Regional Biomechanical Property of Intracranial Tissue using Dynamic Diffusion MRI: A Phantom Study

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INTRODUCTION:

We have reported that the apparent diffusion coefficient (ADC) in cerebral white matter significantly changed during the cardiac cycle, due to the arterial-blood volume loading of the cranium even though minimizing the bulk motion effect [1]. This change in ADC provided information on the biomechanical properties, and was useful for diagnosis of normal pressure hydrocephalus [2]. To clarify the mechanism, i.e., the fluctuation of the water molecules in the intracranial tissue, we determined the temporal ADC waves obtained with diffusion magnetic resonance imaging (MRI) using a hemodialyzer phantom.

METHODS:

The hemodialyzer phantom consisted of capillary vessels, extravascular space, and intracranial capacitor (pressure damping) components, which were filled with syrup solution (ADC = 0.6 mm^2/s) and air (Fig. 1). These correspond to a blood capillary, brain tissues, and brain capacity, respectively. Then, the volume loading was periodically applied to the capillary vessels of the phantom by a to-and-fro flow pump for simulating the fluctuation of water molecules of the brain (Fig. 1d). On a 1.5-T MRI, diffusion weighted images (DWI) were obtained in synchronization with the volume-loading using ECG-triggered single-shot diffusion EPI (30 phases) with sensitivity encoding and half-scan techniques to minimize the data sampling window (Fig. 1d). ADC maps in a direction perpendicular to the capillary vessels, i.e., x-y plane, were calculated from the DWIs (b = 0 and 1000 s/mm^2) at each volume loading phase (Fig. 1c). We compared the ADC wave and the internal pressure wave in the extravascular space during the volume loading cycle (high- and low- volume loadings were 0.165 and 0.097 mL, respectively).

RESULTS AND DISCUSSION:

The peak ADC in the x-y plane corresponded with the maximum slope of the internal pressure (Fig. 2, Fig. 3). Changes in the ADC in x-y plane and internal pressure in extravascular space in high- volume loading were larger than those in low- volume loading (Fig. 2, Fig. 3). However, the ADC-change/volume-loading and the compliances (volume-change/ pressure-change) in the phantom were almost the same between high- and low- volume loadings (approx. 2.63 $mm^2/s/mL$, 0.041 mL/mmHg). These results show that the water molecules in extravascular space were fluctuated by the volume loading in capillary vessels, i.e., the ADC change depends on the volumetric change per unit time. This relation provides the biomechanical information of the phantom, i.e., intracranial tissue.

CONCLUSION:

Our original phantom makes it possible to analyze the change in ADC due to the volume loading, assess the biomechanical property, and verify the mechanism of the fluctuation of water molecules in the intracranial tissue.

REFERENCES:

[1] Nakamura T et al., Radio Phys Technol 2009; 2: 133-137.

[2] Ohno N et al., Proc. Intl. Soc. Mag. Reson. Med.; 2010.

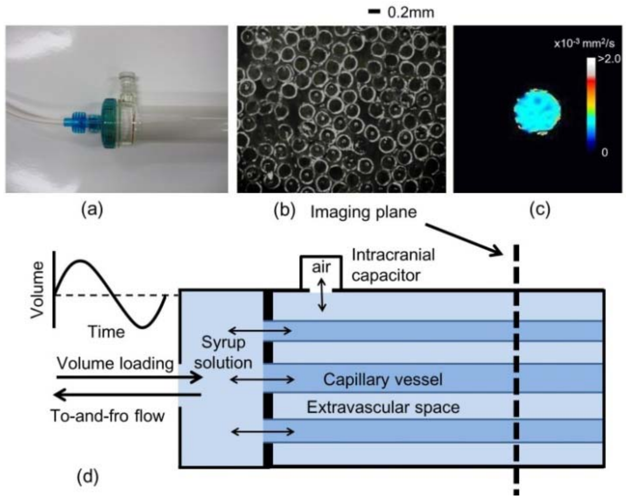

Fig. 1(a) Lateral view of the phantom, (b) microscopic image of imaging plane, (c) acquired ADC image in a state of rest, and (d) phantom for simulating that the water fluctuation was affected by biomechanical factors.

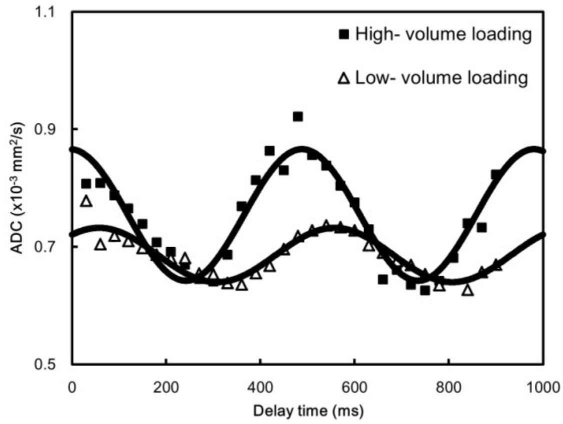

Fig. 2 ADC wave during volume loading cycle.

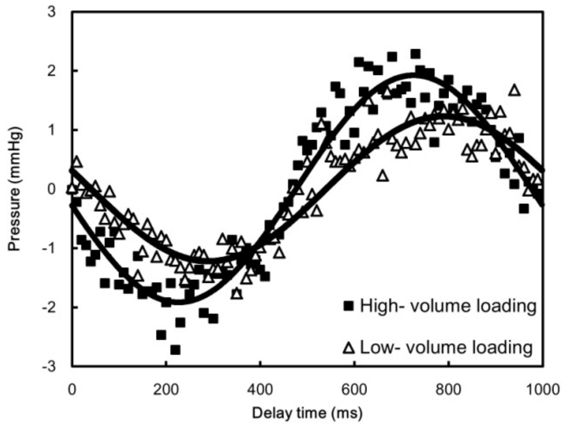

Fig. 3 Internal pressure wave in extravascular space during volume loading cycle.