ANALYSIS OF COMBINED EXTRACORPOREAL LUNG AND KIDNEY SUPPORT USING A COMPUTATIONAL CARDIOVASCULAR MODEL

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Introduction

Extracorporeal membrane oxygenation (ECMO) is commonly used in intensive care to support cardiac and respiratory failure, yet up to 70 % of these patients also suffer from acute kidney injury. Treatment for this complication involves connecting continuous renal replacement therapy (CRRT) to the ECMO circuit. To date, its connection configuration varies depending on the operator's practice and proficiency, without any gold standard. This study aims to develop a cardiovascular model to investigate the interactions between ECMO and CRRT circuits in veno-arterial ECMO (VA-ECMO) patients, see Figure 1. Using Global Sensitivity Analysis (GSA), the study focuses on improving model fitting by assessing parameter importance, ultimately quantifying the effects of CRRT connection schemes and ECMO pump speed.

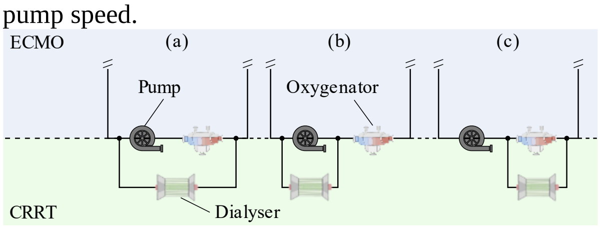

Figure 1: Example for combination of CRRT and ECMO.

Methods

A computational cardiovascular model was extended by both ECMO and CRRT systems with external pumps, filters, and additional cannulas. A GSA was conducted using Sobol indices to identify the model parameters most relevant for the fitting. The model was fitted to six patients with the identified parameters and using gradient-based optimization with multistart. The influence of different CRRT connection modalities and ECMO flows was then investigated for one patient. For this, a GSA was performed including CRRT connection schemes and ECMO pump speed as input parameters, allowing to quantify their influence on clinical outputs. Input samples for each GSA were created using Saltelli sampling and their size is chosen so that convergence is achieved.

Results

Figure 2 presents scatterplots of the model predictions against clinical data for various pressures in a) and flows in b) for six patients. These show a strong correlation with R^2 values of 0.98 for pressures and 0.99 for flows.

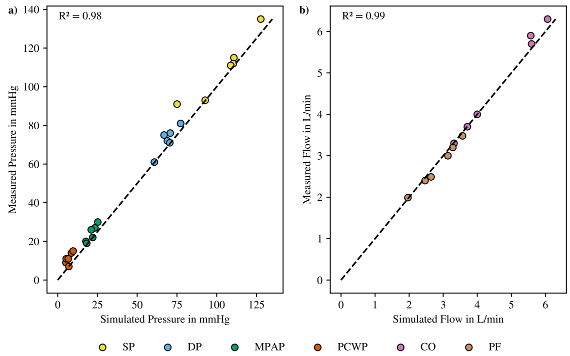

Figure 2: Simulated against measured pressures in a) and flows in b) for six patients. SP, DP: systolic and diastolic pressure of aorta. MPAP: mean pulmonary artery pressure. PCWP: pulmonary capillary wedge pressure. CO: cardiac output. PF: pump flow.

Figure 3 a) illustrates the total effect of model parameters on outputs, while b) quantifies their cumulative total effects. Pump speed (rpm), cardiac properties, vascular resistances, and location of the CRRT return cannula have a high influence, in contrast to all other parameters.

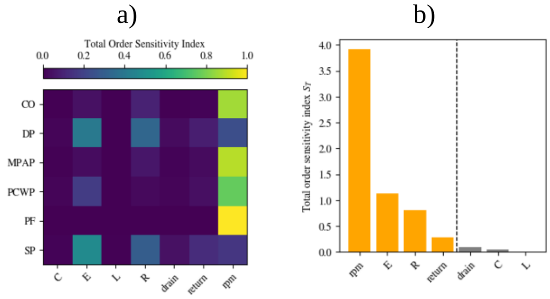

Figure 3: Total effect of model parameters, CRRT connection and ECMO rpm in a) and their cumulative effect in b). Parameters grouped into cardiovascular compliances (C), inertias (L) and resistances (R), and cardiac properties (E).

Discussion

Applying GSA to a cardiovascular model with ECMO and CRRT revealed that using a subset of parameters reduces computational cost without losing predictive accuracy. This model can reliably simulate physiological conditions of VA- or VV-ECMO patients. It was found that the position of the CRRT return cannula has a significant influence on hemodynamic markers. This aids physicians in selecting the optimal CRRT and ECMO combination based on the patient and ECMO flow.

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