INTRODUCTION
Upper extremity tendon transfer surgeries are performed for a variety of conditions such as stroke, palsy, and trauma where muscle function is lost. The surgery involves transferring a tendon from the dysfunctional muscle and directly suture to another functioning muscle. Our group has proposed a new tendon transfer surgical technique where an engineering mechanism in the form of a hierarchical pulley mechanism is used in place of the direct suture to connect one muscle to multiple tendons. Specifically, when a hierarchical pulley mechanism is used to connect one muscle to four tendons, such as when the extensor carpi radialis longus muscle is connected to the flexor digitorum profundus tendons in the tendon transfer surgery for median-ulnar nerve trauma, the pulley mechanism improves hand function by enabling the fingers to adapt naturally to an object’s shape during physical interaction tasks such as grasping. In this paper, we evaluate the fatigue and yield strengths of the pulley mechanism when constructed from biocompatible materials.

METHODS
The implant design comprised of three cable-sheave systems arranged in a hierarchical manner to allow control of four fingers by one tendon (Figure 1). The pulley was constructed from Ti6Al4V Grade 5, and the cables were Jerry Brown Line One Spectra (UHMWPE braided rope). This ensured that the entire mechanism was biocompatible. The pulley dimensions were chosen so that the mechanism could support 350 N loads with a 2X safety factor. Cables of three different loading capacities (150 lb, 200 lb, and 300 lb) were used. (Full details of the mechanism design are withheld for intellectual property reasons). A crimp was used to secure the cable to the pulley head.

For simplicity, the yield strength and fatigue of only one pulley was tested. For the yield test, a scale was used to tug on the pulley with a maximum force of 440 N. For the fatigue test, the pulley was immersed in 32 °C water (to mimic conditions inside the human forearm). A robot was used to pull on the pulley and create low force cyclic loads on the pulley-cable mechanism at a frequency of 1.8 Hz with a maximum force of 6.4 N until either the pulley or the cable failed.

RESULTS AND DISCUSSION
The 150 lb. (667 N) cable failed after 219,500 cycles while under 5.245 N. The 209 lb. (930 N) cable lasted 241,200 cycles while under 4.73 N. The 312 lb. (1389 N) cable completed 191,600 cycles before damaging the pulley while under 3.86 N. It was noticed that the heavier duty cabling which was thicker came out of the groove and failed due to rubbing with the sheave. In the yield test, the titanium pulley began to disassemble at a 440 N load. However, the individual components did not fail.

CONCLUSIONS
The tests showed that even though the pulley material itself did not yield at the maximum applied load of 440 N, by visual inspection, the assembly of components did not survive the test. This disassembly occurred where the parts were joined due to the large moments that caused the parts to separate. Also, it is important to choose cabling that fits in the pulley groove and does not come out. Future work on the project will include design changes and additional testing. Design changes include making the device shorter and thinner, developing a new crimp or splicing technique, and using stronger cabling (Dyneema Purity). Additional testing procedures include fatigue testing using different sheave diameters with the same rope. Finally, a numerically controlled manufacturing process could be developed to insure quick, accurate part manufacturing.

REFERENCES