High-speed MR Imaging of Intervascular Physiolgy

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Introduction. Systemic physiological oscillations due to changes in cardiac output, autonomic blood pressure, or respiration create dynamic fluctuations in cerebral perfusion. In the brain of healthy adults, the propagation of these systemic changes into the brain is modulated by both complex biofeedback mechanisms referred to as dynamic cerebral autoregulation and by the biomechanical properties of blood vessels and the rigid dural and skull layers enclosing the brain. The relationships between oscillations in the major cerebral arteries and systemic physiology are revealing of these properties and have been previously explored to characterize cerebral autoregulation with transcranial Doppler ultrasound methods.

In this work, we developed ultra-fast (9.4 hertz) T1-weighted dynamic MRI and used this method to record spontaneous inter-vascular cerebral oscillations in normal healthy volunteers. This high-temporal resolution time-series allowed visualization of the cardiac, respiratory, and blood pressure related oscillations, which were localized to the large arterial and venous cerebral blood vessels. Phase-contrast angiography images were used to identify the underlying vascular structures and to define regions-of-interest corresponding to the internal carotid and vertebral arteries, the anterior, middle, and posterior cerebral arteries, and the sigmoid, straight, and sagital sinus. We preformed time-frequency analysis of the dynamic oscillations in these various vascular structures and examined their relationships to systemically measured cardiac and respiratory function.

Methods. High temporal, T1-weighted MRI scans (TR/TE/θ =107ms/5.4ms/70^o) were recorded using a 3.0T Phillips Achieva scanner at the Dartmouth Hitchcock Medical Center. An 8-channel SENSE head coil was used with a SENSE acceleration factor of 2.3. We acquired nine axial slices with a slice thickness of 3.75mm and a slice gap of 3.75mm and an in-plane resolution of 3.75x3.75mm (64x64 resolution matrix) using a gradient EPI sequence. The axial edge of the field-of-view was positioned just below the internal carotid arteries as shown in Fig 1A. A finger-clip pulse oximeter and respiratory belt were recorded at 100Hz and synchronized to the MRI acquisitions. Sagital phase=contrast images were also acquired with a velocity encode factor of 30cm/s, which allowed visualization of both the arterial and venous structures.

Results. A range of low and high-frequency physiological oscillations was clearly visualized within the cerebral blood vessels. In the large arteries, the cardiac oscillations were highly correlated with the systemic pulse-oximeter measurements. These oscillations were dampened and spectrally broadened in the venous blood vessels (Fig 1C), which was expected based on the mechanical dampening of the cardiac wavefront as it propagates through the vasculature and brain tissue. Cross-correlation analysis (Fig 3B) further revealed very different spectral patterns in the arterial and venous systems.

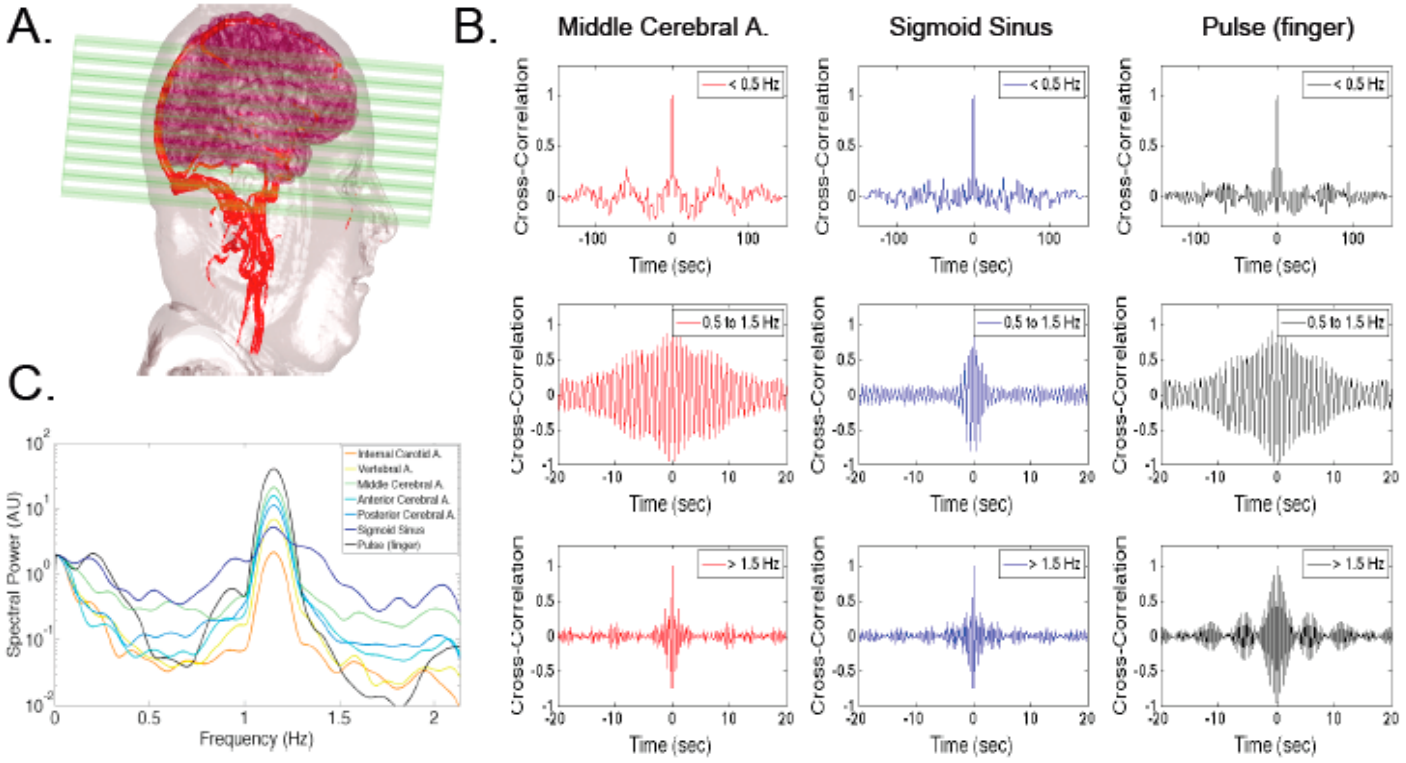

Fig 1. A) Slice orientation for dynamic scans overlain on structural and angiography volumes. B) Cross-correlation spectrum for the middle cerebral artery, sigmoid sinus, and pulse-oximeter for low (<0.15Hz), medium (0.5-1.5Hz) and high (>1.5Hz) frequency bands. C) Power spectrum for the arterial and venous regions-of-interest around the cardiac frequency band.

Conclusions. We hypothesize that the ability to measure cerebral fluctuations using dynamic MRI can provide new tools to assess the vascular fitness and biomechanical properties of the cerebral vasculature and may provide future insights into risk factors of cerebral vascular diseases.