Design of implantable Blood Flow Manipulator for Improving Fluid Dynamics at the Total Cavopulmonary Connection(TCPC), a Computational Fluid Dynamic Study

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Background : The children born with single ventricle pathology are treated with palliative surgery commonly termed as Fontan operation. At present the commonly performed Fontan variant is described as total cavopulmonary connection (TCPC) with SVC-IVC offset. Fig.1 [3]

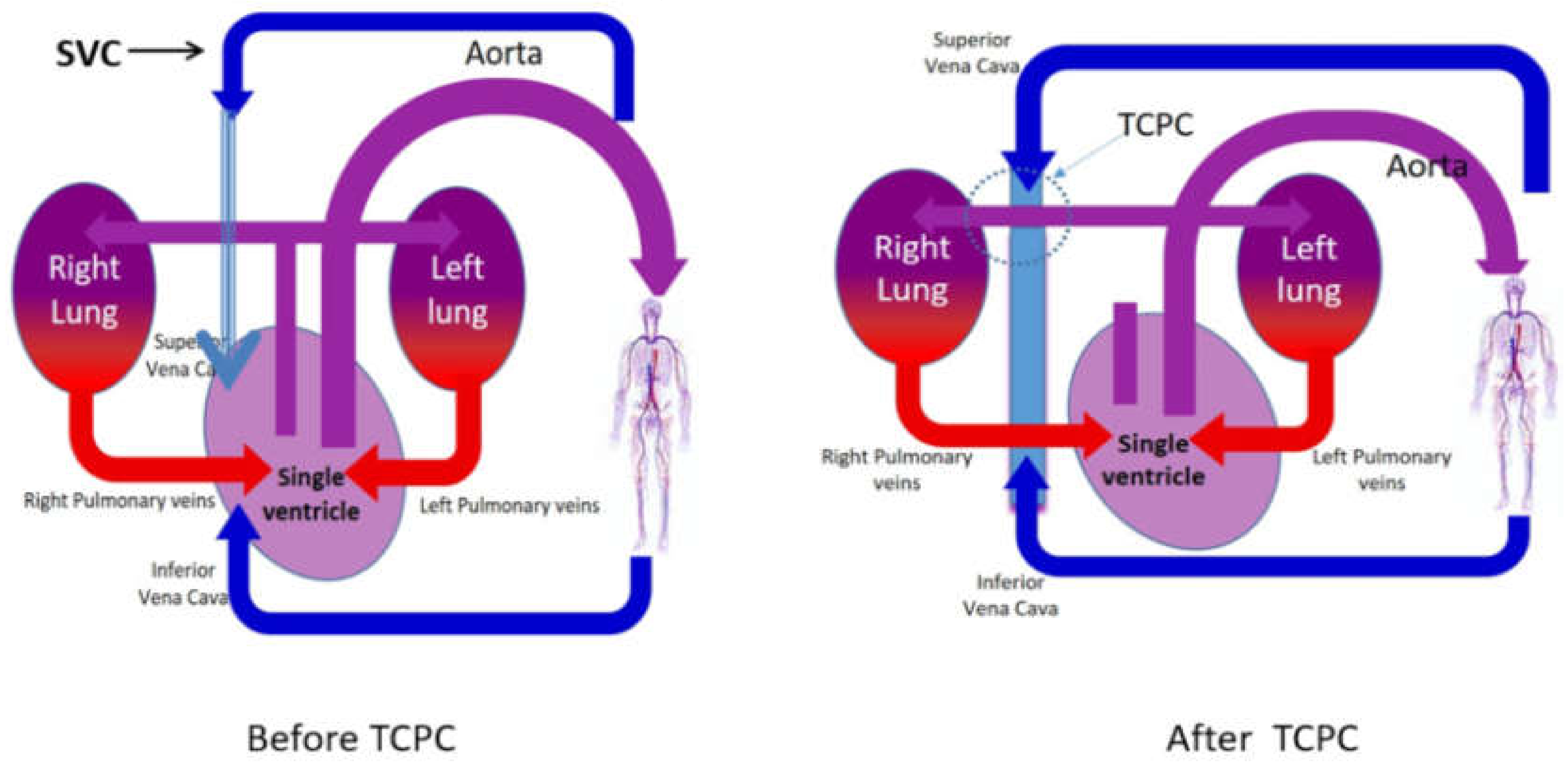

Figure 1. Total cavopulmonary surgery

From fluid mechanics point of view, there are two main problems encountered late postoperatively in these TCPC patients

1. Asymmetric streaming of IVC blood to the offset side of the lungs depriving contra-lateral lung of hepatic factor necessary for lung growth eventually causing arteriovenous malformations in that lung. Fig 2.[5]. The AV malformation further leads to circulatory failure and early morbidity. Thus once the asymmetric streaming of IVC blood flow is recognised it is necessary to correct this problem in order to avoid pathological progress. It has also been noticed that correction of this streaming problem leads to regression of the pulmonary AV malformation.

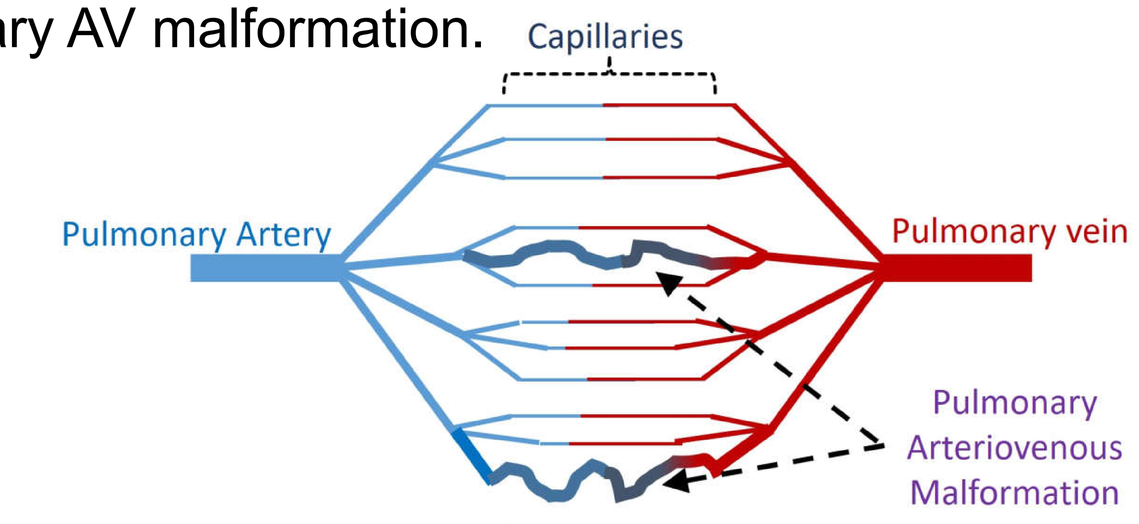

Figure 2. Arteriovenous malformation

2. Energy loss due to collision of vena caval blood streams when SVC and IVC are anastomosed to right pulmonary artery without offset. Moreover, this energy loss is aggravated due to phase and amplitude differences between SVC an IVC flows..

Method : In order to reduce the flow abnormalities at the total cavopulmonary junction, implantable passive flow manipulator is designed and its efficacy is assessed by computation fluid dynamic tools. Using the CFD the shape optimisation of the geometrical parameters of implant for equal splitting of IVC blood and maximum power saving is performed.

The computation flow dynamic study include the creation of idealized geometry, **mesh generation** (Unstructured tetrahedral mesh. The elements varied in the range of 1-6 X $10^{5.}$

Boundary conditions used are

1. Blood vessel walls are assumed to be impermeable and rigid.
2. Blood assumed to be an incompressible, homogeneous, Newtonian fluid with a density of 1060 kg·m−3 and a viscosity of 0.004 kg·m−1·s1.
3. Steady laminar flow model with No-slip at the walls. [1]

Numerical analysis done using the finite volume solver package ANSYS ®-FLUENT 15.0. The semi-implicit (SIMPLE) method was chosen to solve the discretized 3D incompressible N-S equations for different flow and pressure within pathophysiological range. The simulation is carried out by varying the geometry of implant.

Discussion: At present there is no satisfactory solution for TCPC patients developing AV malformation and circulatory failure. The Y graft solution [4,6] is a redo surgery without commercial availability of graft [2]. This study provides a pathway for development of catheter based implantable device at the junction of TCPC.

The figure 3 shows the flow simulation in a TCPC geometry where there is curved IVC conduit, offset with high flaring of anastomosis of IVC with RPA. In this case as shown in the subset b the horizontal flow splitter cannot effectively split the IVC stream in equal proportion. Hence It is necessary to design the flow splitter with extension into the IVC AND SVC as shown in the figure subset c

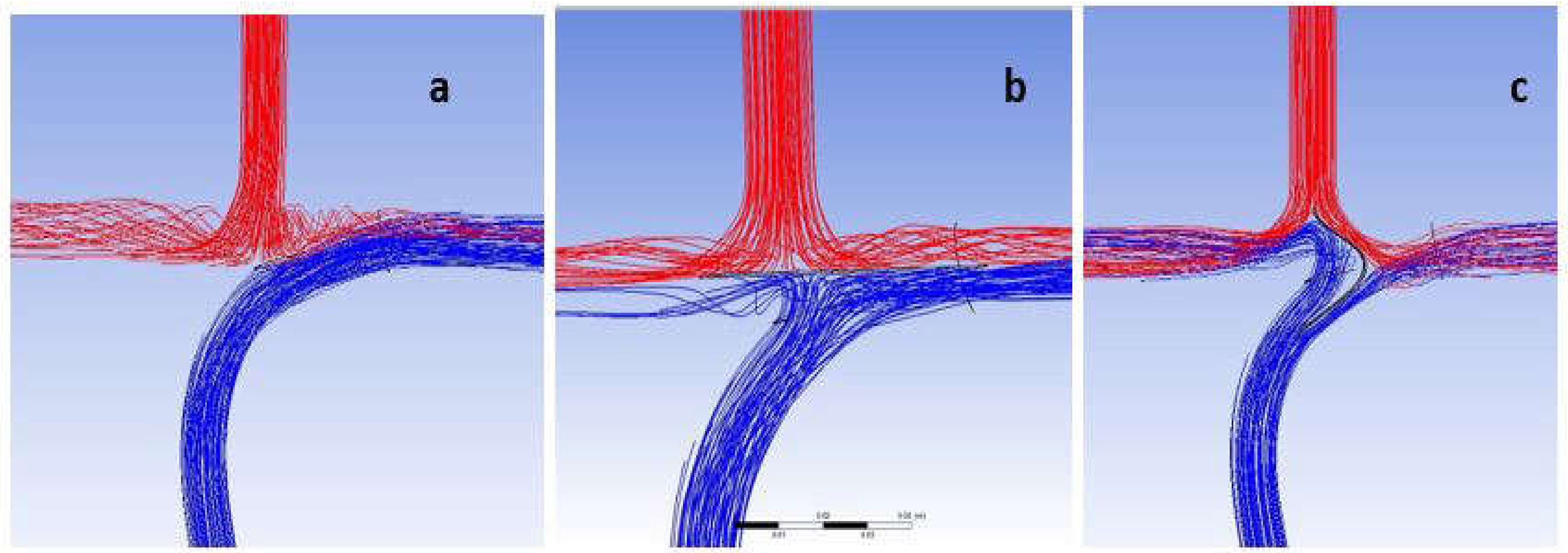

Figure 3. Flow simulation study : TCPC with offset

a) shows IVC stream is directed to LPA. b) shows Flat flow splitter design not effective in this case. c) Curved design equally splits IVC stream. The device extends in to SVC and IVC.

Conclusions:

1. The study shows the mechanism of its effectiveness of implantable flow splitter by computational fluid dynamic simulation study under varying flow and pressure conditions.
2. This implantable device splits the IVC stream equally to LPA and RPA thereby preventing as well helping to regress the AV malformation.
3. The implantable device also reduces power loss at TCPC junction

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