A New Phased Array Magnetic Resonance Imaging Coil For Hbo2 Studies

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Abstract*—Functional Magnetic Resonance Imaging (fMRI) measures brain activity by detecting blood flow changes as cerebral blood flow and neuronal activation are coupled. fMRI is noninvasive, is considered safe, and may allow studying the brain under hyperbaric conditions. This new coil may be necessary for studying decompression sickness and disorders of hyperbaricity, including nitrogen narcosis. This study focuses on the safety and technical details of building fMRI coils for human hyperbaric studies. One of the most remarkable properties of this novel technology is that the new multichannel arrays provide high-quality images at 3 Tesla (T) MRI, one of the highest strength magnets among the most common MRI scanners available in the market. The paper describes all the risks associated with simultaneous MRI and Hyperbaric oxygen therapy (HBO2) and discusses mitigation strategies and regulatory testing. One of the most significant risks for this type of study is a fire in the hyperbaric chamber caused by the sparking of the MRI coils due to high voltage RF arcs. RF pulses at 128MHz elicit signals from the human tissues, and RF sparking occurs commonly and is considered safe in normobaric conditions. We describe how we built a coil for HBO2-MRI studies by modifying an eight-channel phased-array MRI coil with all the mitigation strategies discussed. The coil was fabricated and tested with a unique testing platform that simulated the worst-case RF field of a 3 Tesla MRI in a Hyperlite hyperbaric chamber at 3 atm pressure. The coil was also tested in normobaric conditions for image quality in a 3 T scanner in volunteers and SNR measurement in phantoms. Further studies are necessary to completely characterize the coil safety for HBOT/MRI studies by following the Guidance for Industry and Food and Drug Administration titled "Testing and Labeling Medical Devices for Safety in the Magnetic Resonance (MR) Environment".

Keywords-hyperbaric oxygen therapy; MRI; safety; diving medicine.

I. INTRODUCTION

Magnetic Resonance Imaging (MRI) and functional Magnetic Resonance Imaging (fMRI) have rapidly gained acceptance as "the gold standard" for diagnosing and evaluating neurologic conditions. This adoption comes from MRI's perceived non-invasiveness, avoidance of ionizing radiation, and ability to elucidate the human nervous system's fine anatomic and functional nuances. MRI and fMRI have, however, not been utilized in the study of Hyperbaric Oxygen Therapy (HBO2) due to the genuine dangers that these two challenging environments present.

HBO2 has been accepted for the treatment of many neurological conditions (e.g., decompression sickness, carbon monoxide poisoning, cerebral arterial gas emboli, etc.) and postulated to help in many others (stroke, cerebral palsy, and even autism); however, there has not been a safe method to utilize the tools of MRI and fMRI to evaluate mechanisms and efficacy of HBO2. The hyperoxic high-pressure environment of HBO chambers and the powerful magnetic fields of the MRI scanner are traditionally incompatible. There are genuine risks of mechanical injury to the integrity of most chambers by magnetic forces, space, and access challenges to the patients in both monoplane chambers and MRI scanners, and --likely the most concerning-- the risk of fire from radio frequency (RF) MRI generated arcing in a hyperoxic environment. For many years HBO2 has provided safe and effective treatments for many diseases. Hyperbaric chambers provide oxygen administration in a manner that has few side effects. Combining these two technologies (HBO2 and MRI) can reveal other illnesses that HBO2 and fine-tuning established HBO therapies can treat, such as stroke rehabilitation [1]. In this paper, we discuss the risks as well as strategies and technological approaches to mitigate these risks and enable MRI and fMRI studies to be performed under hyperbaric conditions. We hope that these technological breakthroughs will permit both an increased understanding of HBO2 mechanisms as well as a clinical tool to evaluate the efficacy of HBO2.

II. METHODS

A new type of receive array MRI coil was designed and built to minimize fire hazards by using a combination of electronic protection components and fire retardant epoxy for insulation. Figure 1 (left panel, Top), in which eight surface coils are connected each to an independent amplifier and receiver channel (see below). The outputs from the receiver channels are combined in an optimum manner with a phase correction dependent on the point in space from which the signal is originated. Technical issues related to the mutual inductance of the coils have been addressed by using partial loop overlap [2]. In contrast, we followed the current state-of-the-art MRI systems by adopting a phased array coil design.

III. RESULTS

The new MRI coil for HBO2 was fabricated (Figure 1, left panel) and tested at 3 Tesla. The constructed array coil passed the safety tests [3] without additional adjustment beyond the bench adjustments. The design included an 8-channel phased array with extremely large area coil loops that have resulted in very high image quality. The head coil was composed of (Figure 1 left panel, middle): (A) lattice balun with a PIN diode for detuning during transmit and every soldering was inspected and photographed, (B) copper wires loops, (C) distributed capacitors, and (D) fuses.

The following image acquisitions were performed on a human volunteer for a total scan time of approximately 2 hours. Figure 1A (right panel) shows the amplitude and phase of a field map. A field map can help reconstruct high-fidelity images as it is typically acquired during the MRI system tuning. Furthermore, lipid suppression can be much more robust by measuring the field map and adjusting the acquisition parameters.

One of the most common MRI sequences is the T1-weighted scan which depicts differences in signal based upon intrinsic T1 relaxation time of various tissues. Figure 1B-C (right panel) shows the typical and high-quality T1-weighted images. In these images, fat tissue realigns its longitudinal magnetization with B0, which appears bright. Conversely, tissues predominately made out of the water, such as central spinal fluid, have a much slower longitudinal magnetization realignment after an RF pulse and appear dark.

Separate MRI and HBO2 studies have shown that imaging is a quantitative biomarker that can help guide and optimize HBO2 therapy [4]. However, only performing simultaneous fMRI and HBOT will enable studying the brain-altering effects of nitrogen narcosis or oxygen toxicity.

IV. CONCLUSIONS

To the best of our knowledge, this is the first work aiming at imaging the brain in extreme pressurized environments, like HBOT, which have significant repercussions for understanding the brain in conditions like decompression sickness, which are currently poorly understood. We expect to complete the safety studies and request IRB/IDE to complete the HBO2/fMRI studies in future work.

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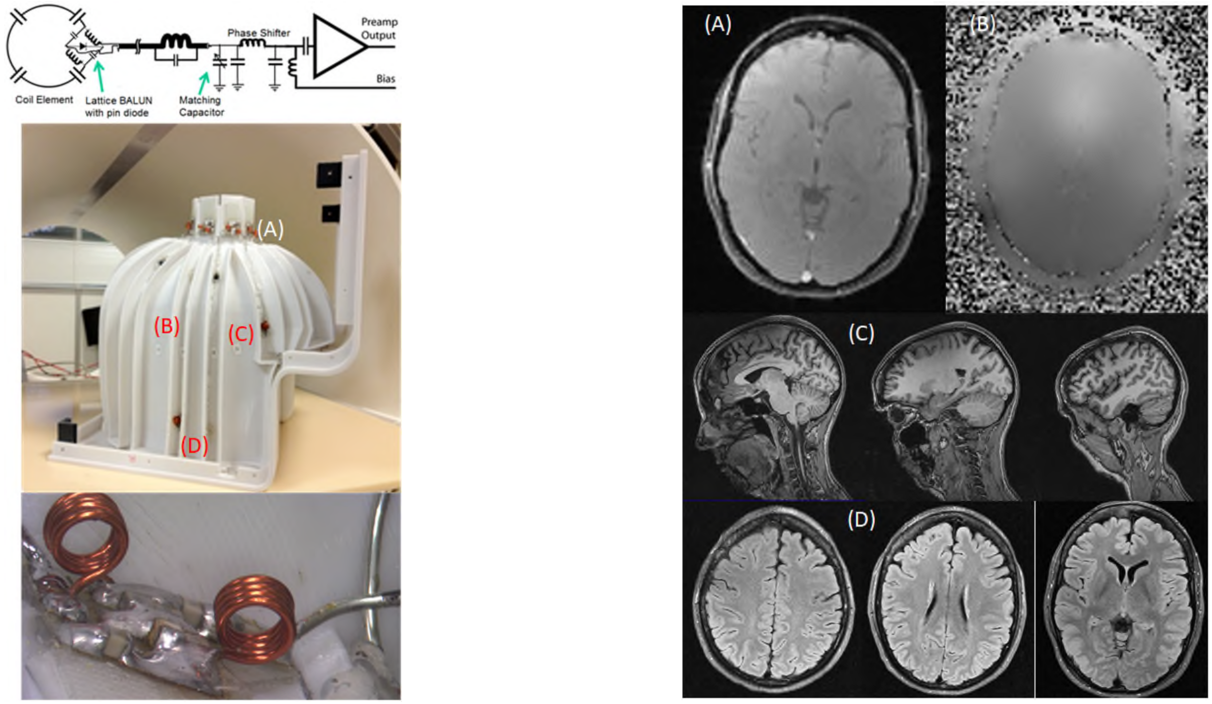

Figure 1 (LEFT PANEL) The MRI Coil. (Top) Design of the layout and schematics of the 8-channel Phased Array Coil System. (Middle) The new coil: (Bottom) lattice balun. (RIGHT PANEL) 3 Tesla normobaric MR images. (Top) Field map images of magnitude (A) and phase (B), sagittal (C), and axial (D) T1-weighted MPRAGE images.