Noninvasive Measurement of Pulmonary Artery Pressure via EIT

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There is a high clinical demand to measure pulmonary artery pressure (PAP). However, existing solutions are either highly invasive or only allow for intermittent measurements by a trained clinician. Research at CSEM during the last years has revealed a potential alternative to measure PAP by means of electrical impedance tomography (EIT). Being low-cost and safe, EIT allows for the fully noninvasive and continuous measurement of PAP. This was first evaluated in a study on healthy volunteers, confirming its potential. More recently, these findings were corroborated in a second study on neonatal lambs where EIT-derived measurements were compared to the invasive gold-standard PAP reference over a large range of pressure values. These promising results pave the way towards a novel way of PAP measurement in clinical settings.

While non-invasive measurements of systemic arterial pressure are routine, few techniques exist to measure pulmonary artery pressure (PAP). Even though PAP can be measured with ultrasound, it requires a high level of expertise, is not possible in all patients, and cannot provide continuous readings. A potential solution is electrical impedance tomography (EIT), a noninvasive medical imaging modality. With EIT and CSEM's original approach[1], the pulsatile signal measured in the lungs can be used to estimate the pulmonary pulse arrival time (PAT) which is inversely related to PAP.

In a first study, this approach was tested on 27 healthy human volunteers in a controlled desaturation study. EIT-derived PAP showed good agreement with transthoracic echocardiographic (TTE) measurements[2,3], as also shown in Figure 1.

In a second step, this approach was verified against the gold-standard PAP reference (right heart catheter) and with larger variations in PAP. To this end, an animal experiment was performed on 11 healthy neonatal lambs. Analysis on four animals led to a high overall correspondence between EIT and gold-standard PAP measures with an average correlation of r = 0.81 (range 0.76 – 0.87). Representative data for one animal is shown (Figure 2), showing good agreement between PAP measures, except in the last phase of the protocol, in which the epinephrine injection caused a decreased duration of the pre-ejection period, thereby affecting the EIT-derived PAT measurement. Data of three animals were rejected due to EIT electrode errors or missing data. In four more animals there was no lung signals present in the EIT data, which is assumed to be due to circulatory shunts in young animals. This phenomenon has never been observed in EIT recordings on humans (neither healthy nor patients) and corroborates the assumption that it is due to the animal model and likely not a limitation of our approach.

Our results demonstrate the feasibility for non-invasive and continuous monitoring of PAP by means of EIT in an unsupervised manner. This opens new perspectives for the clinical management of pulmonary hypertensive patients.

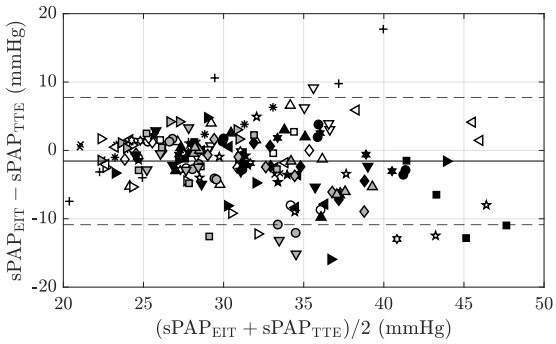

Figure 1: Bland-Altman plot comparing EIT-derived systolic PAP (sPAP) versus TTE-derived sPAP for 27 healthy human volunteers undergoing normobaric hypoxia exposure in a controlled desaturation study.

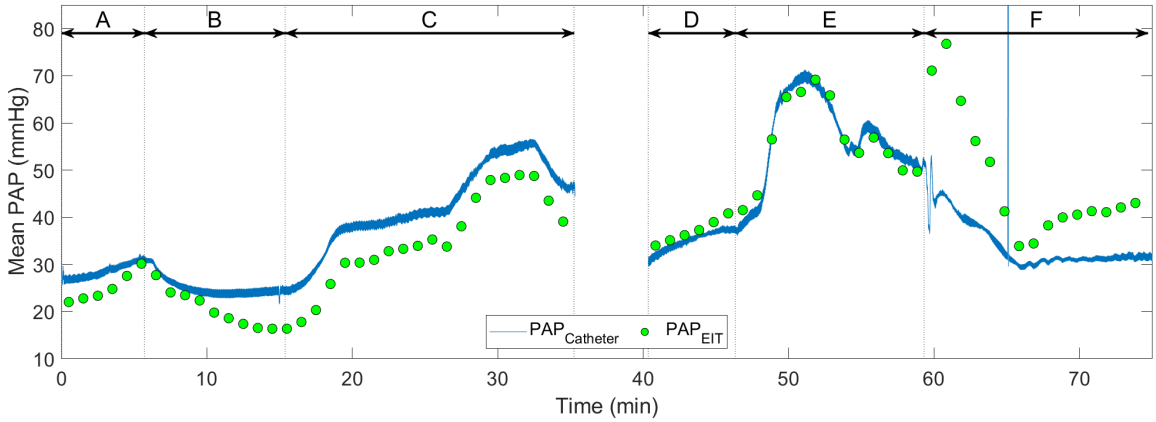

Figure 2: Invasive reference $PAP_{Catheter}$ versus PAP_{EIT} for one representative animal. A: FiO_2 = 21 %, B: FiO_2 = 100 %, C: FiO_2 = 12–14 %, D: FiO_2 = 21 %, E: FiO_2 = 12–14 % + hypoventilation, F: FiO_2 = 100 % + epinephrine.

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[1] J. Solà, J. Brunner, "Method and Apparatus for Time-Based Analysis of Electrical Impedance Tomography Data", Patent: WO/2012/007425 (2012).

[2] M. Proença, *et al*., "Non-invasive monitoring of pulmonary artery pressure from timing information by EIT", Physiological Measurement, vol. 37, no. 6, pp. 713–726 (2016).

[3] M. Proença, *et al*., "Non-invasive pulmonary artery pressure monitoring by electrical impedance tomography: validation in a preclinical controlled desaturation study", in preparation, 2019.