A convertible pneumatic actuator for brain and phantom elastography

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Introduction

Here we present a pneumatic actuator design developed for human brain magnetic resonance elastography (MRE). The MRE is part of the MR examination protocol, which provides input data for a neurosurgical oncology rehearsal and training system. Authentic information on mechanical properties of healthy and tumor tissue makes realistic emulation of haptic perception in the neurosurgical simulations possible.

Methods

The following criteria are important in actuator design:

- minimize possible interference of the actuator with other MR examinations e.g. fMRI, DTI etc.,which are included in the protocol. For example, susceptibility artifacts from the actuator could corrupt fMRI data, mechanical actuator parts could visually obscure the projection of images during fMRI, etc.
- easy and fast setup of MRE examination in order to fit within the time restrictions available for the examination,
- provide maximal convenience and safety for the patient,
- flexible design, which allows reconfiguration of the actuator for experiments using phantoms.

Considering these criteria, a pneumatic actuator concept was chosen [1], as an alternative to an electromechanical actuator used in previous MRE brain studies [2;3]. After experimenting with different shapes and configurations of pneumatic drivers, we found that some of the polyethylene containers commonly used for food or personal care products could be exploited for this purpose. We used a pair of liquid honey (noname® brand) bottles because of their shape and flexible walls. A homemade fitting was used to connect the bottleneck to the hard-walled flexible tubes of 8 m length and 32 mm diameter. Two modified active subwoofers placed outside the magnet room were used to deliver acoustic pressure waves into the drivers (see Fig.1(a)). The hoses from the speakers enter the magnet room trough the waveguide filters installed on the shielding cage in order to eliminate any eventual electromagnetic interferences. One speaker is set to operate with a phase difference of 180^0, using a toggle switch. The arbitrary function generator (Tektronix AFG3022B), triggered from the MRE pulse sequence was used to generate the desired acoustic waveforms. The system is capable to operate in a frequency range of 25 -150Hz. Three different MRE actuator configurations are available:

Head actuator - thermally molded tray, which could be slit into the head coil, serves as the base for the head actuator (see Fig. 2B). Velcro® strips are used to attach the drivers to the tray. The drivers are placed in a “V” shape around the back of the head. Foam-padding installed between them provides additional support for the head. A small exchangeable towel covers the bottles and foam pad during the exam for hygienic reasons.

Probe actuator – the drivers are placed in homemade brackets and attached to the coil instead of head restrainers (see Fig. 2C). The T-bar placed between the drivers is secured with Velcro® strips. The height of the actuator contact plate is adjustable, using a screw. Various contact plates can be used with the actuator according the phantom’s size and shape.

Bed type actuator – when a large contact area with the source of oscillations is desirable or when the sample is enclosed in a container, the configuration can be changed to a so called bed-type actuator [4]. The holder, equipped with four rollers, is positioned into the bottom part of the head coil. The sample cart is placed on the rollers between the drivers (see Fig 1D). Two notches on the bottom keep the cart secure on the rollers during vibrations.

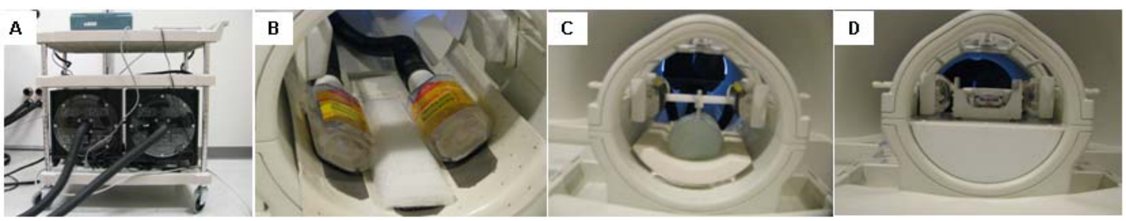

Fig.1 The modified subwoofers are used to deliver acoustic pressure waves into the actuator drivers (A), head actuator (B), probe type actuator (C) and bed type actuator (D).

Results and Discussion

A modified gradient echo and an EPI phase contrast sequence were used on a 3T TIM Trio Siemens MRI scanner. The local frequency estimate (LFE) algorithm (MRE/Wave software from MRI research lab, Mayo Clinic) has been used to calculate the elastograms. Fig. 2 shows images of a cylindrical agarose gel phantom (0.5% matrix, 0.75% inclusion) obtained with the gradient echo sequence using TR/TE=350/15ms, FOV=150mm, resolution of 128x128 pixels and a slice thickness of 5mm. The probe type actuator was used with 150Hz wave excitation and 8 time points were encoded with one cycle of the motion encoding gradient (MEG) of 4mT/m amplitude. Fig. 3 shows MRE images of brain acquired at a mechanical excitation of 50 Hz. The EPI sequence was used to acquire 20-wave snapshot images (Fig. 2B) with one cycle of MEG of 30mT/m amplitude.

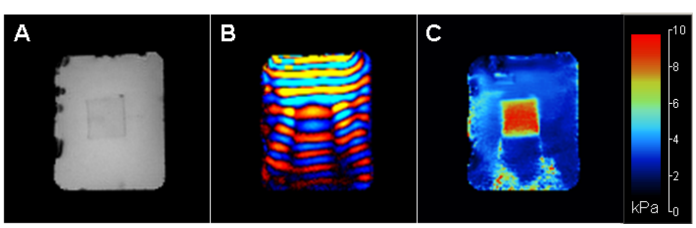

Fig.2 MRI image of the gel phantom with inclusion (A), wave image obtained at 150Hz (B) and the estimated shear stiffness (C).

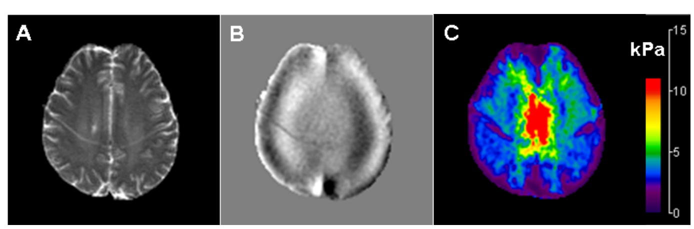

Fig.3 MRI image of a brain (A), wave image obtained at 50Hz (B) and estimated shear stiffness (C).

Conclusion

In this paper, we describe a convertible pneumatic actuator design to generate vibration for MRE experiments. The experimental results on both the phantom and volunteer showed that the actuator produces suitable shear waves for the calculation of viscoelastic properties of tissues and materials in the frequency range of 25-150Hz. The unique feature of our design is its flexibility and ease of use.

References

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