Radiofrequency properties of two different Licox® parenchymal brain tissue oxygen probe designs

Ari Ercole[a,b]

[a]*Division of Anaesthesia, University of Cambridge, Cambridge, United Kingdom.*
[b]*Corresponding author: ae105@cam.ac.uk*

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1. Introduction

Neuroimaging and continuous multimodality neuromonitoring are both central to the intensive care management of patients with severe traumatic brain injury [1]. Guidelines recommend the use of multimodality monitors including brain tissue oxygen ($P_{bt}O_2$) sensors to assess the adequacy of cerebral oxygen delivery [2]. Devices such as the Licox® sensor (Integra LifeSciences, Plainsboro, NJ) employ a miniature implantable electrochemical cell. Temperature compensation is essential for accurate measurements and the device is now available with an integrated temperature sensor (Model CC1P1)[3]. Both devices are rated as MR compatible to 1.5T by the manufacturer.

With the common availability of 3T instruments, the radiofrequency (RF) properties of such implantable probes at $f_{proton} = 127.74$MHz is of interest. The wavelength of electromagnetic radiation at such frequencies becomes comparable to the scale of common monitoring equipment. The combined CC1P1 probe is physically very different than the original probe (Model CC1SB) without temperature sensing. In particular, its length of around 40cm represents a quarter wavelength at 187MHz which is not too different from f_{proton} and could conceivably approach the 3T Larmor frequency if loaded appropriately. In contrast, the CC1SB probe (which we have been using at 3T for some years in our institution without incident after extensive phantom investigation) is less than half this length.

2. Materials and methods

The author has investigated the RF properties of both the CC1P1 and CC1SB probes by inductively coupling them to a vector network analyser (HP8752A) using a toroidal inductor positioned approximately half-way along the length of the probe (where the magnetic field should be strongest at resonance). The coupling inductor consisted of 40 turns of 30SWG enamelled copper wire on a small ferrite toroid (EPCOS AG, Munich, Germany) (17.2mm od x 8.5mm i.d. x 7.3mm, N87 material; inductance factor $A_L = 1420$nH). This was mounted using epoxy on a small piece of coplanar waveguide made from 0.8mm double-sided FR4 fibreglass printed circuit board constructed using ultraviolet photolithography itself coupled to a SMA connector (Figure 1). A single-port (reflection mode) calibration was used to null the inductive load characteristics. Measurements were made using 1601 points with a 3% of full scale smoothing window was applied to clean the data. The data was exported from the device using custom USB / GPIB interface software written in Python.

3. Results and discussion

Figure 2 shows the magnitude of the complex reflection coefficient S_{11} as a function of frequency. The electrically longer, temperature compensated CC1P1 probe shows a strong resonance centred at approximately 150MHz which has broad tails which overlap and therefore could couple to f_{proton}. This resonance could easily be 'pulled' by coupling with any nearby objects although this was very sensitive to the exact probe configuration and the nature of the objects around. In particular it was possible to unpredictably electrical 'lengthen' the probe and down-shift this resonant frequency even closer to f_{proton}. Such an effective lengthening is possible by attachment to a patient. Given this observation, it is highly likely that this resonance could be excited in some circumstances *in vivo* depending on the detailed layout of the probe and patient within the scanner. No such resonance is seen with the shorter CC1SB probe.

A resonant frequency so close to f_{proton} is concerning as, if a particular patient configuration caused it to become strongly coupled to the scanner RF field, it could lead to localised heating of the brain due to actual or displacement currents that would then be generated exist at the end of the probe. It would seem prudent in the design of such implantable probes to avoid physical dimensions which may be prone to resonate like this. Alternatively, if such dimensions are unavoidable, then either MR-compatible chokes will be needed to electrically lengthen the devices and push the resonant frequency well below f_{proton} or resistive elements engineered to make the resonance sufficiently lossy as to dissipate any absorbed energy harmlessly away from the patient. Such considerations will become even more important if 7T MRI machines are to be used for research into traumatic brain injury in the hyper acute phase.

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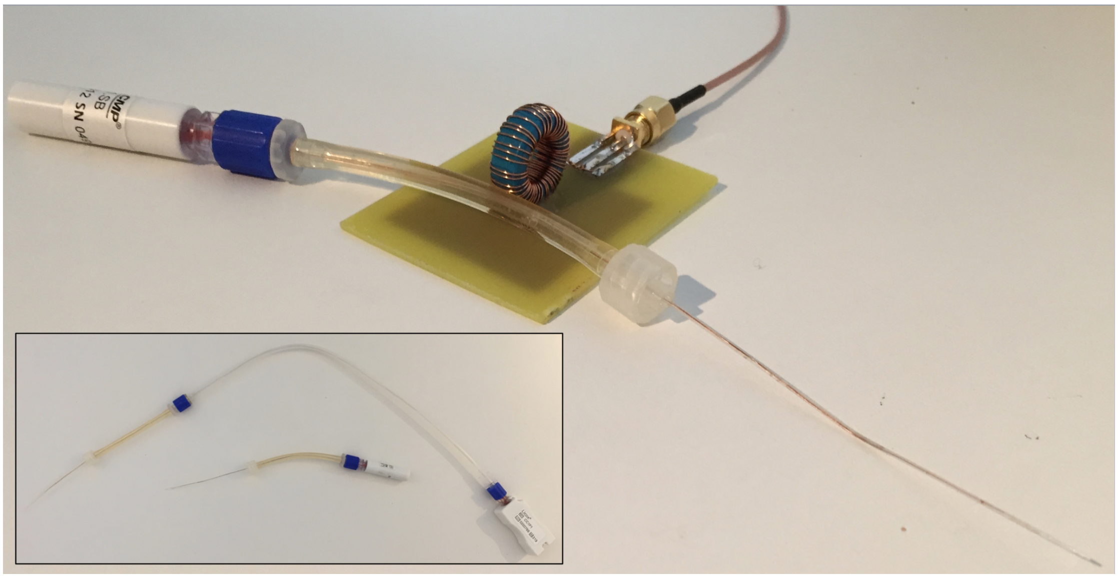

Figure 1: Experimental apparatus. The inductor is constructed from a ferrite toroid wound with approximately 40 turns of 30SWG enamelled copper wire. Coupling to the probe was achieved through proximity. Pictured is a Model CC1SB $P_{bt}O_2$ probe without integrated temperature sensing. The inset shows the CC1SB (lower device) and CC1P1 next to each other. The difference in lengths is apparent.

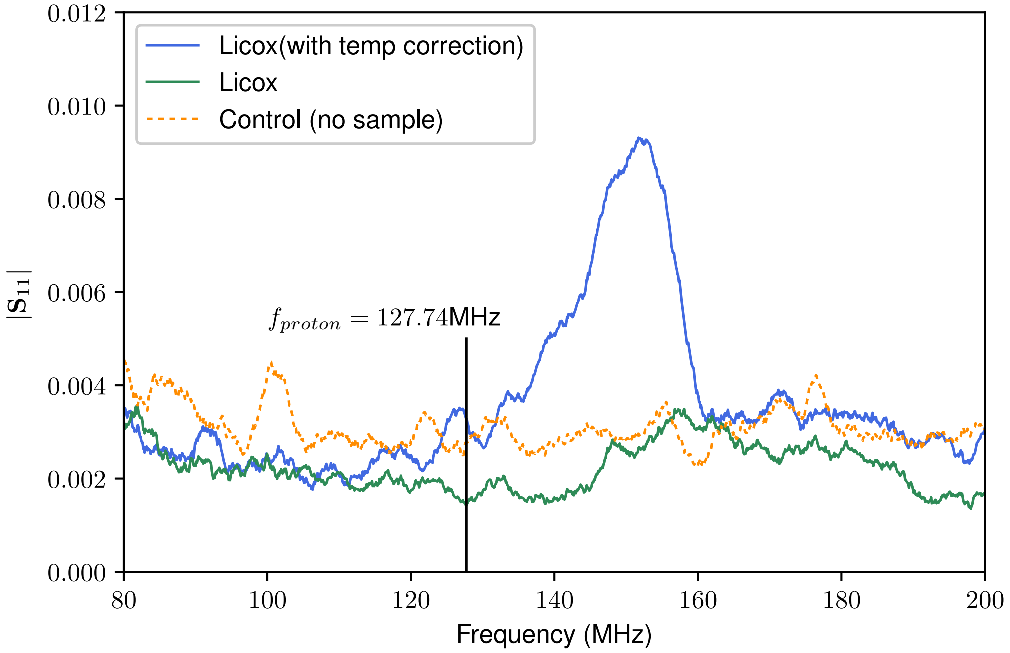

Figure 2: Modulus of the complex reflection coefficient S_{11} as a function of frequency. The proton Larmor frequency for 3T is indicated by the vertical line.

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