What moves the blood?

Due to the complex nature of the circulation various hydraulic and electrical models of circulation have been proposed. These models vary in the way the measured parameters such as pressure, flow and resistance are interpreted however, all invariably assume that the heart is the sole source of blood propulsion. According to the widely accepted pressure-propulsion model (PPM) of circulation the heart, equipped with muscular chambers and valves, maintains the pressure difference between its outlet, the aorta, and its inflow, the right atrium. The heart is thus considered to be the principal source of blood's propulsion. (Fig. 1A) However, there are numerous problems with this conventional circulation model which has dominated the field of physiology for well over 200 years. An increasing number of experimental and clinical observations have been described which can no longer be explained.

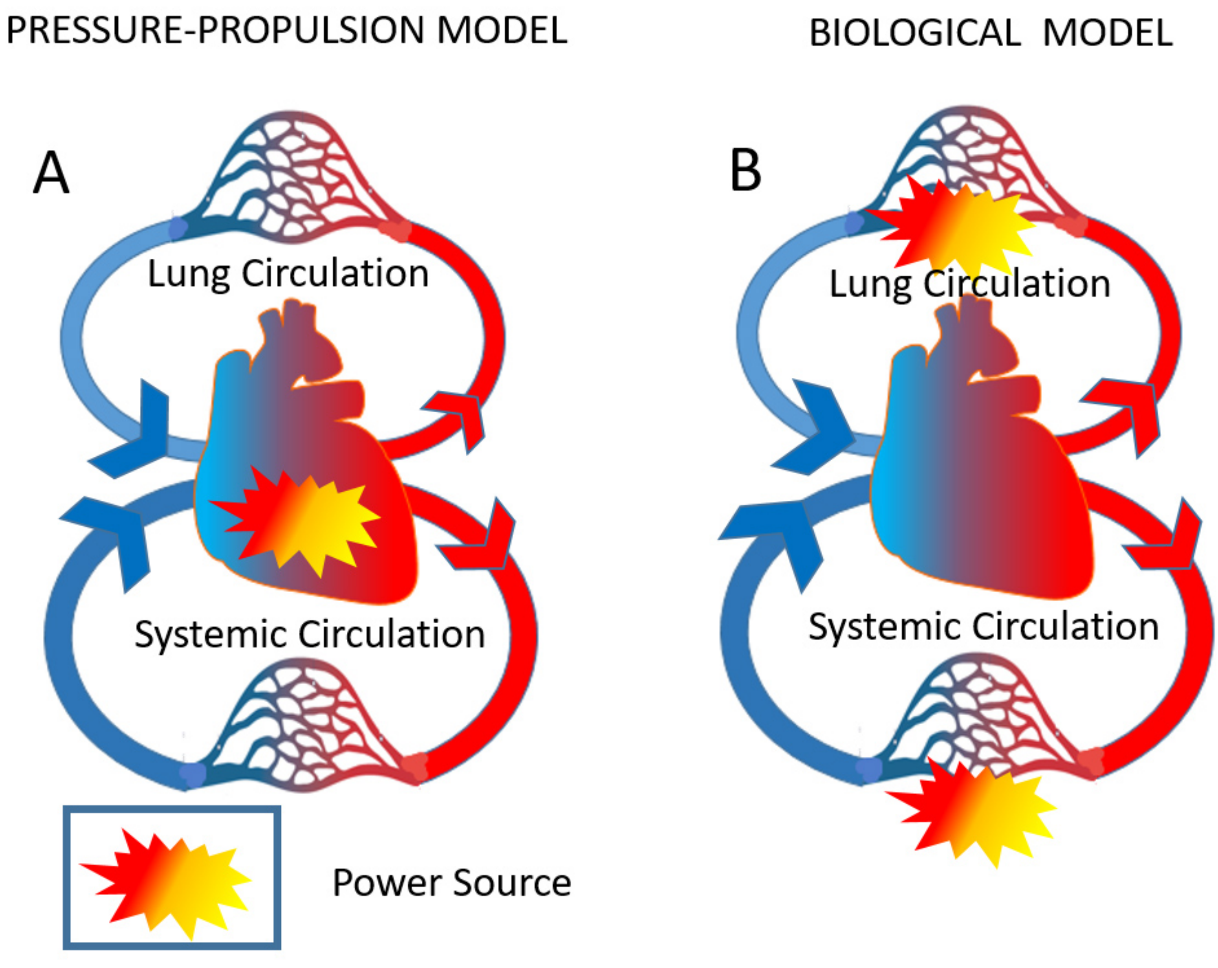

Fig. 1. Schematic diagram of circulation. According to the conventional pressure-propulsion model (A) the heart acts much like a pump in a water distribution system. It pushes the blood, an inert fluid, along the pressure gradient between the arterial (red) and venous (blue) limbs of the systemic and pulmonary circulations.

In the biological model of circulation (B) the blood is a living, self-moving organ which supplies tissues and organs with nutrients and oxygen according to metabolic needs of the tissues which determine the capillary flow. The heart functions as an organ of restraint, i.e., an impedance pump, and maintains pressure in systemic and pulmonary circulations by rhythmic interruption of the flow.

For example, unlike the mature four chamber heart, the early embryo heart has only two chambers and no valves. It has therefore long been assumed that the embryo heart functions like a peristaltic pump, that is, by ‘milking’ the blood along its lumen, similar to the way the esophagus and stomach advance ingested foodstuffs. However, a recent discovery that the blood travels faster through the heart than the velocity of the peristaltic wave, has invalidated this long-believed mode of the embryonic heart’s action. It is now thought that rather than being a propulsion pump, the embryo heart functions as an *impedance* pump, rhythmically interrupting the flow of blood. The blood thus circulates *before* the heart is fully functional, a fact also confirmed by circulation in primitive vertebrates, such as the lancetfish, which have no heart as the central organ of circulation.

Tightly controlled experimental studies in animals and clinical observations in humans have demonstrated that complete occlusion of the thoracic aorta – a procedure routinely performed during surgery in patients with aortic dissection – results in *increase* in the volume of blood returning to the heart. This is clearly a paradoxical finding since one would expect a marked *decrease*, if not a cessation of flow after occlusion of the ‘outlet’ of a propulsion pump. Similarly, a number of large clinical trials have demonstrated a failure of the aortic balloon pump – a device used to support the action of the heart after a massive heart attack – to improve clinical outcomes. After years of experimental and clinical trials the use of permanent total artificial hearts had to be abandoned in the early 2000’s because of high patient mortality. It is current practice to fit the severely weakened heart with a ventricular assist device until a suitable donor heart becomes available. Such auxiliary pumps intercept the blood returning from the lungs to the left ventricle and propel it directly into the aorta via an artificial conduit.

At rest about 5 liters of blood leave and return back to the heart each minute in a 70 Kg person. To supply the working muscles with adequate amount of oxygen during aerobic exercise the heart rate more than doubles, and this volume flow, the cardiac output, triples or quadruples during aerobic exercise. Because of physical limitations, such as the chamber size and a shortened filling time, the heart can eject only about half of this volume. The remaining amount of blood is supposedly provided by the so called ‘muscle pump’ – a proposed mechanism by which the working muscles ‘milk’ the blood in direction of the heart. Recent research, however, has failed to confirm the existence of such a ‘muscle pump’. So, how does the circulation work and what is the function of the heart?

A century ago a radically different circulation model was proposed but remained unnoticed. This biological model has now been validated by observations of the phylogenetic and embryonic development of the circulatory system in various vertebrate species as well as by experimental studies and clinical case scenarios. The model suggests that the primary source of blood propulsion resides in the capillaries and is chiefly controlled by the metabolic demands of the tissues. (Fig. 1B) The primary ‘sensors’ of the tissues’ needs for oxygen are none others than the red blood cells, the purveyors of oxygen. The heart rhythmically interrupts the flow of blood and with the help of muscular walls and valves maintains adequate filling and pressures in the systemic and pulmonary circulations.

Branko Furst
Department of Anesthesiology, Albany Medical College, Albany, NY, USA

Publication

The Heart: Pressure-Propulsion Pump or Organ of Impedance?
Furst B
J Cardiothorac Vasc Anesth. 2015 Dec