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ObeSense RTD 2013

Impact of heart motion on stroke volume estimation via electrical impedance tomography

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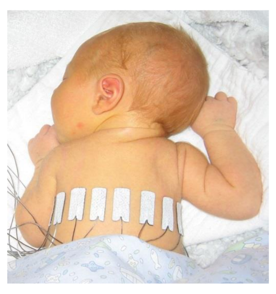
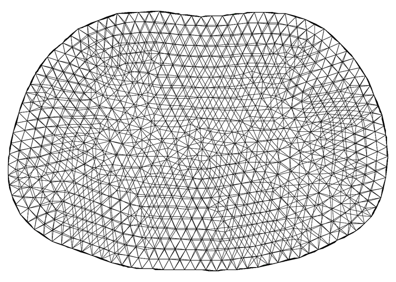
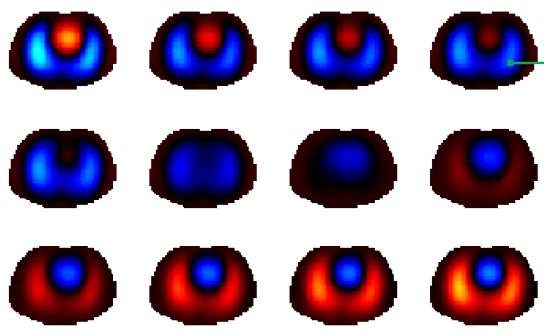
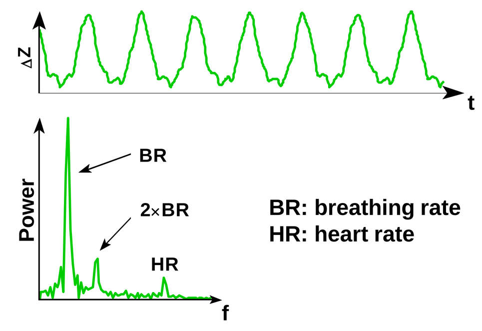
Electrical impedance tomography (EIT)


Impedance measurements

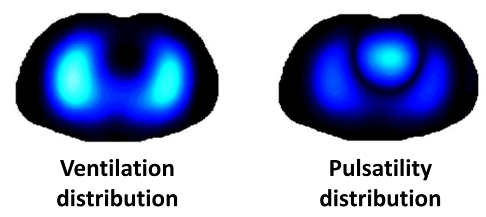

Impedance distribution reconstruction on a finite element model


Real-time visualization of intra-thoracic impedance changes



Pixel-wise analysis of impedance time series

- Continuous non-invasive estimation of respiration-related and hemodynamic parameters
- Assessment of ventilation and pulsatility distributions



Stroke volume via EIT

In EIT, the amplitude of the impedance change in the heart region is usually assumed to correlate with stroke volume, but results in the literature are mixed [1-3]. We thus hypothesize that sources non-related to blood volume are affecting the cardiac impedance change.

Hypothesis #1 The impedance change in the heart region is not only related to blood volume variations but also affected by the mechanical interaction of the myocardium with its surrounding tissues. If true, this hypothesis could explain the mixed results reported so far in the literature.

Experiment #1 A dynamic bio-impedance model was created from magnetic resonance (MR) data. Three scenarios were simulated: In Scenario A (best-case scenario), cardiac blood volume-related impedance changes were reproduced by simulating the filling and emptying of the cardiac cavities. In Scenario B (worst-case scenario), myocardial motion-induced changes were reproduced by simulating the dynamics of the heart muscle. Finally, Scenario C (real-case scenario) simulated both blood volume-related and motion-induced changes, thus Scenarios A and B together.

Hypothesis #2 In some conditions, despite these heart motion artifacts, the cardiac impedance change can still be used as an indicator of ventricular blood volume.

Experiment #2 The global impedance change in the heart region (ΔZ) – obtained during Experiment #1 – was used as an EIT-based estimate of total ventricular volume (TVV_{EIT}) by mapping it onto the reference total ventricular volume (TVV_{REF}) obtained from the MR data. The error (in actual millilitres) induced by the use of motion-affected EIT cardiac signals can thus be evaluated.

Results

Contribution of heart motion to the total impedance change in the heart region

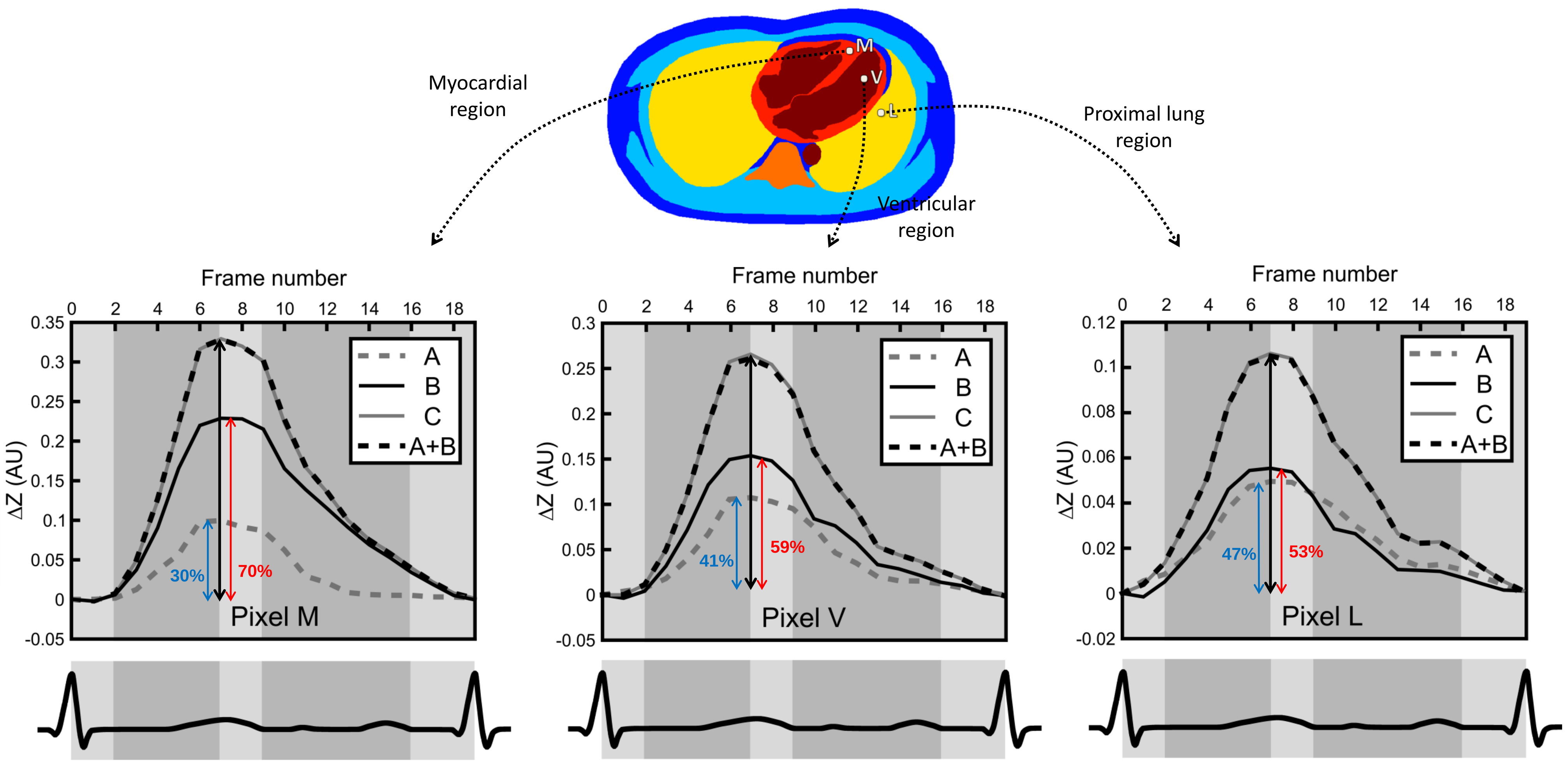
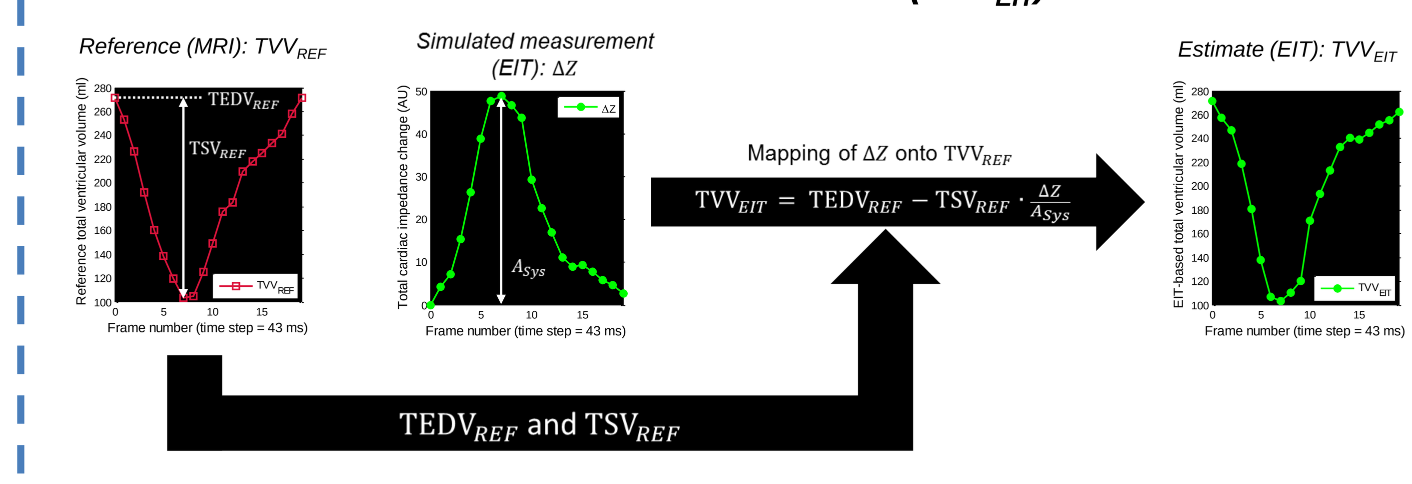


Figure 1: Impedance change occurring in myocardial (M), ventricular (V) and proximal lung (L) regions for all simulated cardiac scenarios. A schematic electrocardiogram is also displayed as an illustrative timing reference. The blue arrows depict the amplitude of the impedance change due to blood volume-related changes (Scenario A), while the red arrows are related to heart motion-induced changes (Scenario B). Both are expressed as a percentage of the total impedance change occurring in reality (curve of Scenario C). Heart motion is thus the main contributor to the total cardiac impedance change.

EIT-based estimate of total ventricular volume (TVV_{EIT})



Total ventricular volume (TVV): Impact of heart motion on the matching between TVV_{REF} and TVV_{EIT}

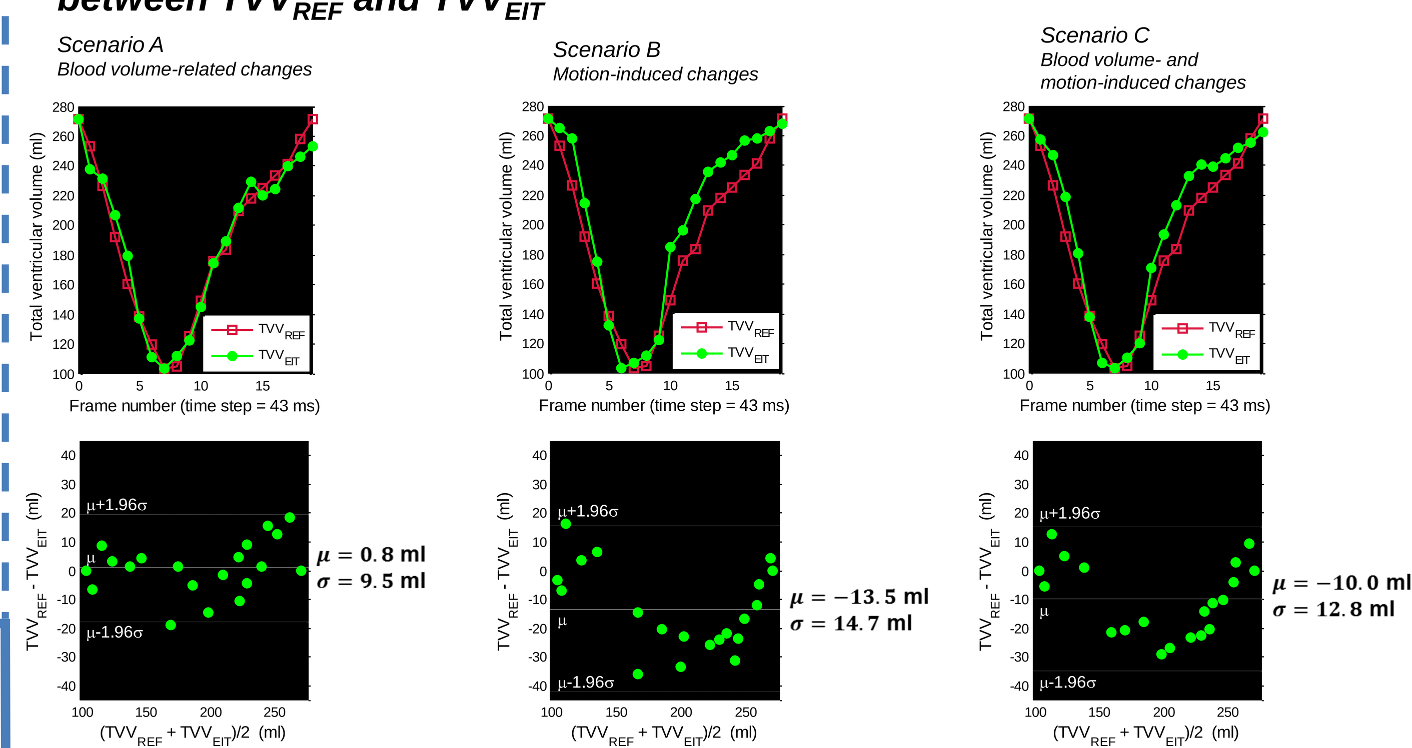


Figure 2: (Upper row) For each scenario (each column), the EIT-based estimate of the total ventricular volume (TVV_{EIT}) is compared with TVV_{REF}. It appears clearly that the matching is much better for Scenario A (ideal motion-free scenario) and strongly affected for Scenario B (worst-case scenario). (Lower row) The same observation can be made from the Bland-Altman plots, depicting the error between TVV_{REF} and TVV_{EIT}, which is of -10.0±12.8 ml in a real-case scenario (Scenario C).

Conclusions

According to simulations performed on a dynamic bio-impedance model, it was found that the cardiac EIT signal in the heart area is dominated up to 70% by motion-induced changes (64% for the whole heart region) [4].

It was further found that, in presence of heart motion (real-case scenario), the impedance change in the heart fits only partially the true ventricular volume. Yet the error (-10.0±12.8 ml) remains sufficiently low to be clinically useful in normal subjects, when myocardial motion and ventricular volume are well correlated [5]. EIT is thus a valid modality for stroke volume estimation.

References

[1] S. Zlochiver et al. Physiol. Meas. 27 (2006)
[2] A. Vonk-Noordegraaf et al. Physiol. Meas. 21 (2000)
[3] R. Pikkemaat et al. Anesthesia & Analgesia (2014) , in print.
[4] M. Proença et al. in BIOSTEC 2014, Angers, France.
[5] M. Proença et al. in EIT 2014, Gananoque, Canada.