$\dot{V}/\dot{Q}$ analysis with 3D EIT

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Abstract: Bedside measurement of $\dot{V}/\dot{Q}$ matching with EIT has clinical potential. Previous work showed feasibility in 2D, but 3D lung heterogeneity is significant. We demonstrate $\dot{V}/\dot{Q}$ in 3D in data from pigs. Additionally, analysis software is made available.

1 Introduction

Critically ill patients often have significant alterations in gas exchange. Regional matching of ventilation and perfusion ($\dot{V}/\dot{Q}$) is key to ensure optimal gas exchange in the lungs, and thus the importance of bedside monitoring of $\dot{V}/\dot{Q}$ matching. However, even healthy lungs are highly heterogeneous, and current work in EIT-based $\dot{V}/\dot{Q}$ only describes a single 2D image of the thorax [1]. In this study, we develop a two-plane, 3D analysis of regional $\dot{V}/\dot{Q}$.

While EIT-based measurement of air flow ($\dot{V}$) is well understood, work on perfusion ($\dot{Q}$) is ongoing, and both pusatility- and conductivity bolus-based techniques are used. In all techniques, lung perfusion analysis requires complex signal processing techniques to remove the cardiac component. We developed a software tool using a first pass kinetics bolus approach [1] to determine pulmonary blood flow and report regional $\dot{V}/\dot{Q}$. This software is made available (see [3]) to allow comparisons of the signal processing.

2 Methods

With ethics approval, eight female, Yorkshire cross pigs (four months, 55–59 kg, were included. Pigs were sedated anesthetized and mechanically ventilated in a supine position. Standard ICU clinical parameters were monitored. A Swan-Ganz catheter was floated to the pulmonary artery and used to inject saline bolus (10 mL of 7.2% hypertonic saline) during an 30 s apnea. The study consisted of phases designed to modify $\dot{Q}$: Baseline, Dobutamine infusion, Phenylephrine infusion, and Controlled hemorrhage. EIT data were recorded at 47.7 frames/s using a Sentec Pioneer Set and a custom-made, 2×16 electrode EIT belt was placed over the shaved chest region. Three transverse EIT image layers were reconstructed [2].

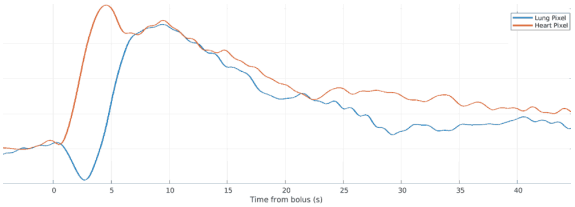

Figure 1: Heart and Lung voxels after bolus injection.

Ventilation images were generated by ensemble averaging over multiple breaths. Perfusion imaging followed the approach of [1]. Voxels corresponding to the heart and lungs were identified manually, the propagation of the bolus through the heart was fit to a gamma function. This function was then fit to all other image voxels and subtracted to yield the lung-perfusion signal (see Fig 1).

The $\dot{V}/\dot{Q}$ ratio for each voxel was calculated using the 3D ventilation, $\Delta Z_{\dot{V},\mathrm{vox}}$, and perfusion, $\Delta Z_{\dot{Q},\mathrm{vox}}$, distributions. Units were calculated using tidal volume (V_T), respiratory rate (RR), cardiac output (CO) and dead space fraction (V_D/V_T), calculated using the Bohr equation:

$$\frac{\dot{V}_{\mathrm{vox}}}{\dot{Q}_{\mathrm{vox}}} = \frac{\frac{\Delta Z_{\dot{V},\mathrm{vox}}}{\Delta Z_{\dot{V},\mathrm{tot}}} \times V_T \times RR \times (1 - \frac{V_D}{V_T})}{\frac{\Delta Z_{\dot{Q},\mathrm{vox}}}{\Delta Z_{\dot{Q},\mathrm{tot}}} \times CO} \quad (1)$$

This equation can be motivated as follows: impedance ratios represent the unitless fraction of impedance change in each voxel. Conversion to $\dot{V}$ and $\dot{Q}$ units requires multiplication by air and blood flows: $V_T \times RR \times (1 - \frac{V_D}{V_T})$ represents effective alveolar ventilation.

3 Results & Discussion

Using these calculations, it is possible to calculate 3D EIT image of the distributions of $\dot{V}$,$\dot{Q}$ and their ratio $\dot{V}/\dot{Q}$ (Fig 2). Note the variability of all parameters across the planes, with a ventral movement in the anterior plane.

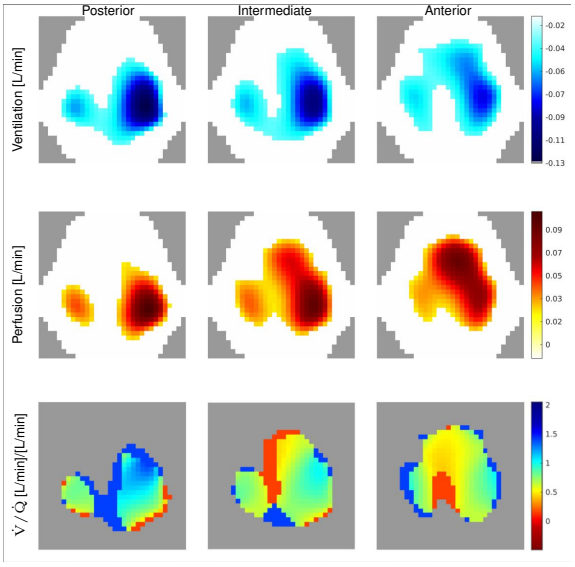

Figure 2: Example (cranial, intermediate and caudal) image slices in an animal. Top: Ventilation, Center: Perfusion, Bottom: $\dot{V}/\dot{Q}$.

In this paper, we are motivated by the importance of monitoring the 3D distribution of $\dot{V}/\dot{Q}$ matching, which would be important clinically due to the heterogeneous nature of these phenomena. We conducted experiments and developed analysis software software to demonstrate feasibility. To further collaboration, software have been released [3] under the GPL license.

References

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[3] J Araos *et al*, sf.net/p/eidors3d/code/HEAD/tree/trunk/dev/VQ_analyze/ "$\dot{V}/\dot{Q}$ analysis software", 2023