Ventricular Assist Devices

One treatment for a heart with inadequate ability to pump blood is the installation of either a *left ventricle assist device (or LVAD)* or, less commonly, a *right ventricle assist device (or RVAD)* as shown diagrammatically in figures 1 and 2 (sometimes both are installed). A $LVAD$ takes blood from the left ventricle and

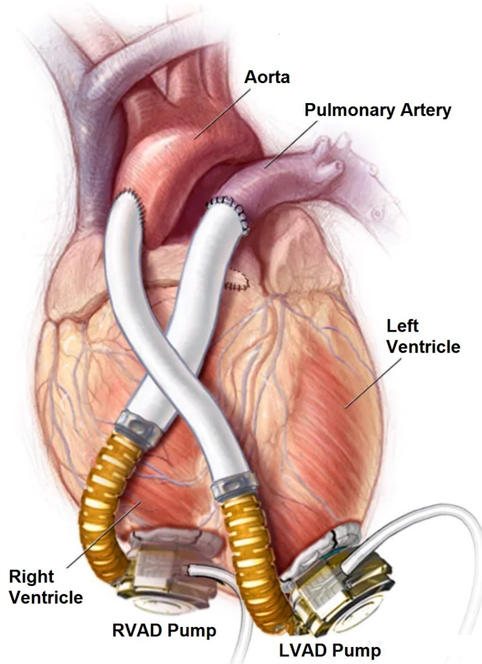

Figure 1: Diagram showing the installation of left and right ventricular assist devices.

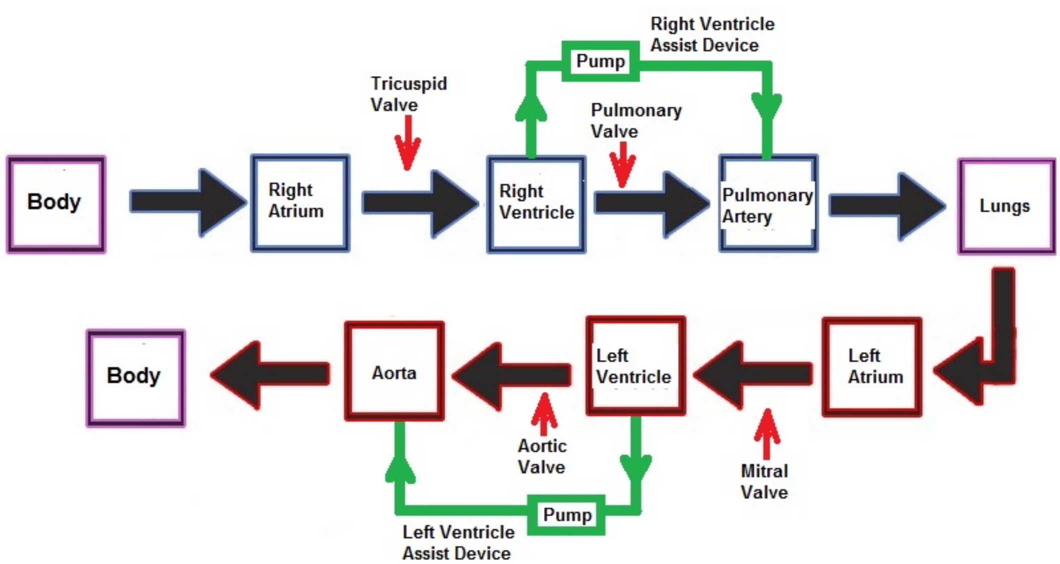

Figure 2: Schematic the attachments of left and right ventricular assist devices.

pumps it into the aorta and hence to the body. A $RVAD$ takes blood from the right atrium or ventricle and pumps it into the pulmonary arteries and hence to the lungs. Thus they respectively augment the pumping of the left and right sides of the heart. As shown in figure 2, these devices include a pump whose power supply is provided external to the body. Unlike the normal blood flow in the heart they supply a continuous flow of blood.

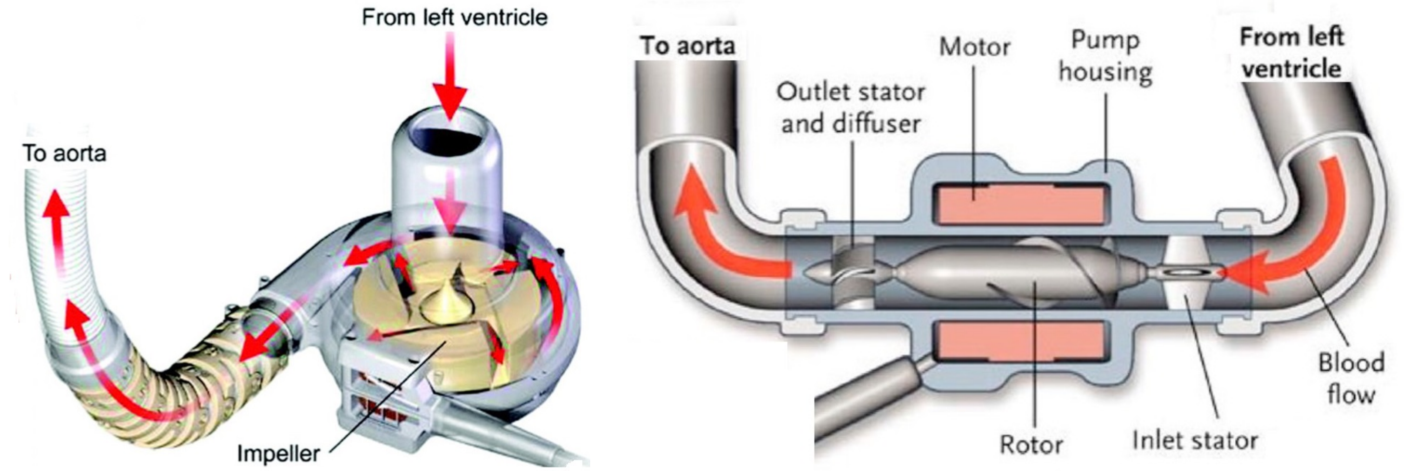

Figure 3: Centrifugal (left) and axial (right) pumps in ventricular assist devices. The examples shown are for $LVADs$ but similar alternatives are used for $RVADs$.

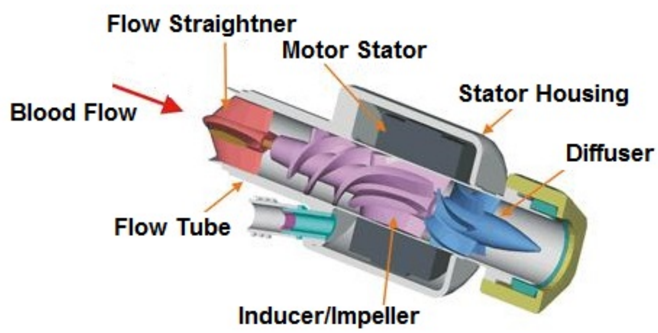

Figure 4: The MicroMed deBakey VAD.

Designs of these ventricle assist pumps include both centrifugal and axial flow impellers as shown in figure 3. Examples are the centrifugal VAD of WorldHeart HeartQuest and the axial pump VAD of the MicroMed deBakey VAD (figure 4). As with all such pumps, the first step in the design process is to evaluate the *specific speed* which in turn will determine the most effective pump geometry. As described in section (Mbbd) the specific speed, N, is equal to $\Omega Q^{1/2}/(\Delta p^T/\rho)^{3/4}$ where the required pump performance is given by the flow rate Q (in m^3/s) and the head rise, $\Delta p^T/\rho$ (in m) (where Δp^T is the total pressure rise generated by the pump and ρ is the fluid density). The rotational velocity is denoted by Ω in rad/s. With the above-listed units, the values of N for most common turbomachines lie in the range between 0.1 and 4.0; as described in section (Mbbd), lower values of N indicate a centrifugal pump design while higher values indicate an axial flow design. In the context of ventricular assist devices, the required Δp^T and Q are approximately $12kp$ and $160cm^3/s$. With a fluid density of $1000kg/m^3$ and a rotational speed of $5000rpm$ this leads to a specific speed, $N = 1.0$, and would suggest that a centrifugal design would be optimal or perhaps a mixed flow design if higher speeds were indicated (see below).

The second step in the design consideration is to determine the appropriate flow coefficient, $\phi = Q/2\pi BR^2\Omega$ (see section (Mbbc)) and then the impeller tip radius, R. From figure 9, section (Mbbe), the recommended ratio, B/R, is about 0.25 and the recommended flow coefficient is about 0.13. Therefore an appropriate impeller radius, R, is

$$R^3 = Q/0.13 \times 0.5 \times \pi \times \Omega = 4.9 \times Q/\Omega \tag{Ebd1}$$

and with $Q = 0.00016 m^3/s$ and a speed of $5000 rpm$ this yields a recommended impeller radius of about $1.15 cm$; alternatively speeds of $4000 rpm$ or $3000 rpm$ yield impeller radii of $1.23 cm$ and $1.37 cm$. Thus these lower speeds require larger impellers. But larger sizes are difficult to fit within the chest cavity. Moreover an important design consideration is the potential for increased hemolysis at higher speeds and next we consider this facet of the design.

In these pumps, as in other flows, the rate of hemolysis will be proportional to the typical fluid shear rate which, in turn, is given by ΩR where R is the impeller tip radius (perhaps $\Omega R/a$ where a is the dimension of a red blood cell but since a is constant we omit it for simplicity). From equation (Ebd1), it follows that ΩR and therefore the rate of hemolysis would be equal to $4.9Q/R^2$. Therefore at a given flow rate, the larger the impeller the lower the rate of hemolysis.