EVALUATION FRAMEWORK FOR IMAGE RECONSTRUCTION IN ELECTRICAL IMPEDANCE TOMOGRAPHY

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INTRODUCTION

The life of patients undergoing surgery under full anesthesia or recovering in intensive care units depends on mechanical ventilation of the lungs. While this procedure is vital in clinical routine, artificial and unphysiological pressure conditions within the lungs can damage the lungs and cause severe complications. The detection of related injuries currently relies mostly on the associated changes of hemodynamic parameters, like blood pressure or oxygen saturation, which respond only indirectly to adverse pulmonary events. In order to accurately determine the state of the lungs, high resolution imaging techniques like computed tomography (CT) are typically utilized. Sophisticated medical imaging, however, can only be applied with the drawback of radiation exposure and laborious transportation effort.

In this context, a novel imaging modality, electrical impedance tomography (EIT), has the potential for radiation-free lung function monitoring directly at the bedside. Small currents are injected and the resulting voltages are measured via multiple surface electrodes (usually 16 or 32) attached around the thorax. From these measurements, 2D-images can be reconstructed, visualizing the impedance distribution inside the thorax at high temporal resolution (about 50Hz). The mathematical formulation behind this reconstruction is highly ill-posed, resulting in virtually infinite solutions. In order to identify reasonable impedance distributions, forward solvers (e.g., finite element models) and regularization are applied. Therefore, the resulting images vary based on prior assumptions and the specific algorithms, limiting the objective diagnostic power of EIT.

In this work, a framework is described, which allows for a thorough validation of algorithms based on well-established parameters which can be derived from (i) simulations, (ii) image analysis and (iii) comparison to gold standard modalities. The purpose of this evaluation is to demonstrate the high influence of reconstruction settings on EIT-images and their derived clinical parameters.

METHOD

As forward model, a finite element model (FEM) was created based on piglet CT data, freely available within the open source framework EIDORS [1]. In order to identify the influence of thorax shape on the reconstruction, the original contours were filtered by exclusion of Fourier descriptors (FD), which represent higher spatial frequencies [2]. In total, 6 FEMs were created including all, 15, 5, 3 and 1 FDs and, in addition, an independent model based on a circular shape. Based on these FEMs, GREIT [3] reconstruction matrices (**RM**) were created, see Fig.1.A.

In GREIT, the EIT problem is linearized based on figures of merit that describe the performance of reconstruction after simulated training targets are inserted into FEM, i.e., the forward model. In this work, we generated **RM**s with different training target size *ts*, weighting radius *rw* (i.e., point spread function), and noise figure *nf* (describing the noise amplification of the reconstruction). In addition, lung and heart regions inside FEMs were weighted with different conductivity assumptions $w_{1\text{-}4}$. This results in a set of 9600 different **RM**s (Fig. 1.B). For FEM generation and the definition of forward and inverse solvers, NETGEN and EIDORS framework was used.

Simulation: **RM**s were first described using established figures of merits derived from FEM simulations, i.e., amplitude response *AR*, position error *PE*, resolution *Res*, shape deformation *SD* and ringing *R* [1] (Fig. 2.A).

Image analysis: A single voltage measurement was then reconstructed with all **RM**s and physiological parameters, i.e., center of ventilation *CoV*, right-left ratio *RL*, and global inhomogeneity index *GI*, were calculated (Fig. 2.B).

Gold standard validation: Using CT images, a comparison of these physiological parameters, e.g., root mean square error *RMSE*, can then be performed for each **RM** (Fig. 2.C).

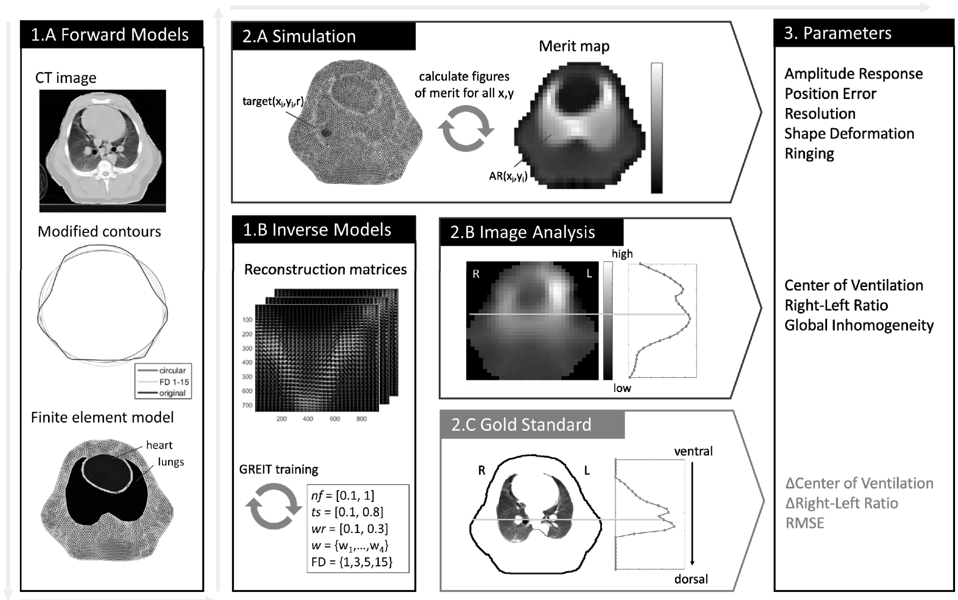

Figure 1 Framework for thorough evaluation of the influence of different reconstruction settings in EIT.

RESULTS AND DISCUSSION

For all output parameters, a strong variability between different **RM**s could be observed. In simulation, values for *AR*, *PE*, *Res*, *SD* and *R* ranged from 0.47 to 2.12; 0.02 to 0.14; 0.21 to 0.50; 0.06 to 0.38; and 0.07 to 0.96. Similar variations were observed during image analysis in *CoV*, *RL* and *GI* with ranges of 33.8% to 55.2%; 0.29 to 0.70; and 0.77 to 4.72.

CONCLUSION

In this work, a novel framework was proposed, which allows a thorough evaluation of EIT reconstruction models, ranging from simulations to image analysis and to final validation. Even though a first evaluation showed a significant influence of reconstruction settings, further evaluation is crucial to describe interrelations and reasonable ranges of output parameters in more detail. In order to provide guidelines for specific EIT applications (e.g., lung monitoring), the validation against a gold standard method will be essential.

REFERENCES

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