Streamline Flow in Veins

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<**Opening credits**>

<**David Lloyd James narrates**>

In the small veins of the mesentery there is no doubt that the flow of the blood is streamlined or laminar. Look at the behaviour of a dye which is injected into a tributary vein – it keeps to one side of the larger vein, remains as a distinct stream and it doesn't mix with the rest of the blood.

But what of the larger veins? Here is a single stream of dye running along the inferior vena cava in the abdomen of a rabbit, and it too is quite distinct but you will notice that it oscillates slightly; this is due to the respiratory movements which are small in this part of the body. But in the chest these movements are much larger, their effect is greater and here the flow pattern is very disturbed. So clearly, before we can generalise about the other veins, we must first examine the physical conditions which determine whether the flow is streamlined or not.

<**Intertitle: Laminar Flow**>

Streamlines can easily be demonstrated with water and dye in a glass model. And here we have a pattern very similar to the one we saw in the mesenteric veins. Here's the same thing in a straight tube. With this type of flow the fluid particles are all moving in layers or laminae, parallel to the sides of the tube. The viscosity of the liquid produces a variation in the velocity across the tube and this ranges from zero in the boundary layer to a maximum along the axis of the tube, the so-called axial stream. The profile of the velocities becomes a parabola and the mean velocity in the tube is half the axial velocity. In the glass model, the long, drawn out flow parabola is outlined by the advancing dye.

<**Intertitle: Turbulent Flow**>

When the velocity of laminar flow is gradually increased, the flow first of all becomes unstable and then rapidly turbulent. Now, all the fluid particles are moving irregularly and dye and water are thoroughly mixed. The velocity is almost the same right across the tube. Velocity, tube diameter, density and viscosity all determine the type of flow and in 1884 Osborne Reynolds worked out this relationship between them for water flowing in pipes. This gives a figure, the Reynolds Number, the critical value of which is 2000; above that the flow is turbulent, below it is laminar. Let's apply this to the rabbit vena cava. Velocity 20cm a second, diameter about ⅓ of a cm, density 1.05 and viscosity 0.02 poises. This gives a Reynolds Number of 346 which is far below the critical value and one would not expect therefore to find true turbulence anywhere in the veins of the rabbit.

But in the human, the inferior vena cava is 8 times the size although the viscosity is a little higher. This gives 1,750 for the Reynolds Number – still below the critical value but near enough to it for the flow to be unstable and very readily upset by external factors such as the respiratory movements.

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<**Intertitle: Disturbed Flow**>

Junctions are another possible cause of disturbance. Here, the Reynolds Number is 500 and the flow appears quite stable as one would expect. Now the velocity is doubled and the Reynolds Number becomes 1000 and at once vortex rings appear at the junction. These churn up the flow long before true turbulence is reached. The total disturbance will increase as the Reynolds Number approaches its critical value.

Let's look at the rabbit again. This single persistent stream in the inferior vena cava was produced by injecting dye into the femoral vein. Here, in larger close-up, is a similar stream in another vein – clearly, if a sample of blood is taken from a vein like this, it will vary in composition according to the position of the tip of the sampling catheter; a point to remember in clinical investigation.

In yet another part of the same vein, a tiny stream of darker blood comes in from an upper branch vein. This is a spontaneous streamline which shows a pulsation due to the respiratory movements. Below it is a stream of dye from an injection in the femoral vein; the Reynolds Number here is about 400.

Even in the chest, the Reynolds Number is still not much more than 600, but because the vein is moving about so much, eddies have appeared and the flow is very disturbed and almost intermittent. By contrast, in the superior vena cava, the external movements cause only a slight disturbance. This dye was injected into the jugular vein and it can just be seen as a stream passing right down into the heart. Here also sampling errors are likely to appear, not only in the rabbit but also in the human where the conditions are comparable.

The mesenteric veins are interesting for we can follow streams right from the intestine to the liver. On the left of the picture is the polythene cannula which was used for the injection of the dye. And now here comes the dye, keeping to one side of the vein all the way. The Reynolds Number is extremely low in these veins, less than 1 in the smallest of them, and so the streams are very stable. Here's the first stage in bigger close-up. At a nearby junction there is a more complex flow pattern and here at least 3 quite separate streams of blood can be seen in the largest vein. They vary in size according to the force of the injection but their position remains constant. These streams are now followed into the larger vessels – the stream from the branch below stays on its own side and a quite separate stream is seen running along the upper side of the arc of the main vein. Now the streams have reached the portal vein and here the effect of the respiration is quite marked, giving them a winding movement though they can still be clearly seen. The Reynolds Number here is about 250; in the human the corresponding value would be 750, so the conditions are essentially the same there.

The streams still persist right into the liver where they are distributed over a strictly limited area and one can predict that this also occurs in the human liver which is a fact of considerable importance for it determines the spread of diseases there. This is another example of the effect of streamlined flow which, as we have seen, we will always find in the small veins, whereas both theory and observations show we should expect considerable, if not complete mixing.

<**End**>