Manipulator-mounted optical/NMR dual-modality probe for multimodality scanning in MR guided and robot-assisted interventions

Junmo An[1], Ahmet E. Sonmez[1], Mahmut Unan[1], Robert D. Darrow[2], Ileana Hancu[2], R. Jason Stafford[3], Andrew G. Webb[4], and Nikolaos V. Tsekos[1]
[1]University of Houston, Houston, Texas, United States, [2]GE Global Research Center, New York, United States, [3]University of Texas MD Anderson Cancer Center, Texas, United States, [4]Leiden University, Leiden, Netherlands

Target Audience: interventional MRI, multimodality, optical and MRI

Purpose: Multimodality biosensing is emerging as a valuable approach for characterizing the pathophysiology of tissue. Optical fluorescence and MR spectroscopies (MRS) may offer complementary information about endogenous or exogenous fluorophores and metabolites, respectively. While depth penetration is an issue for optical tomography, endoscopic approaches position the probe near the region of interest, therefore reducing this limitation. Recently the combination of light-induced fluorescence (LIF) and MRS was demonstrated[1]. We describe a forward looking optical/NMR probe for loco-regional in situ biosensing for collecting LIF and 1H MRS from the same region. This dual modality probe was mounted on an MR compatible manipulator to (I) co-register MR image, LIF and MR 1H spectra, and (II) mechanically scan to assess the spatial distribution of fluorophores (from LIF) and metabolite (from MRS).

Methods: Fig. 1 shows the optical/MR probe composed of: (1) a 1.25mm OD 7-fiber optical sensor and (II) an RF coil (OD 2.3mm, length 2.2mm, five turns 26 AWG). Six fibers were connected to an LED (filtered at 450nm) for high power light emission and one fiber was used for reception of light connected to an optical spectrometer (USB 2000+, Ocean Optics). For 1D spatial scanning, the probe was pulsed by an in-house shielded PiezoWalk motor (PI, Germany). This probe was tested on three-compartment phantoms with characteristic optical Fig. 2(a) and 1H signals Fig. 2(b): (I) comp-1 water-based gelatin (1H at 4.9 ppm) and fluorescein for LIF, (II) comp-2: oil-based gelatin (1H peak at 1.4 ppm) and no fluorophore, (III) comp-3: water-based gelatin with choline (1H at 3.3 ppm) and fluorescein/ rhodamine-B for LIF. The manipulator, and thus the LIF/MR probe, was first registered to the MR scanner from images collected with the microcoil as a Tx/Rx fiducial marker. Scanning entailed the steps: (1) motion of the sensor to a new position, (2) trigger MR to collect a free induction decay (FID) (flip angle = 20°; 5000 Hz and number of points = 2048), (3) trigger optical spectrometer for LIF spectra (5s collection). The spectra were then ordered based on the spatial position of the probe from the registration and the optical encoder signals, and presented as contour plots of the spectra with the vertical axis being the axis of scanning (for clarity the water proton signal at 4.9 ppm was omitted).

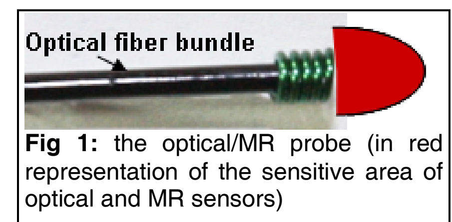

Fig 1: the optical/MR probe (in red representation of the sensitive area of optical and MR sensors)

Results: As reported in the table, the presence and operation of the probe and manipulator had no effect on the SNR of GRE images and 1H spectra. Fig. 2 shows spectro-spatial contour plots for both modalities clearly showing the two boundaries between the three compartments. LIF spectra show fluorescein in comp-1, Rhodamine-B/fluorescein in comp-3, and lack of any signal in comp-2. The MRS exhibits identical patterns: comp-1 has only water signal at (not shown), comp-2 has oil signal (peak at 1.4 ppm), and comp-3 has choline (peak at 3.3 ppm). Spatial matching was within the LIF/MRS mechanical resolution of 0.5 mm: the boundaries from MRI were calculated at -9.2 and +3.3 mm, from LIF spectro-spatial plot at -8.8 and +3.6 mm and from MRS at -8.2 and +3.7 mm.

Motor Status	Spectra	Images
unpowered	12023±487	72.96±2.79
unpowered	11956±570	77.68±3.80
powered (no motion)	12294±530	73.34±2.80
powered (motion)	12188±648	73.00±2.81

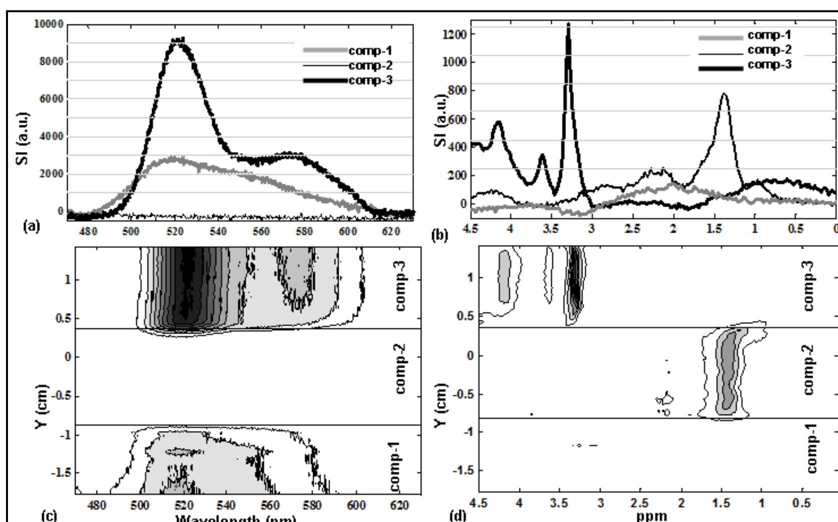

Fig 2: (a) LIF and (b) 1H MR spectra from each compartment. (c, d) contour plots of (c) LIF and (d) 1H spectra collected along the Y MR scanner axis. Horizontal lines in (c, d) delineate the boundaries of the compartments.

Discussion: The use of MR and optical sensors may have impact in improving diagnosis in situ, as well as in performing basic research in vivo. For instance, it may enhance the detection of tumor margins and even used to guide biopsies[2]. Compared to a prior work that reports LIF/MRS[1] (A) our probe has spatially matched optical and MR profiles (without post-processing[1]) and (B) the side-firing probe scans via an NMR tube that is inappropriate for in vivo and clinical studies[1]. Clinically, the herein described probe can be operated the same way as a standard clinical confocal endoscope (i.e. placed in the scanned area and pulled back[3] or it can be directly mounted on the end-effector distal end.) Currently, we investigate other microcoil shapes. In addition, we study the 3D spatial matching of the LIF and MR sensors with simulations (LIF profile with Monte Carlo and coil with Biot-Savart). This type of sensor can be modified, e.g. for optical conference tomography (OCT) and with coils for phosphorous (^{31}P) or sodium (^{23}Na) MRS.

Conclusion: We describe a forward looking MR compatible optical/MR probe for assessing the spatial distribution of co-registered optical and 1H signal sources using a pull mechanical scan.

References: (1) Sonmez et al, JMR 222, 16-25 (2012), (2) Zhu et al IEEE-TBME 56, 2518-2528 (2009) (3) Sung et al IEEE TBME 49, 1168-1172 (2002)