Simultaneous Quantitative Flow-Measurement using MRI and Optical Coherence Doppler Tomography

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Introduction

Optical Coherence Doppler Tomography (OCDT) is a functional extension of Optical Coherence Tomography (OCT) [1], which is a novel non-invasive optical imaging modality that allows cross-sectional imaging with a very high spatial resolution (in the order of 10 μm), albeit in a limited penetration depth (around 2 mm in turbid medium). OCDT is capable of imaging static structures and spatially resolved flow dynamics of the sample simultaneously, which could be potentially a very useful tool that can be combined with MRI system and performed simultaneously in applications such as capillary-level blood flow measurements or flow-pattern imaging in fluid dynamics. This abstract presents the development of an MR-compatible OCDT system and demonstrates its first application inside a high-field (4T) MRI system for simultaneous quantitative flow-measurement using a phantom.

Methods

The MR-compatible OCDT system was built based on a fiber-optic based Michelson interferometer (Fig.1) and employed an MR-compatible optical probe (Fig.2). The light source used was a broadband light source (SLED) with the center wavelength at 1300 nm, whose light was coupled to the interferometer via single-mode optical fiber and divided at a 2x2 fiber coupler into reference and sample arms of the interferometer via single-mode fibers (Fig.1). The MR-compatible optical probe was designed based on a piezoelectric transducer bender (PZT) for lateral scanning capability and on a conventional lens relay system for light relay to and from the sample and was connected to sample arm of the interferometer via single-mode optical fiber for light transmittal and detection duty inside a high magnetic field environment. Axial (depth) scanning capability of system as well as control of detected signal's carrier frequency was achieved by rapid scanning optical delay line (RSOD) employed in reference arm, which was designed based on group delay generation using Fourier domain optical pulse shaping technology that employs a diffraction grating and a galvano mirror [2]. The backscattered light from sample that was collected by the probe and path-length matched at the fiber coupler between the reference and sample arms is amplified and detected by an InGaAs-based photodetector which was coupled to the fiber coupler via single-mode fiber. The detected signal is digitized with a 12-bit A/D converter before being transferred to a PC for image process. Image processing involved short-time fast Fourier transform on the detected time-domain signal in which the static and velocity images of sample were constructed using the power spectrum at carrier frequency of detected signal and the Doppler shift in center frequency of power spectrum, respectively. Use of optical fibers allowed all of sensitive optical and electronic components of system to be mounted on an optical table that was positioned in a location away from strong magnetic field environment of 4T MRI scanner with only the MR-compatible probe placed inside the RF-coil (Fig.3). Intralipid solution (~1%) was used as laminar-flow model in testing the system as well as demonstrating its performance during the simultaneous flow-measurement with 4T MRI, for which phase-contrast based sequence using a bipolar flow-encoding gradient [3] was used to measure flow.

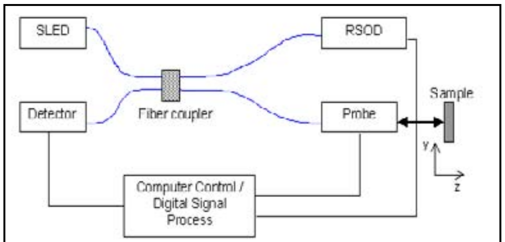


Fig.1: Schematic of the MR-compatible OCDT system

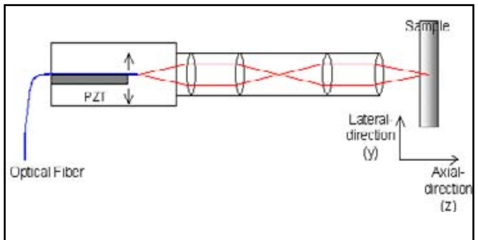


Fig.2: Schematic of the MR-compatible optical probe

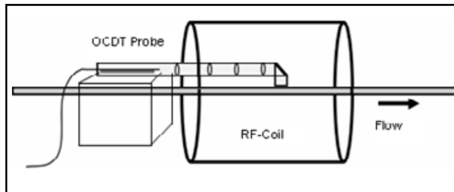


Fig.3: MR-compatible optical probe inside RF-coil

Results

Figs. 4 (a) and 4 (b) show a cross-sectional view of laminar-flow velocity distribution and the velocity profile across the middle (d=2.2 mm), respectively, as measured by the MR-compatible OCDT system. Fig. 5 (a) and 5 (b) show the velocity profiles simultaneously obtained with OCDT and MRI and then co-registered across a laminar flow (d=2.2 mm) and their correlation, respectively.

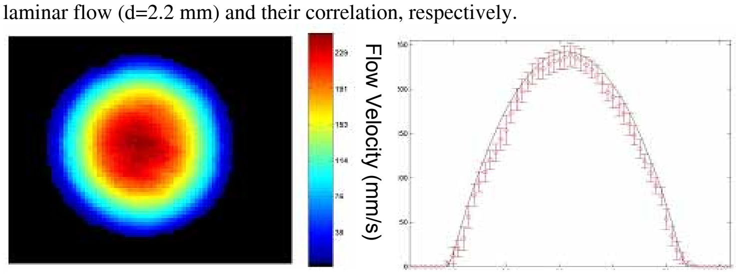


Fig. 4 (a) at left and Fig. 4 (b) at right: Color-coded circular cross-sectional laminar-flow velocity distribution (left) and the velocity profile across the diameter (right), solid-line expected and red-dot measured with OCDT.

Fig.5 (a)

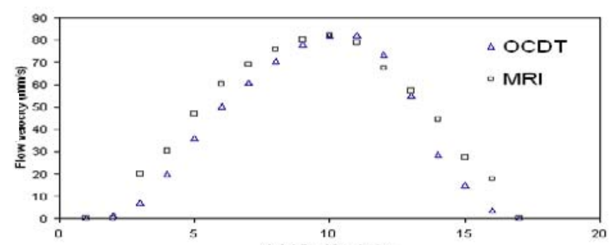
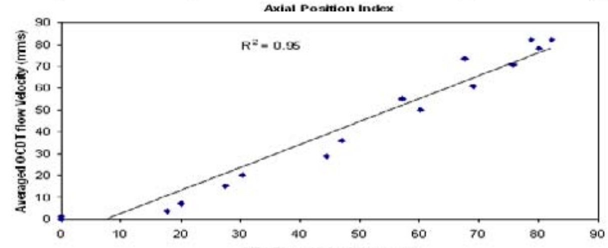


Fig.5 (b)



Discussion

Our study presented here represents the first simultaneous application of OCDT and MRI in flow-measurement, demonstrating a good quantitative correlation of the velocity profile between these two imaging modalities. OCDT could potentially be used to complement MRI in flow-measurements using its much higher spatial resolution as well as means to validate MRI measurements when used simultaneously. The wide gap in spatial resolution between these modalities, however, requires a robust means of co-registration method between them in order to fully realize their potentials in simultaneous applications.

Ref.: [1] Huang et al. Science 254: 1178-1181, 1991. [2] Tearney et al. Opt. Lett. 22: 1811-1813, 1997. [3] Moran et al. Mag. Res. Imag. 1: 197-203, 1982.