Chapter 5

Concluding Remarks

In the excitement of the impedance pump phenomenon, a number of publications have been written trying to model the behavior of a valveless tube pump. Nevertheless, little had been done experimentally to determine the nature of the pumping being modeled. Presented in this thesis are the experimental results that provide the basis for comparison between models and insight into the dominant parameters that are critical in its function. Though this phenomenon has been known for many years and has inspired interest in modeling its behavior using analytical and computational means, no one has actually looked at it in-depth experimentally. Previous investigators were unable to validate their results, capture unique behaviors, and focus on the parameter space that is integrally bound with the impedance pump. Computational studies are time-consuming and rely on the careful application of boundary conditions to achieve a meaningful result. Analytical work is also complex, and relies on the simplification of a phenomenon to make the problem tractable. The experimental results we have collected provide a new perspective on the problem of the impedance pump and can now serve as a foundation for future modeling work.

Behaviors intrinsic to the functioning of the impedance pump have been demonstrated. Imaging of the wall motion shows wave propagation and reflection at the tubing interfaces. The compression is seen to be in phase with the wall motion during peak net flow. This alludes to the resonant behavior observed in the response to an impulse of the system, from the net flow rate as a function of compression frequency, and from the FFT's of the flow rate at varying compression frequencies. Transient response measurements show that it may take up to 5 seconds to build to a steady net flow. This is critical for use in computational modeling that will require where computing power still limited. Pressure flow relationships at the exit of the impedance pump demonstrate lower energy input required during resonance than when off resonance. A double periodic response at high frequencies is also seen. The feature most over-emphasized in previous models is the use of elasticity as a form of restoring force. We have shown elasticity is not specifically required and that any restoring force will suffice for a pumping effect to occur.

Bulk flow responses under a variety of conditions have been measured. The effects of the frequency of compression, position of compression, and transmural pressure each demonstrate the importance of wave propagation in the fundamental functioning of impedance pumps. Variation in the width of compression changes the rate of volume displacement by the pinchers, but does not affect the wave speed so the peaks in the frequency response of the net flow rate remain steady while the amplitudes differ. Adjustment of the systemic resistance and duty cycle shows that the pumping phenomenon observed is a true pump capable of sustaining a net pressure head and compensating for flow resistance rather than a mathematical curiosity.

An appropriate model describing the function of the impedance pump can provide the means to better identify an impedance pump system. There are a number of distinguishing features of impedance driven flows, which can be used in this identification. An impedance pump requires an active element only at one position (not in the center) along the length of the wave-propagating section. The wave speed traveling on the tube does not necessarily have the same velocity, nor must it be in phase with the flow rate. The flow exiting an impedance pump is pulsatile. And, the net flow rate has a non-linear relationship to the frequency of activation with characteristic peaks and flow reversals dependent on the natural resonant frequency of the system.

A model can also be used in the design of pumping systems. Such work is already under way with applications ranging from cardiac assist devices to micro-fluidic pumps to the better understanding of naturally occurring systems such as the zebrafish embryonic heart.