Using a Microwave Sensor as an Online Indicator of Neurological Impairment during Surgical Procedures

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Abstract. Lactate is known to be an indicator of neurological impairment during aortic aneurysm surgery. It is suggested that cerebrospinal fluid removed during such surgery could provide useful information in this regard. Medical professionals find the prospect of online detection of such analytes exciting, as current practice is time consuming and leads to multiple invasive procedures. Advancing from the current laboratory based analysis techniques to online methods could provide the basis for improved treatment regimes, better quality of care, and enhanced resource efficiency within hospitals. Accordingly, this article considers the use of a low power microwave sensor to detect varying lactate concentrations. Microwave sensors provide a rapid non-invasive method of material analysis, which is robust, cost-effective, and has huge potential for a wide range of biomedical applications.

Introduction

Patients who are undergoing surgical or endovascular aneurysm repair (EVAR) of acute and chronic thoraco-abdominal aortic disease [1, 2] have an inherent risk of paraplegia. This is caused by restriction of the spinal cord blood flow and lack of oxygen during the procedures, typically referred to as spinal cord ischemia [3]. The current preventative measure practiced by surgeons is to collect CSF by inserting a spinal drain. In doing so, pressure upon the spinal cord is reduced, and thus, so too is the inherent risk of paraplegia.

At the moment any CSF collected would normally be discarded as biological waste. However, researchers are Liverpool Heart and Chest Hospital (LHCH) are active in looking for ways to identify the onset of paraplegia in patients. Part of this work involves CSF analysis in the search for indicators of sub-clinical cord ischemia and compromise. This notion at that CSF might harbor such important information is supported by Drenger *et al* [4], who observed that lactate concentration in CSF increased with the onset of patient paraplegia. One would normally expect to see physiological levels of lactate in blood around 1mmol/L; in pathology this may rise to 10-15mmol/L, or higher in the case of exercise [5].

Analysis of CSF would be most practical immediately after it has been drained from a patient, since in many cases this would allow the surgeon to take immediate corrective action. In many cases this could remove the need for subsequent surgical procedures, thus improving the efficiency of hospital resources and arguably improving patient care. Previous work by the authors [6, 7] has considered of *microwave spectroscopy* using a resonant microwave cavity as a potential method to rapidly analyse CSF in real-time as it is extracted from a patient in-surgery.

Research Methodology

Previous work by the authors [8, 9] has considered the detection of lactate, a known indicator of paraplegia, in simple media such as water. The work presented here is a progression of this, looking at increasing the complexity of the background media in which the lactate is contained, in addition to using smaller quantities of lactate to better mimic the real-world.

To this end, the work involves dilutions of lactate in phosphate buffered saline (PBS) solution, which is analogous to water; at low microwave frequencies (< 2 GHz) very little is distinguishable between PBS solution and serum. The levels of lactate present in the PBS are restricted to physiological levels; 0.0, 1.25, 2.5, 5.0, 10.0, 15.0 and 20.0 mmol/L. All samples were prepared immediately stored in a refrigerator to prevent fouling. Quartz NMR tubes (2.5mm radius, 180mm length) were used to store the samples, with the sample volume being 0.6ml; note that the tubes are not filled as the cavity is sensitive only to volumes of < 0.5ml. Sample temperature was controlled simply by removing the samples from refrigeration for very short periods of time. It is notable that previous work has typically relied on much larger sample volumes (10-15ml) so this also represents a significant improvement in the current work.

The experimental setup used for this work is shown in Fig. 2. The samples were exposed to a purpose built 2-port resonant microwave cavity in which the fundamental mode occurs at approximately 1.75 GHz when empty, as predicted by work from Pozar [10]. The cavity has internal dimensions of 65mm (radius) and 30mm (height). A Rohde and Schwarz ZVA24 vector network analyser (VNA) was used for the purposes of data acquisition, with this unit being appropriately calibrated according to manufacturer specifications. Data was captured in the frequency range 1-16GHz in for both reflected ($|S_{11}|$) and transmitted ($|S_{21}|$) power. Post processing of the data identified a number of interest regions, particularly within the $|S_{11}|$ data – it is these results which are presented in this paper. Each sample was tested three times and an average taken. The results presented in this paper show calibration curves at key areas of interest within the captured microwave spectrum.

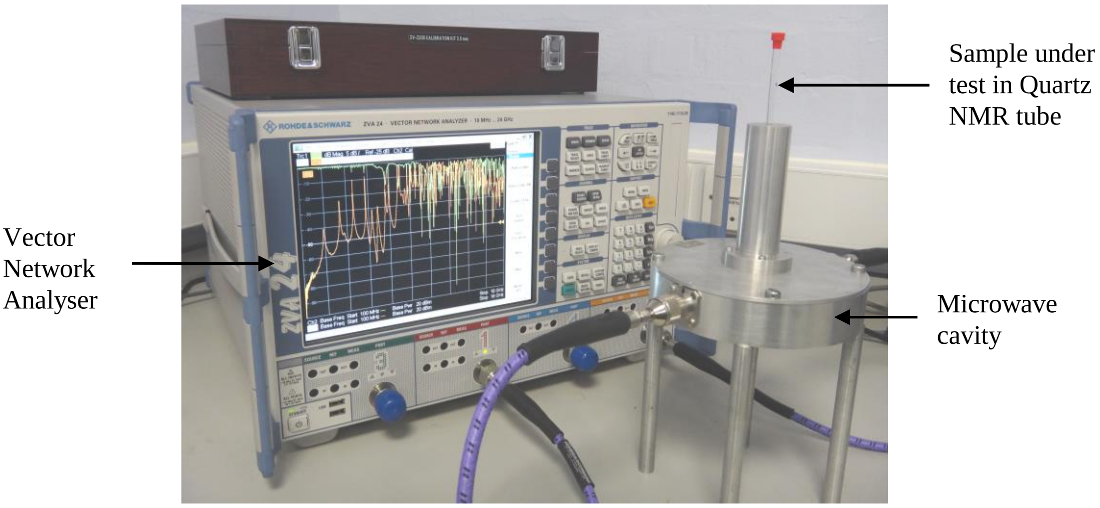

Fig. 1. Experimental setup, showing the utilised microwave resonant cavity, vector network analyser and sample under test.

Results

Fig. 2 shows an example of the results obtained after data processing to find areas of change in the captured spectrum. It is assumed that that the change can be directly correlated with varying lactate content as no other parameter is varied during the experimental procedure. Temperature variation is often a source of error in measurements such as these [11, 12]. However, such phenomena often manifests as broad spectral shifts – Fig. 3 demonstrates that such spectral shifts are not present, particularly where one might expect them to be displayed (i.e. at lower fundamental resonant frequencies) if one were to measure simple dielectric material properties via the small perturbation method [13, 14]; the authors have engaged in such measurements in previous work [15].

A number of interest regions were discovered in the acquired spectrum, namely at the frequencies *9.5379*, *11.6806* and *13.4450GHz*. The response at each of these frequencies varies in terms of amplitude. The amplitude response at each of these frequencies is shown in Fig. 4, with each data set conforming to a 4th order polynomial best fit curve (as indicated by a dashed line at each frequency). Table 1 details the changes exhibited in the range of 0-20mmol/L, assuming a linear response.

Summary

This paper discusses work toward a novel method of early detection for impending spinal cord ischemia and compromise through utilising CSF drawn from the patient during surgical procedures such as EVAR. Real-time instantaneous monitoring could prove useful to save time, both for patients and for hospital trusts, as any problems discovered could be corrected as part of a single on-going surgical procedure.

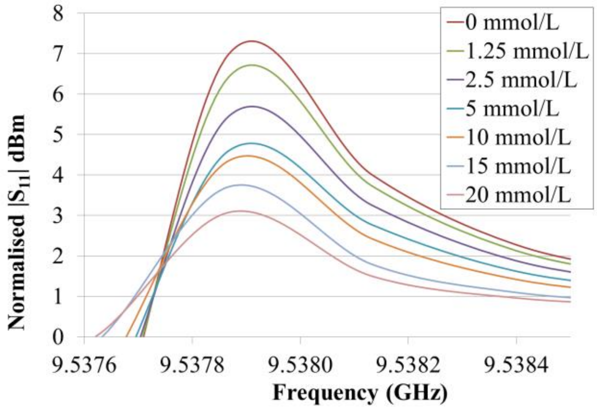

Fig. 2. Example of results obtained, showing $|S_{11}|$ in the frequency range 9.5376 – 9.5385GHz.

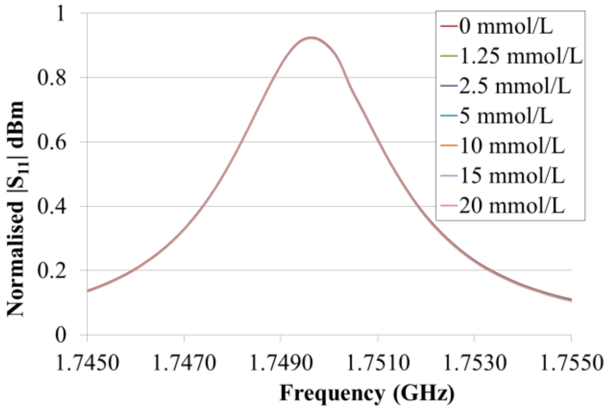

Fig. 3. Change is not spectrum wide, at fundamental modes signals overlap.

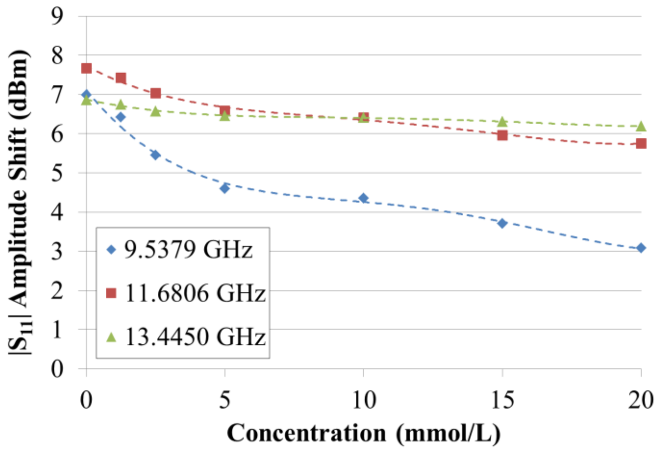

Fig. 4. Amplitude changes exhibited at 9.5379, 11.6806 and 13.4450 GHz using a cylindrical cavity resonator and varying lactate concentrations in PBS solution.

	Amplitude changes exhibited (dBm)	
Frequency (GHz)	*Per mmol/L*	*Entire range*
9.5379	0.1955	3.9107
11.6806	0.0961	1.9233
13.4450	0.0334	0.6669

Table 1. Change exhibited by the sensor at 9.5379, 11.6806 and 13.4450 GHz.

Studies have shown that lactate is a marker of such a condition, and this paper strengthens the belief that it possible to detect physiological levels of lactate in small volumes of PBS solution, which has been shown to behave similarly to whole blood at microwave frequencies. This builds upon previous work by the authors in the area of sensors for during surgical procedures, and gives confidence that the method could be used as a real-time indicator. The change demonstrated by the sensor in response to change from normal to abnormal lactate levels suggests that it would be relatively simple to construct a simple traffic light type device where green indicates normal lactate levels (i.e. ≈ 1mmol/L) and red indicates higher than expected levels (i.e. ≥ 10mmol/L). In addition, the sensor exhibits good sensitivity to small changes giving promise also for other applications within the medical field. Future work will seek to confirm the robustness of the technique in serum, in addition to investigating further the specificity of the sensor in relation to various other analyte materials which might be present in varying quantities. Finally, the identified regions of interest in this paper will be inspected more closely to characterise fully the nature of the exhibited changes (i.e. in terms of amplitude *and* frequency shifts).

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