Cavatappi Artificial Muscle Application

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Abstract

Team Cavatappi was tasked with continuing research conducted by Dr. Diego Higueras-Ruiz, who developed hydraulically actuated artificial muscles. Cavatappi actuators were given their name because of their resemblance to coiled "cavatappi" pasta (Fig. 1). Previous research focused on the material properties of muscle, and continuing research focused on application as well as improvement of technology in the areas of manufacturing and muscle bundling. Additionally, Team Cavatappi conducted further research on muscle scalability.

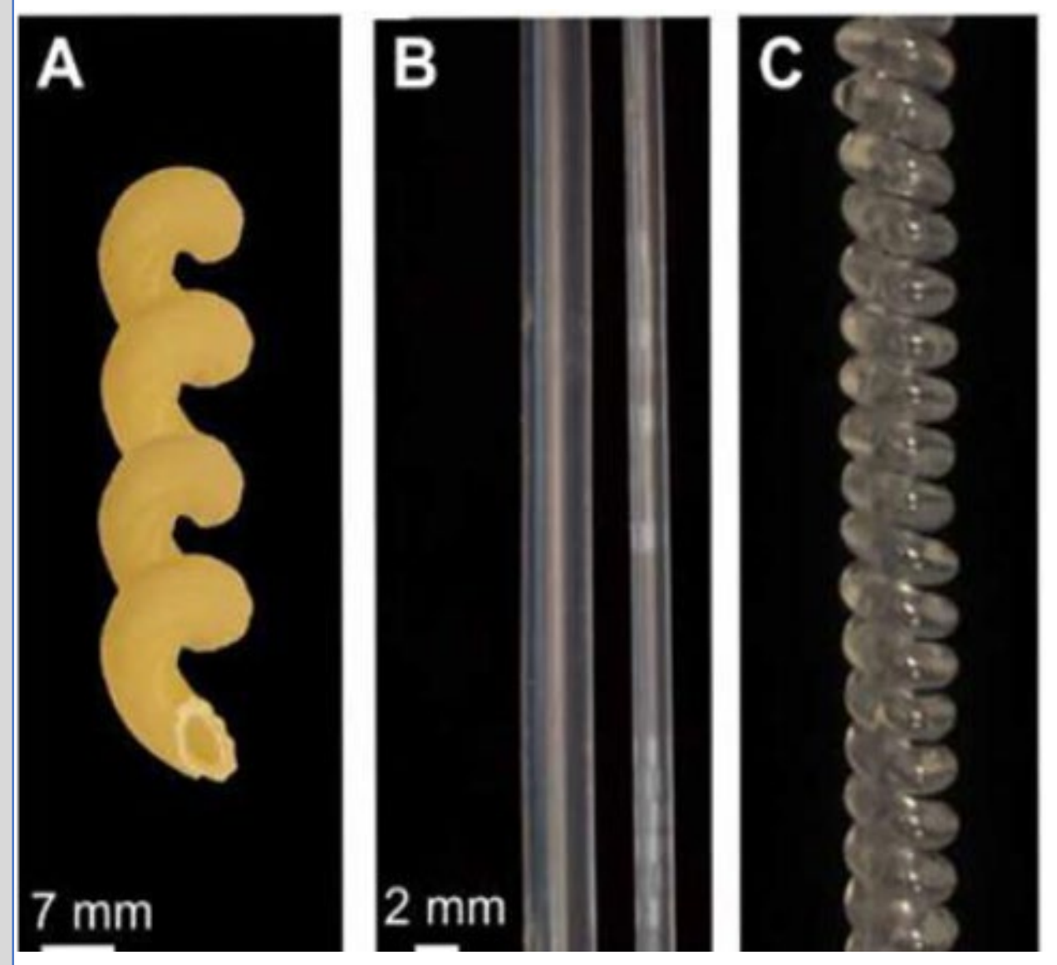

Fig 1: Cavatappi Pasta (left), Tygon tubing (middle), and Cavatappi muscle (right) [1]

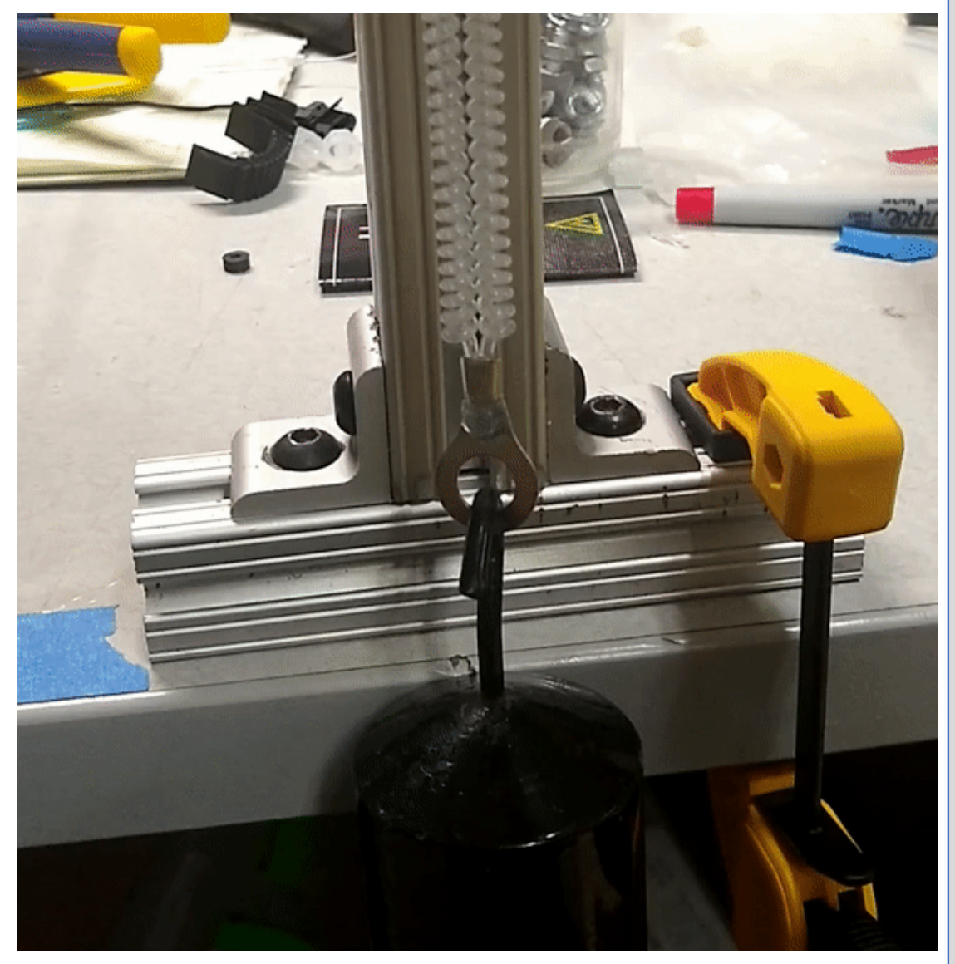

Fig 2: Cavatappi bundle attached to a weight

The muscles consist of a polymer tubing that is twisted and coiled onto a mandrel. This muscle strand is then clamped and annealed at a predetermined temperature to maintain their coiled shape when unconstrained. The final delivered physical product is an arm terminating in an end effector whose individual digits are each articulated by separate bundles.

Requirements

The requirements for updating the manufacturing method were subjective and focused on minimizing the amount of scrap produced. This includes:

- ☐ Identifying potential points of automation
- ☐ Redesign of existing manufacturing hardware
- ☐ Adding steps/processes to make the overall process more consistent

Actuator application focused on:

- ☐ End effector size: less than 10 cm^3
- ☐ Muscle scalability
- ☐ Increased muscle efficiency
- ☐ Safety of the final mechanism
- ☐ "Glove" or "Trumpet"-like actuation
- ☐ Development on muscle bundles (multiple Cavatappi are driven by one fluid source)

Results

Manufacturing Method:

Team Cavatappi designed and fabricated a manufacturing system (Fig. 4) that combined the manufacturing capabilities of the original manufacturing system (Fig. 3) with pre-spooled pre-twisted material, to maximize system efficiency. The redesigned system allows for a single individual to consistently coil muscle material onto precut mandrels with the use of a power drill, instead of rotation of the clamp.

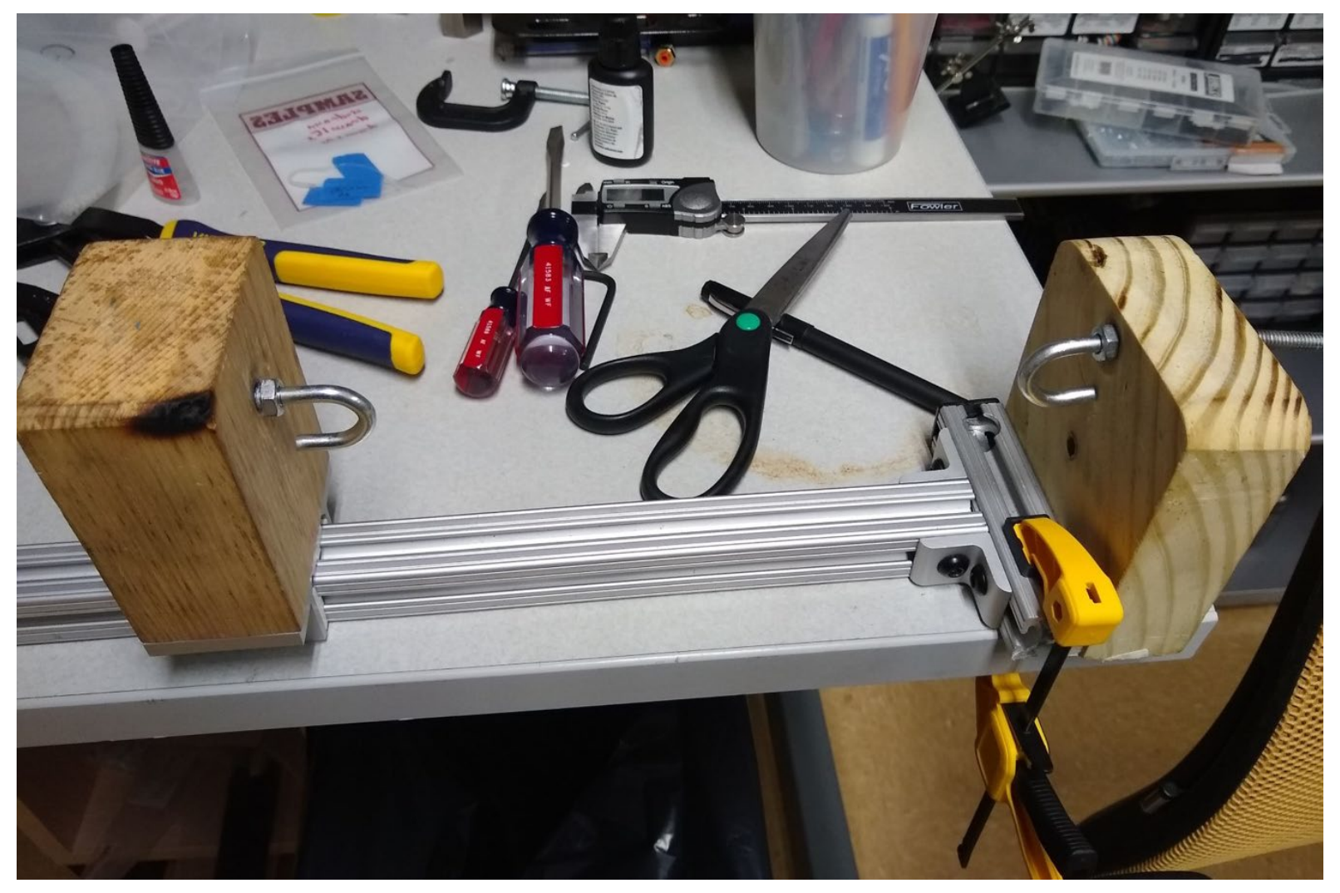

Fig 3: Original Manufacturing Setup

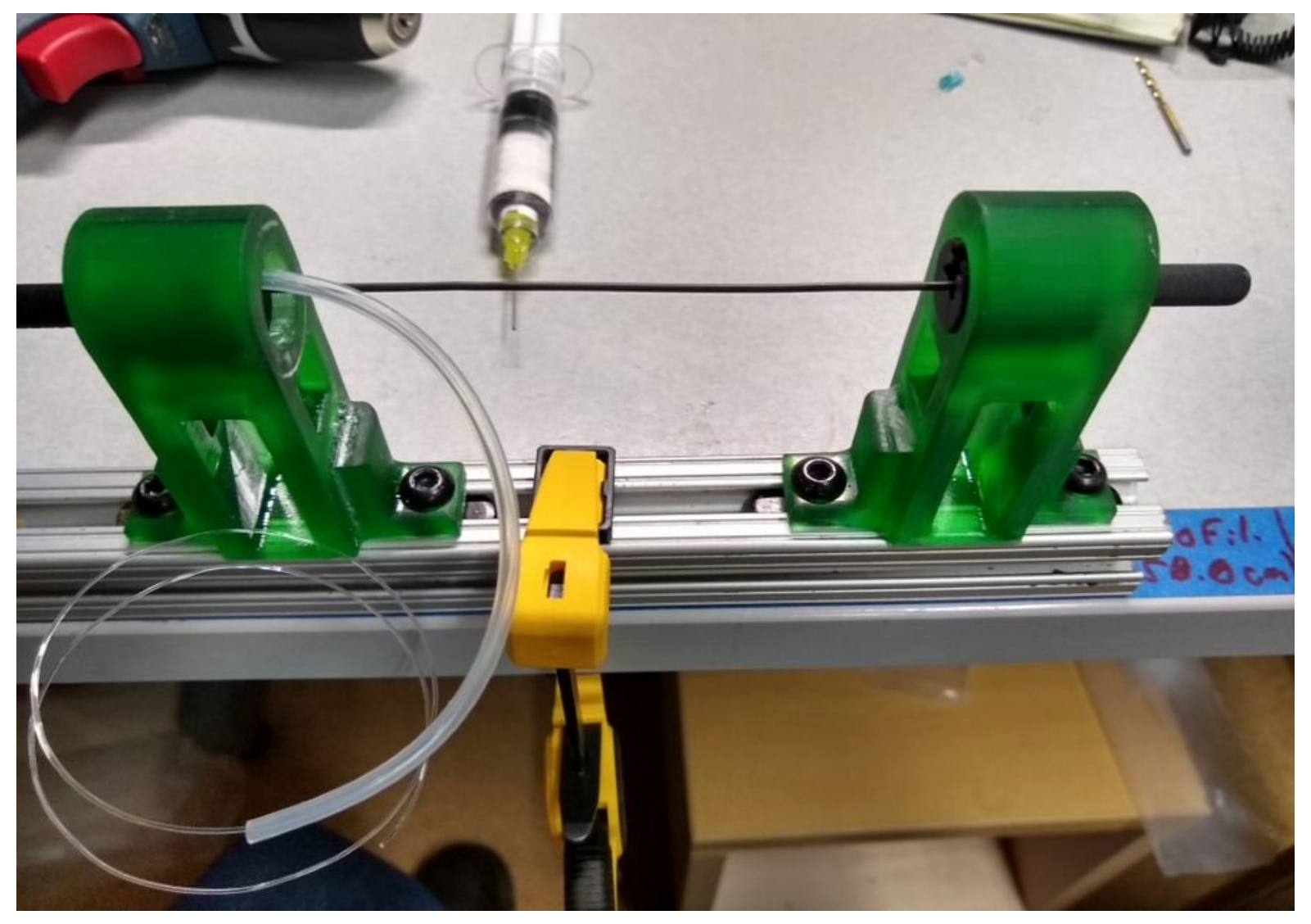

Fig 4: Manufacturing Method Redesign

Clamping/Annealing:

Additional changes that were made to the manufacturing setup included modifications to the annealing methods and clamping materials. The team faced issues manufacturing multiple muscles with the initial system due to only having a single set of clamps. To combat this problem the team designed 3D-printed clamps (Fig. 5) that would fulfill clamping needs without damaging muscle material. Later the team would utilize off the shelf saddle clamps (Fig. 6) that were efficient and easy to produce. The annealing method was updated from a commercial toaster oven to vacuum sealed muscles heated in a water bath, producing more even heating. These changes resulted in increased manufacturing efficiency from 25% to 85% in some cases.

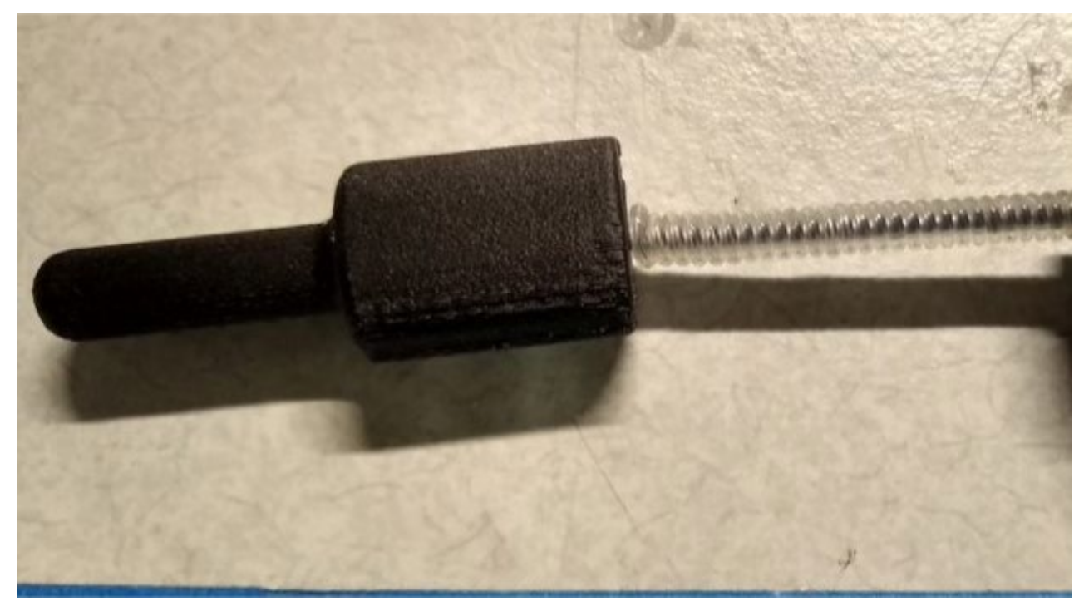

Fig 5: 3D Printed Clamps

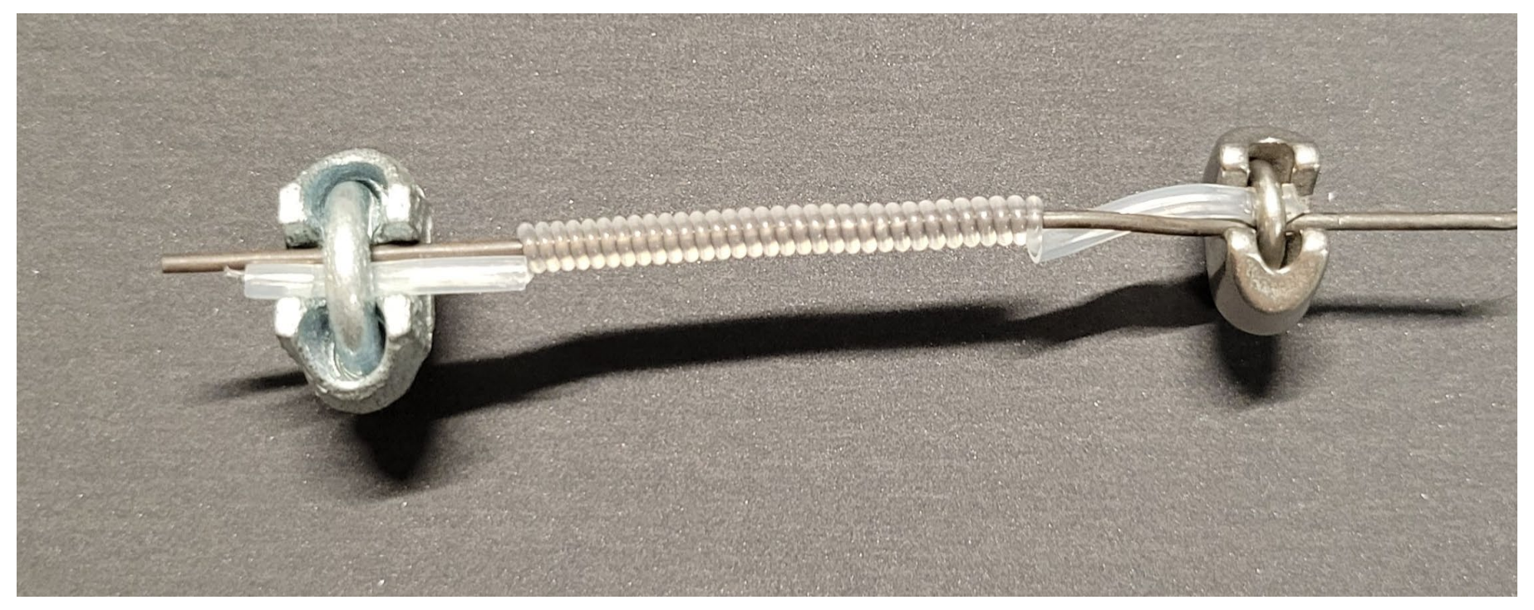

Fig 6: Saddle Clamps

Manufacturing methods were tested with three different sizes of material: the large size that was used in previous research, the smallest size known as mini-Cavatappi, and a mid-sized material. Testing yielded that the mini-Cavatappi were too delicate to produce viable muscles, due to an inability to seal muscles into a hydraulic system. The mid-size material had a high interior diameter to wall thickness ratio relative to elasticity, this material allowed for consistent muscle manufacturing, but annealed muscles did not produce enough work to justify force input. The client determined that the best course of action would be to continue with the full-size material and a change in scope was issued.

Muscle Bundling and End Effector:

The team developed several iterations of 3D printed manifolds that would allow for the transfer of hydraulic force from a single syringe to multiple muscles (Fig 7). depicts the three iterations of manifold that the team developed tested before settling on a design that would be functional, scalable, and watertight. Conclusion of testing yielded that the two-muscle variation was the best in relation to actuation and input force (Fig. 7 far right).

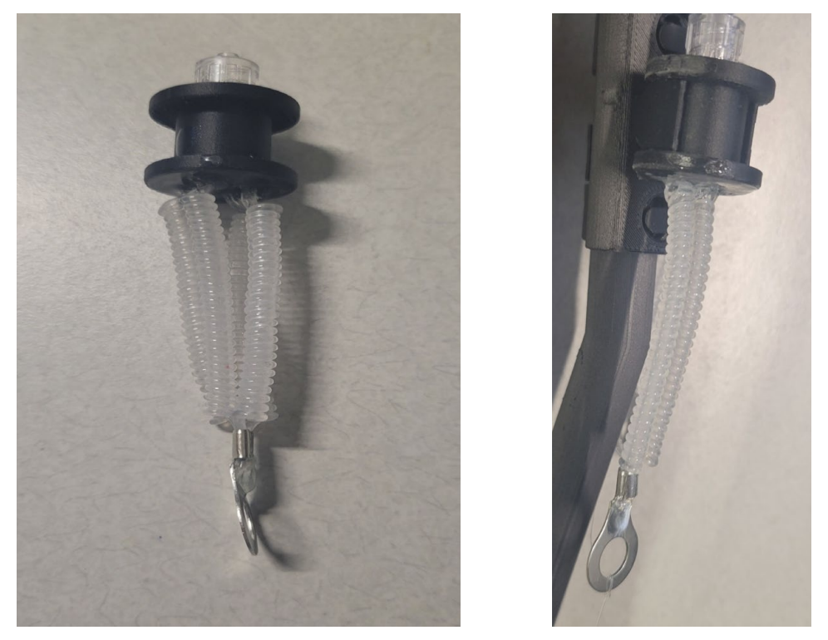

Fig 7: 3, 4, and 2 Muscle Manifolds

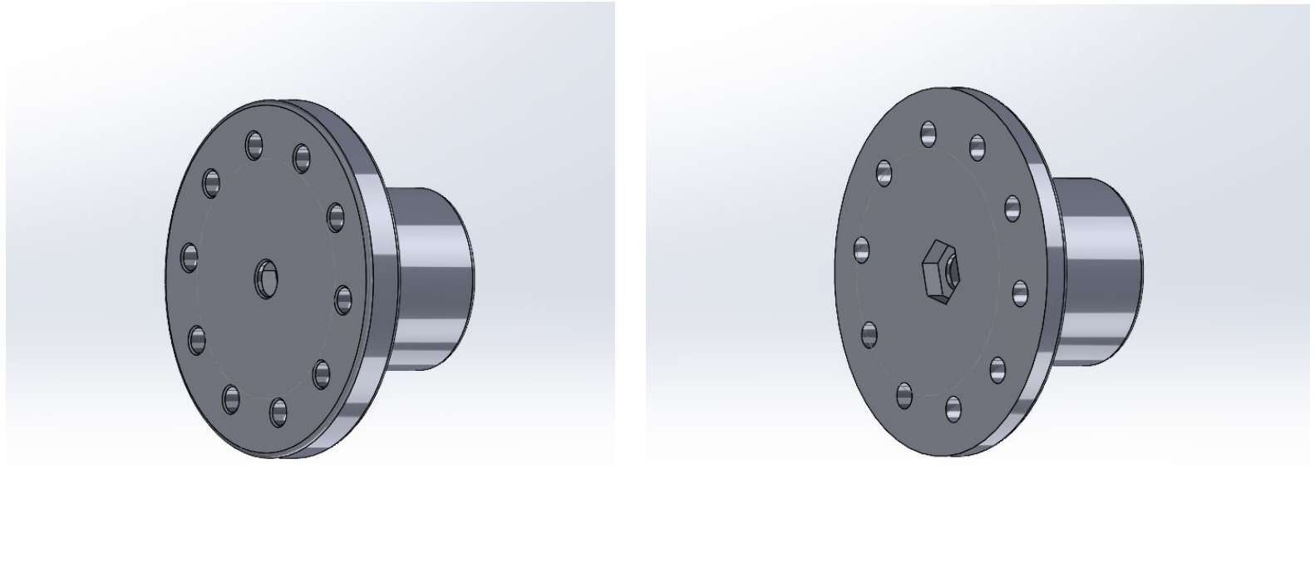

Fig 8: "Wrist"/Adapter plate (left) Cutaway showing in-print hex nut pocket (right)

The manifold was then mounted to a base structure the team referred to as the "bone" due to its biomimetic design. The client also requested that the end-effector, the mechanical attachment that interacts with the environment, be attached via an adapter plate. The adapter plate would allow for additional end effector designs to be attached to the system. The team devised a "wrist" that collected the monofilament coming from the bundles to keep them from being tangled but also had a metal nut printed inside to allow for the quick detachment of a given end-effector (Fig. 8). The fingers themselves were held in an unactuated position by elastic run through designed holes (Fig. 10) and monofilament to deliver force from the bundles on the other side. The bundle would open or close the end-effector was dependent on which side these two were on. The full build is shown below in Figure 9.

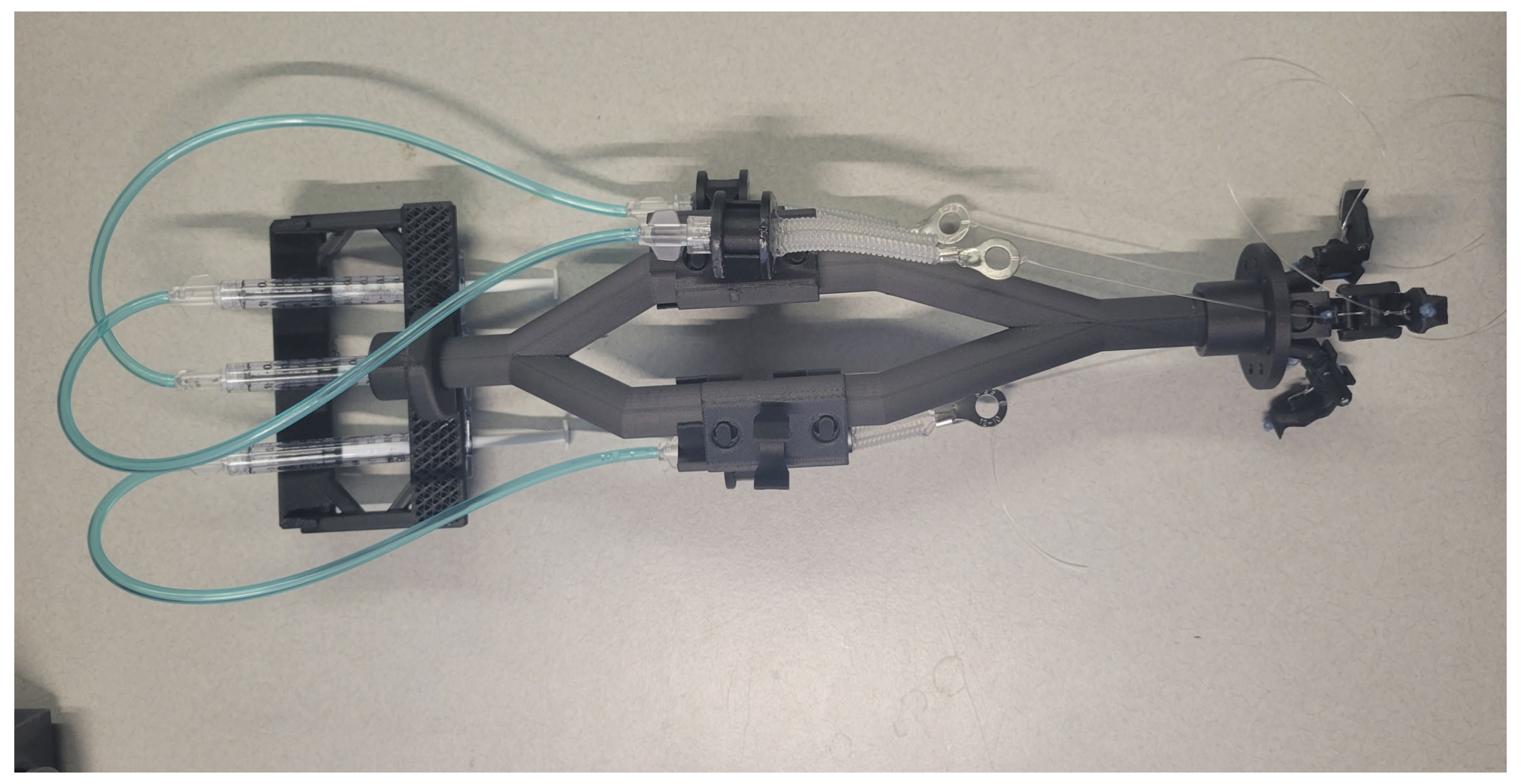

Fig 9: 100% Build of the mechanism

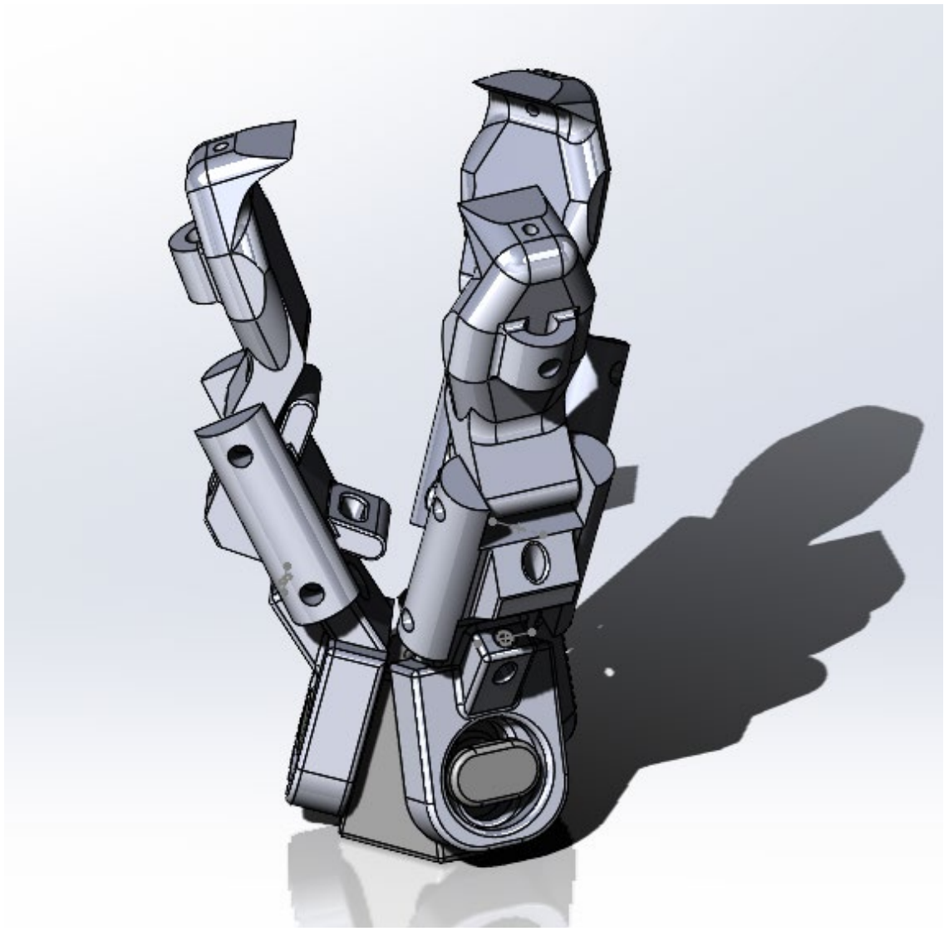

Fig 10: End Effector CAD model

References

[1] D. R. Higueras-Ruiz, M. W. Shafer, and H. P. Feigenbaum, "Cavatappi artificial muscles from drawing, twisting, and coiling polymer tubes," *Science Robotics*, vol. 6, no. 53, 2022.

Acknowledgements

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