COMPUTATIONAL SIMULATIAON OF HAEMODYNAMICS IN PATIENT WITH VA-ECMO

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Introduction

Extracorporeal membrane oxygenation (ECMO) is a device that assists a patient's cardiopulmonary function by oxidizing the blood outside the body and supplying it back to the patient [1]. In the case of peripheral venoarterial (VA) ECMO (p-VA ECMO) that supplies blood back to the body through the femoral artery, a watershed region may be created in the aorta due to the flow of ECMO going against the natural blood flow. In this study, we undertake haemodynamics simulation using computational fluid dynamics (CFD) to assess the mixing of oxygen-rich blood from ECMO and oxygen-poor blood from the heart in a 3D patient-specific aorta at different ECMO flowrates. This allows us to understand the effects of the ECMO support levels on the treatment efficacy and the risk of complications.

Method

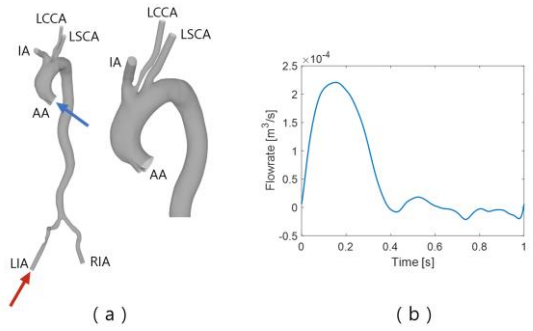

Figure 1: (a) The reconstructed 3D patient geometry (red arrow: ECMO flow inlet, blue arrow: Heart flow inlet) (b) inlet flow waveform for a healthy subject [2]. *AA: Ascending aorta, IA: Innominate artery, LCCA: Left common carotid artery, LSCA: Left subclavian artery, LIA: Left iliac artery and RIA: Right iliac artery*

A 3D patient-specific geometry is reconstructed using a commercial segmentation package, Mimics. Three hybrid meshes composed of tetrahedral elements and prism layers at the walls is created with different total number of elements (approximately 2 to 4.7 million) in Ansys ICEM and the final mesh with a total of approximately 3 million is selected via mesh sensitivity study. Blood is an incompressible and non-Newtonian fluid whose viscosity is assumed to be governed by the Quemada viscosity model [3]. The continuity and momentum conservation equations are solved using Ansys CFX, with the three-element Windkessel model [4] coupled at each outlet and flow waveform imposed at the AA inlet [2] (scaled depending on the ECMO support level), as shown in Fig 1. On the other hand, a time-invariant ECMO flowrate is prescribed at the LIA. The level of ECMO support is defined by the ratio of total ECMO flow to the total cardiac output per cycle.

Results

Streamlines for 50% and 90% ECMO support levels at three time points are presented in Fig 2, where the native and ECMO flows are distinctly indicated by blue and red, respectively. In the case of a 50% ECMO support level, an ECMO flow does not reach IA and LCCA during the entire systole (T1 and T2). On the other hand, for a 90% support level, an ECMO flow passes through the IA and LCCA during the entire systole. The watershed region at the peak systole (T2) is located further down in the descending aorta at 50% support than 90%.

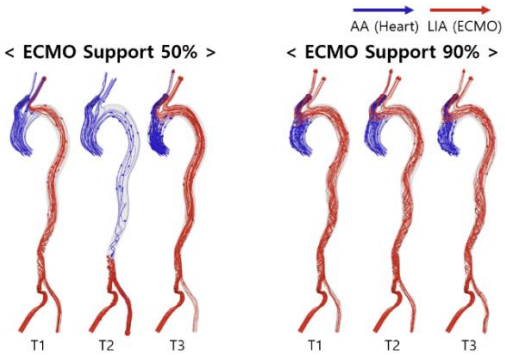

Figure 2: Streamlines over time. T1: mid-systolic acceleration (0.05s), T2: peak systole (0.15s), T3: mid-systolic deceleration (0.3s).

Discussion

At higher ECMO support ratios, the retrograde flowrate through the LIA becomes larger, creating low-velocity areas near the aortic arch adjacent to the heart. The formation of flow stagnation can cause thrombosis, which was also observed in the subject in this study; a thrombus was formed at the aortic root, which is shown as a dent in the reconstructed geometry in Fig 1 (a)). Furthermore, if oxidized blood is not sufficiently supplied to the upper body for patients with heart and lung failure, e.g., 50% support in Fig 2, it can cause north-south syndrome.

References

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