Since the birth of my special needs daughter, I have been captivated by the complexity of the muscles of the human body. Her muscle tone was so low, and I wondered if there was anything that could be done to help make her stronger. Watching the doctors cast and brace her legs to correct her clubbed feet, I pondered the possibilities of artificial muscles for exoskeletons to provide stability and support to patients with chronic low muscle tone. Prosthetics could also be improved using actuators that better mimic the ones they are replacing.

As I started back to school, the possibilities and opportunities of exoskeletons and smart prosthetics expanded for me when I saw a news story about a man that had lost his hand in a sawmill accident. He had just been fitted for a revolutionary bionic hand that looked like a real hand and offered more motility than previous prosthetics. Power for the fingers in natural arms comes from forearm muscles and his were still functioning, as was their control system in the existing nerves. The prosthetic was receiving its triggers from the faint signals these nerves produce yet this man who had lifted heavy items for a living could barely lift a 5-pound weight. While this was an exciting development for this patient, like so many other upper limb prosthetics the motors, gears and batteries made it heavy and noisy. Over 35% of upper limb amputees do not use the prosthetics they are given for those as well as other reasons. It is my goal to work to improve conditions for those with amputations, injuries to muscle tissue, and degenerative diseases to help maximize motility and quality of life.

When my mentor, Dr. XXXXX and I traveled to Glasgow to present our research at the World Parkinson's Congress, I had a chance to visit the birthplace of the bionic hand from the news story and meet with the bioengineering department at the University of Strathclyde, Glasgow. From that meeting I began working with Dr. XXXX XXXXX, an expert in prosthetics and orthotics. She has been working for the past 7 years with the shape memory alloy, nitinol, including consulting for a company that creates vascular devices using these alloys.

Motion in shape memory alloys is based on a change in crystal phase. A wire is heated up (the usual method is by a current passing through the nitinol wire) causing a phase change. In this state, the wire is contracted, rigid and strong. When the wire is cooled, it becomes malleable and can be deformed. When it is heated again it contracts, returning to its predefined shape, again becoming stiff.

Over the past 40 years, the shape memory alloy, nitinol (nickel-titanium) has held great promise for actuation. While these materials are well known, a system to take advantage of their shape memory properties for fast response in high force situations has not been realized. For the past year, Dr. XXXXXX and I have been developing a research project that would allow nitinol to make quieter, lighter and flexible actuators for prosthetics and exoskeletons.

Many in the field have long considered the possibilities of these shape memory alloys, but use of the material has been stymied by slow response cycles due to cooling rates, the low number of cycles to fatigue, sensitivity of the material to the outside environment, and high power requirements, as well as a myriad of other smaller issues. As technology has improved, some of these hurdles can now be overcome. More efficient heating and cooling can improve actuation speeds. A high frequency control system developed by a research team in Australia has improved actuation speed, movement control and cycle limits. There have also been improvements in manufacturing of the wires themselves as well as the containment of the wires that have eliminated the problem of environmental sensitivity.

As the cross sectional area directly affects the cooling rates, a thinner wire with a small actuating force cools faster thereby responding faster. Large wires provide large forces but have slow response times and are power hungry. A collection of separate thin wires can provide a great force and fast response times, but still requires a large amount of power. Previous research separated the wires by a relatively large distance to maintain the fast response times. However, in this arrangement, much of the electrical energy to heat the wires was lost to the environment.

Little work has been done with these same wires in close proximity, and that is the focus of my research. The first objective is to determine if shape memory alloy wires (Nickel-titanium/NiTi was selected) in close proximity or even touching will require the same, greater or less amount of electrical current to obtain the same amount of strain as those relatively far apart. For these tests a pre-"trained" material will be used as provided by the manufacturer. Through research grants from the Portland State University Maseeh College of Engineering and Computer Sciences Innovation Program and other sponsorships, the NiTi and other materials have already been purchased. An experimental setup is concurrently under development and construction to conduct constant load and constant strain over time experiments with variances in the electrical power applied to the wires. The equipment is also able to hold the wires separated by distances from 0 – 2 cm apart in infinite increments. These tests will determine if the power required for actuation can be reduced by bundling and what distance apart is optimal.

The total force actuated by a multiple wire bundle will be compared to published values of specimens with similar actuation force in order to determine if the bundle of thinner wires might be better than a single larger wire for a particular scenario.

The first round of tests will be conducted with room air between the nitinol wires, however the testing apparatus can use other matrix materials. The second round of tests will include a system of heat and coolant reservoirs developed in collaboration with XXXXX XXXXXX, another National Science Foundation Fellowship recipient specializing in microfluids. The system would increase the efficiency by cycling the heat between wire bundles as well as increase the cooling rates, thereby increasing the response time.

The last phase would utilize shape-training techniques which make the nitinol return to a predetermined shape rather than a straight linear transformation. To obtain consistent response over many cycles with a one-dimensional linear actuation, the strain must be kept below 5%. The human muscle contracts about 20% of its length. By conditioning the nitinol wire to return to a predefined shape the amount of linear contraction will be increased to the desired 20% amount.

Discussing the proposed project with experts in electrical motor efficiencies, heat transfer, fluid dynamics and metallurgy outside those mentioned have provided insights and validation. At XXXXXX University, a team is also working on projects in this area. I hope to join with and learn from them in creating actuators that will not only improve prosthetics, orthotics and exoskeletons, but any other application where high force is needed in a small space with little weight.