MULTILAYER IMPEDANCE PUMP:

A Bio-inspired Valveless Pump

with Medical Applications

A thesis by

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I dedicate this thesis to my parents who always valued education and taught me hard work, perseverance, humility, honesty and integrity.

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Abstract

This thesis introduces the concept of multilayer impedance pump, a novel pumping mechanism inspired from the embryonic heart structure.

The multilayer impedance pump is a composite two-layer fluid-filled elastic tube featuring a thick, gelatin-like internal layer similar in nature to the embryonic cardiac jelly, and that is used to amplify longitudinal elastic waves. Pumping is based on the impedance pumping mechanism. Elastic waves are generated upon small external periodic compressions of the elastic tube. They propagate along the tube's walls, reflect at the tube's extremities and drive the flow in a preferential direction. This fully coupled fluid-structure interaction problem is solved for the flow and the structure using the finite element method over a relevant range of frequencies of excitation. Results show that the two-layer configuration can be an efficient wave propagation combination, and that it allows the pump to produce significant flow for small excitations. The multilayer impedance pump is a complex system in which flow and structure exhibit a resonant behavior. At resonance, a constructive elastic wave interaction coupled with a most efficient energy transmission between the elastic walls and the fluid is responsible for the maximum exit flow. The pump efficiency reaches its highest at resonance, highlighting furthermore the concept of resonance pumping.

Using the proposed multilayer impedance pump model, we are able to bring an additional proof on the impedance nature of the embryonic heart by comparing a

peristaltic and an impedance multilayer pump both excited in similar fashion to the one observed in the embryonic heart.

The gelatin layer that models the embryonic cardiac jelly occupies most of the tube walls and is essential to the propagation of elastic waves. A comparison between the exact same impedance pump with and without the additional gelatin layer sheds light on the dynamic role of the cardiac jelly in the embryonic heart and on nature's optimized design.

Finally, several biomedical applications of multilayer impedance pumping are presented. A physiologically correct model of aorta is proposed to test the pump as an implantable cardiovascular assist device.

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