Influence of heart motion on EIT-based stroke volume estimation

Martin Proença[1], Fabian Braun[1,5], Michael Rapin[1], Josep Solà[1], Andy Adler[2], Bartłomiej Grychtol[3], Martin Bührer[4], Peter Krammer[5], Stephan H. Bohm[5], Mathieu Lemay[1], Jean-Philippe Thiran[6,7]

[1]Systems Division, Swiss Center for Electronics and Microtechnology (CSEM), Neuchâtel, Switzerland, map@csem.ch
[2]Systems and Computer Engineering, Carleton University, Ottawa, Canada
[3]Division of Medical Physics in Radiology, German Cancer Research Center (DKFZ), Heidelberg, Germany
[4]Institute for Biomedical Engineering, University and ETH Zurich, Zurich, Switzerland
[5]Swisstom AG, Landquart, Switzerland
[6]Signal Processing Laboratory (LTS5), Swiss Federal Institute of Technology (EPFL), Lausanne, Switzerland
[7]Department of Radiology, University Hospital Center (CHUV) and University of Lausanne (UNIL), Lausanne, Switzerland

Abstract: Cardiac electrical impedance tomography (EIT) signals are affected by myocardial motion. The feasibility of stroke volume estimation using such signals is thus questionable. Results based on a dynamic model show that myocardial motion indeed affects but does not compromise stroke volume estimation.

1 Introduction

In EIT, cardio-synchronous impedance changes in the heart region are assumed to reflect variations of blood volume originating mainly from the ventricles [1]. EIT appears therefore as an interesting continuous and non-invasive modality for monitoring total ventricular volume (TVV), and thus estimating total stroke volume (TSV), defined as the maximal change in TVV over a full cardiac cycle. However, there is increasing evidence that other factors – unrelated to blood volume changes – are contributing to these variations of cardiac-related impedance [2]. In that context, simulations we performed on a finite element 2D extruded dynamic bio-impedance model showed that EIT signals in the heart region might be dominated by myocardial motion-induced changes [3].

These findings raised the question whether heart signals – affected by myocardial motion – remain valid for estimating changes in TVV and thus TSV. The hypothesis that the total impedance change in the heart area remains a true indicator for TVV and TSV is thus investigated here.

2 Methods

To test this hypothesis, we exploited the above 2D dynamic bio-impedance model – created from segmented magnetic resonance (MR) data imaged in the heart horizontal long axis plane – and considered three scenarios: In *Scenario A*, we reproduced cardiac blood volume-related impedance changes by simulating the filling and emptying of the cardiac cavities. In *Scenario B*, myocardial motion-induced changes were reproduced by simulating the dynamics of the heart muscle. Finally, *Scenario C* is the real-case scenario and simulates both blood volume-related and motion-induced changes [3].

These simulations were performed on our finite element model over a full cardiac cycle (corresponding to 20 simulated EIT frames) using the open source EIDORS toolbox, with image reconstruction carried out by the GREIT approach [4]. For each scenario, the impedance change ΔZ – with respect to end-diastole in the heart area – was computed for all frames, thus providing an EIT-based indicator for TVV, according to our hypothesis. Hereafter referred to as TVV_{EIT}, it was expected to perform best with *Scenario A* (no heart motion) and worse with *Scenario B* (heart motion only).

The reference TVV_{REF} was obtained by summing the volumes V_{LV} and V_{RV} of the left and right ventricles. V_{LV} and V_{RV} were computed via the area-length method [5] – with the areas (Σ_{LV} and Σ_{RV}) and lengths (L_{LV} and L_{RV}) coming from the MR data used to create our model:

$$\text{TVV}_{\text{REF}} = c_{LV} \cdot \Sigma_{LV}^2 / L_{LV} + c_{RV} \cdot \Sigma_{RV}^2 / L_{RV} \text{ (ml)}, \quad (1)$$

where $c_{LV} = 8/(3\pi)$ [5] and $c_{RV} = 2/3$ [6]. L_{RV} was measured in the vertical long axis plane [6]. The total end-diastolic volume TEDV_{REF} and the total stroke volume TSV_{REF} inferred from TVV_{REF} (see Figure 1) were used to compute TVV_{EIT} by translating ΔZ – normalized by its maximal (systolic) value – into millilitres:

$$\text{TVV}_{\text{EIT}} = \text{TEDV}_{\text{REF}} - \text{TSV}_{\text{REF}} \cdot \Delta Z_{\text{NORM}} \text{ (ml)}. \quad (2)$$

3 Results

The estimation error (mean±SD) between TVV_{REF} and TVV_{EIT} was of 1.9±13.3, –14.1±19.5 and –10.1±15.7 ml for *Scenario A, B* and *C*, respectively.

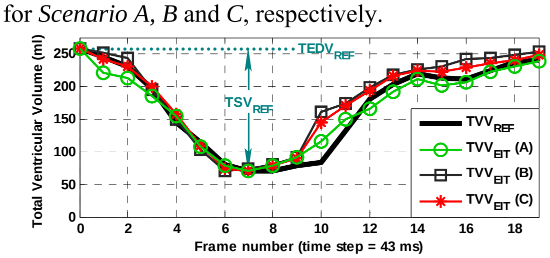

Figure 1: Total ventricular volume estimation using simulated EIT cardiac signals originating from blood volume-related impedance changes (*A*), motion-induced changes (*B*), or both (*C*).

4 Conclusions

In agreement with our expectations, simulations showed that myocardial motion increased the error on TVV_{EIT} and thus EIT-based TSV estimation, without however compromising the approach. When both blood volume changes and myocardial motion are in action (*Scenario C*, real-case scenario) an EIT-based TVV estimation error of –10.1±15.7 ml was obtained, which is sufficiently low to be clinically useful in normal subjects [5].

References

[1] Eyüboglu B, et al. *IEEE EMBM* **8**:39-45, 1989
[2] Hellige G, Hahn G. *Critical Care* **15**:430, 2011
[3] Proença M, et al. In *BIOSIGNALS*. 2014 (in press)
[4] Adler A, et al. *Phys Meas* **30**:S35, 2009
[5] Underwood SR, et al. *Br Heart J* **60**:188-195, 1988
[6] Levine RA, et al. *Circulation* **69**:497-505, 1984