Feasibility of Thoracic Impedance Measurements in Seawater

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Abstract: There is are numerous poorly understood aspects of breathing by aquatic mammals. Impedance measurements and EIT could provide useful information. We conduct simulations and show early results of impedance measurements in seawater.

1 Introduction

Breathing in aquatic mammals is poorly understood; of particular interest are changes in the respiratory mechanics while diving [2]. Improvements in this area may be useful to our understanding of humans diving. The effect of breath-hold diving on pulmonary function humans and marine mammals is poorly understood. Studies have shown that increasing pressure causes alveolar compression and a depth-dependent pulmonary shunt that eventually results in alveolar collapse and cessation of gas exchange. A better understanding of these changes in gas exchange with depth could lead to novel clinical management and perhaps explain stress-associated stranding of marine mammals [1].

Bioimpedance measurements (BioZ) and EIT have seen much use in land mammals as a technique to monitor breathing and the distribution of lung gasses in a non-invasive way. It would be exciting if such measurements were possible in seawater.

2 Methods: Simulations

The key challenge: seawater is much more conductive than body tissues (5.0 S/m compared to 0.7 S/m for blood). This means that current can travel more easily outside the body than inside, and would suggest that the EIT sensitivity to conductivity changes is much lower.

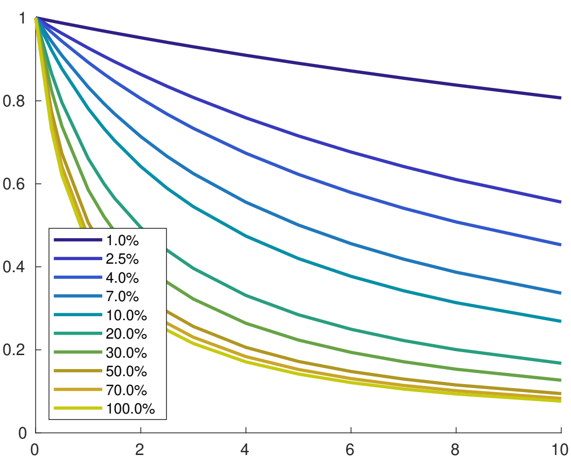

Figure 1: Relative EIT sensitivity to a conductivity change in the centre of a circular body, as a function of the conductivity ratio ($\sigma_{\text{seawater}}/\sigma_{\text{body average}}$) of the liquid into which the body is placed. Lines correspond to the thickness of the liquid layer as a function of the body radius.

In order to understand the impact of this changed sensitivity, we build a finite-element model of a circular body with 16 electrodes with spherical "heart" in the centre which received a bolus of conductive blood. A "seawater" region around the body was created of varying thickness (to simulate either a neoprene-covered body (small thickness) or open water (large thickness). The adjacent protocol EIT signal was simulated and the rms signal normalized to the open air (zero conductivity around the body) case. Results (Fig 1) show that open seawater surrounding a body decreases the signal to less than 10% of it's original value. On the other hand, a non-conductive neoprene layer will expose only a small thickness of seawater around the body, potentially keeping up to 80% of the signal.

3 Methods: Experiment

In order to explore the effect, experiments were made to measure thoracic bioimpedance for a human going from air to salt water. Our volunteer started standing in a salt-water pool with with water at waist height and electrodes placed underneath a neoprene wetsuit. A $t = 20$ s the subject descended into the water. Breathing maneuvers (deep breathing, tidal breathing and breath hold) were performed, and results shown in Fig 2. Results suggest that physiological BioZ changes can be measured in the water.

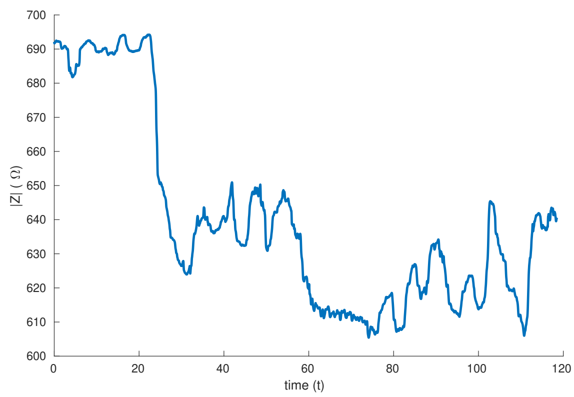

Figure 2: Two-electrodes bioimpedance vs time measured with a MAX30001 bioimpedance demo kit (Maxim Integrated). The subject entered the water at $t = 20$ s. Deep breathing maneuvers were done, and breath was held between $60 - 75$ s.

4 Conclusions

We present simulations and a pilot experiments which suggest that bioimpedance and EIT measurements in salt water are difficult, but possible.

References

[1] Fahlman et al, *Frontiers in Marine Science*, fmars.2021.598633.
[2] Lemaitre et al *J Sports Sciences* 27:1519-1534, 2009.