Studies of a Valveless Impedance Driven Pump: lessons learned from Nature

Morteza Gharib [mgharib@caltech.edu]
California Institute of Technology, Pasadena, CA 91125

Nature has shown us that some hearts do not require valves to achieve unidirectional flow. In its earliest stages, the vertebrate heart consists of a primitive tube that drives blood through a simple vascular network nourishing tissues and other developing organ systems. For example, the 26 hour post-fertilization embryonic zebrafish heart does not possess valves (Hove 2003), yet it demonstrates unidirectional blood flow. Traditional developmental dogma states that valveless, unidirectional pumping in biological systems occurs by peristalsis. However, during our *in vivo* studies we mapped the movement of both the myocardial cells in the developing heart tube wall as well as the flow of blood through the tube and obtained data contradicting the notion of peristalsis as a pumping mechanism in the valveless embryonic heart. From these observations we have developed a physio-mathematical model that proposes an elastic wave resonance mechanism based on impedance mismatches at the boundaries (Hickerson & Gharib, JFM 2006) of the heart tube as the more likely pumping mechanism. In this model fewer cells are required to actively contract in order to maintain the pumping action than are necessary in a peristaltic mechanism. Upon contraction of this small collection of myocytes, usually situated near the entrance of the heart tube, a series of forward traveling elastic waves are generated that eventually reflect back due to impedance mismatch at the two ends of the heart tube (Fig. 1). At a specific range of contraction frequencies, these waves can constructively interact with the preceding reflected waves to generate an efficient dynamic suction region at the outflow tract of the heart tube (Forouhar et al, Science May 2006).

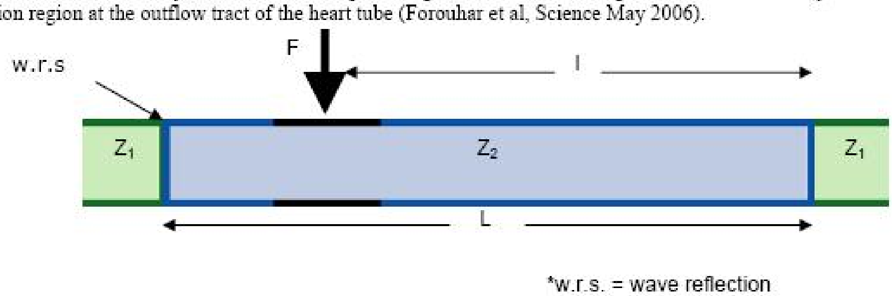

Fig. 1: This schematics shows configuration of an impedance pump based on impedance mismatch. Oscillatory pinching at an asymmetrically location (F) along the length of the compressible section at certain frequency, waveform and duty cycle will generate incident and reflection waves that can interact constructively to generate mean suction at a desired end of the tube.

An in vitro simulation has shown the existence of a non-linear frequency-flow relationship which exceeded the maximum value possible for a peristaltic pump (Fig. 2).

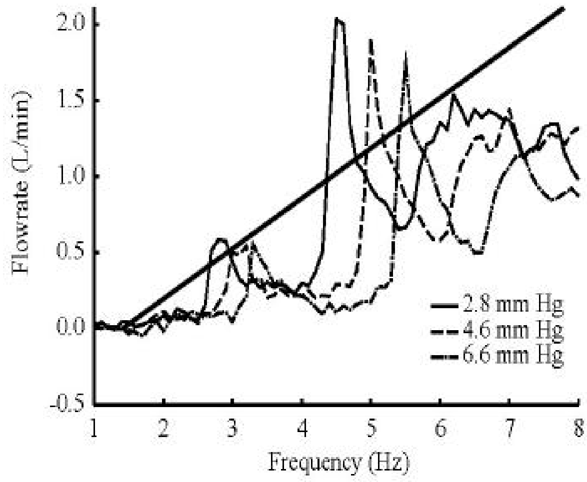

Fig. 2: Flow rate as a function of pinching frequency. Peak flow due to resonance exceeds peristaltic pumping at the same frequency (Linear solid line).

Inspired by this design, we have succeeded in constructing a series of mechanical counterparts to this biological pump on a size scale comparable to that of embryonic zebrafish heart (e.g. ~400 microns). We are using a micro-magnet or Piezo actuator systems to mimic the contractile action of cardiac tissue (Rinderknecht et al, 2005). This new generation of biologically-inspired pumps functions on both the micro- and macro-scale and do not possess valves or blades. These advantages offer exciting new potentials for use in applications where delicate transport of blood, drugs or other biological fluids are desired.

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