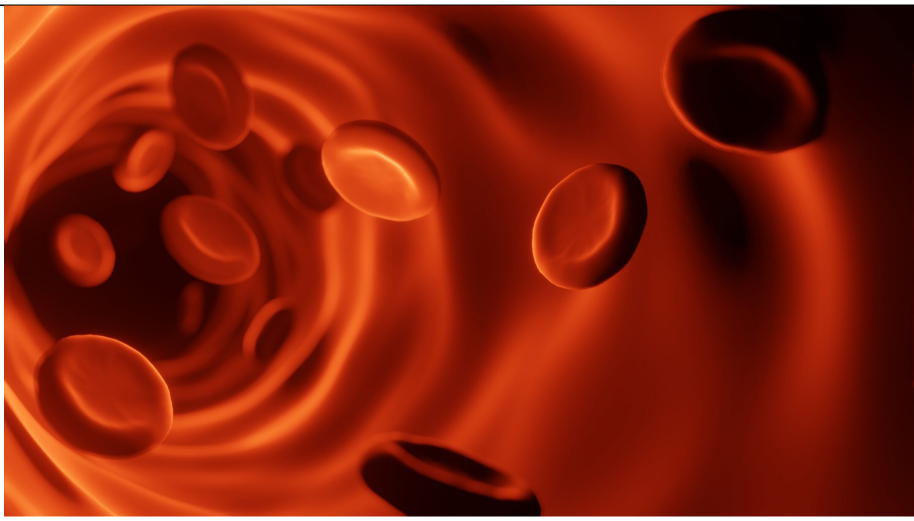
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	心臟跳動的節奏可以減少湍流的程度，降低了循環流體所需的能量。 (The rhythm of beating hearts reduces the energy needed to circulate fluids by reducing the amount of turbulence.)
生物系統 LIVING SYSTEM	人類 (Homo sapiens)
功能類別 FUNCTIONS	#流體的流動 #氣體的流動 #Move in/on Liquids #Move in/Through Gases
作用機制標題	像心臟一樣運行的泵，管道中的阻力減少了 27%，整體能源效率比常規連續運行的泵提高了 9%。 (Pump to operate like a heart, however, in both being pulsatile and having a rest phase, turbulent flow in the pipe became laminar. The result was a 27% reduction in drag and a 9% overall improvement in energy efficiency over a conventional continuously running pump.)
生物系統/作用機制示意圖 (確認版權、註明出處；畫質)	 https://www.shutterstock.com/zh/image-illustration/3d-render-red-blood-cells-bloodstream-2143897999

作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)

在管道中（如血管），流體可以以兩種方式之一流動。在層流流動中，流體沿著管道的整體直線方向平滑移動。在湍流流動中，流體以更加混亂的方式移動，同時以許多不同的方向。流體越混亂，它自身和管道內壁的摩擦（即阻力）就越大，推動流體通過管道所需的力量就越大。在人造管道中，流體的移動通常是湍流的，但在血管中，流體的移動通常是層流的。不同於連續運行的泵，心臟使用脈動模式。它在短暫的收縮期間將血液推出，然後在短暫的舒張期間重新填充。在這個“休息”期間，來自先前推送的血液流速減慢，並且任何正在發展的湍流都會平息。這創造了良好的、平靜的條件，下一次收縮將再次推送另一波血液。這種交替的模式使心臟能夠保持循環系統中的層流流動，大大降低了通過這個龐大的血管網移動血液所需的力量。

人造泵在啟用時持續不斷的運行。然而，當研究人員設計一個像心臟一樣運行的泵時，即具有脈動和休息階段，管道中的湍流變成了層流。結果阻力減少了 27%，整體能源效率比常規連續運行的泵提高了 9%。

In a pipe (like a blood vessel), fluid can flow in one of two general ways. In laminar flow, the fluid moves smoothly along in an overall straight direction parallel to the direction of the pipe. In turbulent flow, the fluid moves more chaotically, in many different directions at once. The more a fluid flows chaotically, the more friction (i.e., drag) it has with itself and with the inner wall of the pipe it's moving through, and the more force required to push the fluid through the pipe. Turbulent flow is the norm in the movement of fluids through human-made pipes, but laminar flow is the norm in the movement of blood through blood vessels.
Unlike pumps that run continuously, the heart uses a pulsing pattern. It pushes blood out with a short contraction, and then refills during a short expansion called "diastole." During this "rest" period, blood flow from the previous push slows down and any developing turbulence settles. This creates favorable, calm conditions as the next contraction sends another surge of blood forward. The alternating pattern enables the heart to maintain laminar flows in the circulatory system, greatly reducing the force required to move blood through this extensive network of vessels.

Human-made pumps run continuously while operating. When researchers designed a pump to operate like a heart, however, in both being pulsatile and having a rest phase, turbulent flow in the pipe became laminar. The result was a 27% reduction in drag and a 9% overall improvement in energy efficiency over a conventional continuously running pump.

文獻引用 (REFERENCES)

「...主動脈流提供了一個例子，其中特別的推進方案，由靜止間隔分隔的脈衝爆發組成，似乎能夠阻止湍流，儘管相對速度急劇增大。」（Scarselli et al. 2023: 71）

「...我們提出有了一種湍流控制的替代方法，透過非穩定的、脈動的驅動來實現制動的減小，特別是模仿心臟跳動周期。」（Scarselli et al. 2023: 71）

「...因此，脈動不一定會導致力矩的降低，更不用說節省能源了。受到主動脈血流中舒張期靈感的以及心臟波形的轉變延遲的影響，我們設計了一個新的周期，在其中插入了一個恆定雷諾數的區域（休息期），有效地輸送與連續的加速階段值得注意的是，現在流動在加速期間以及停止階段的某些部分我們的 τ 值明顯降低。τ 的峰值減少了一半，而在這種情況下，獲得了淨扭矩減少小 23 %的結果...接下來的休息階段使湍流水平下降，並為下一個加速階段設定了有利的終極條件。」（Scarselli et al. 2023: 72-73）

「...循環系統成功結合流速與低剪切剪切水平，這些流速明顯超過了湍流的起始值。充足的流量為有機體的正常功能關鍵，而壓力程度必須保持在血管內皮細胞層可以耐受的範圍內。正如我們所展示的那樣，心臟週期的波形接近於實現這兩個目標的最佳值。週期中的休息階段是減少剪應力的關鍵，同時，這個休息階段必須與附加的快速流動加速階段優化地結合，不僅減少流動阻力，還要優化效率並最大化能量消耗。」（Scarselli et al. 2023: 74)

"…aortic flow provides an example in which a specific propulsion scheme, consisting of impulsive bursts separated by quiescent intervals, seems to prevent turbulence despite relatively large peak velocities." (Scarselli et al. 2023: 71) "…we present an alternative approach to turbulence control in which drag reduction is achieved by means of unsteady, pulsatile driving, specifically mimicking the cardiac cycle…" (Scarselli et al. 2023: 71) "Pulsation, therefore, does not necessarily lead to drag reduction, let alone energy saving. Inspired by the diastolic phase found in aortic flow and the transition delay obtained for the cardiac waveform, we designed a new cycle in which a region of constant Reynolds number (rest phase) is inserted that effectively decouples the deceleration from the consecutive acceleration phase (Fig. 2b). Remarkably, the flow now responds with considerably lower values of τ^* during acceleration, as well as during part of the deceleration phase (Fig. 2e). The peak value of τ^* is reduced by a factor of two, and in this case, we obtain a net drag reduction of 23% (R = 0.23) … The subsequent rest phase enables turbulence levels to die down and sets a favorable initial condition for the next acceleration phase." (Scarselli et al. 2023: 72-73) "The circulatory system manages to combine flow speeds, significantly exceeding the onset values of turbulence, with low shear-stress levels. Sufficient flow rates are crucial for a functioning organism, and the stress levels have to remain tolerable for the endothelial cell layer of the blood vessels. As we have shown, the waveform of the cardiac cycle is close to the optimal value to achieve both of these objectives. A rest phase during the cycle is crucial to diminish wall shear stress, and at the same time, this rest phase has to be optimally timed and combined with a subsequent rapid flow acceleration to not only reduce the flow drag but also optimize efficiency and minimize power consumption." (Scarselli et al. 2023: 74)
參考文獻清單與連結 (REFERENCE LIST) **Harvard 或 APA 格式**
Scarselli, D., Lopez, J.M., Varshney, A. and Hof, B. (2023). Turbulence suppression by cardiac-cycle-inspired driving of pipe flow. *Nature,621*, pp.71-74
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