acquisition matrix, 400-ms TR, 27.7-ms TE, 5-mm slice thickness, 160Hz vibrations (9,600rpm), four time vibration phase offsets, 52-sec one phase offset acquisition time, and 6.25-ms motion sensitizing gradients (MSGs) were applied symmetrically around a refocusing (180°RF) pulse.

Results and discussion

Figure 3 shows the change of measured displacement vs. vibration frequency for the difference of internal ball. Peaks (35Hz, 70Hz) of displacement are sympathetic vibration of ball vibrator. The measured displacement of each internal ball is related to ball weight (W) and rolling radius (r). Moreover, this relationship is consistent with calculation result (Fig.2) of eq.[1]. Even though the vibration frequency increase, the amount of displacement is maintained at a certain value, except a sympathetic vibration.

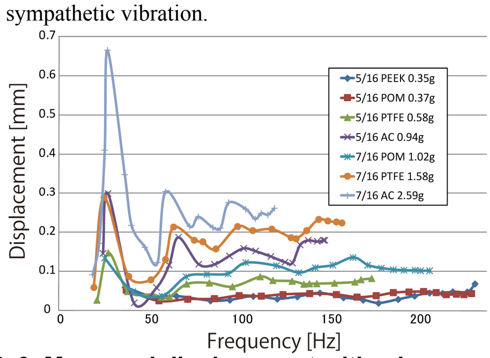

FIG. 3. Measured displacement with a laser sensor

Figure 4 shows the comparison between the uniform phantom images and the unique phantom images. We used a Local Frequency Estimate (LFE) algorithm freeware (MRE/Wave, MAYO CLINIC) for this experiment. The elastogram of uniform phantom shows nearly homogeneous stiffness, except a surface layer (3.0%). By comparing the magnitude image of unique phantom and the elastogram of unique phantom, even though the magnitude image shows nearly homogeneous image intensity, the elastogram is carrying out imaging of internal globular portion (1.25%).

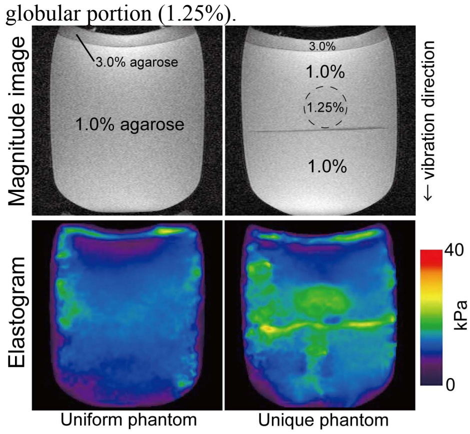

FIG. 4. Agarose-gel phantom MRE study

This ball-vibrator can be used as vibrator for MR elastography.