Mini-Cavatappi Actuated Laparoscopic Tool

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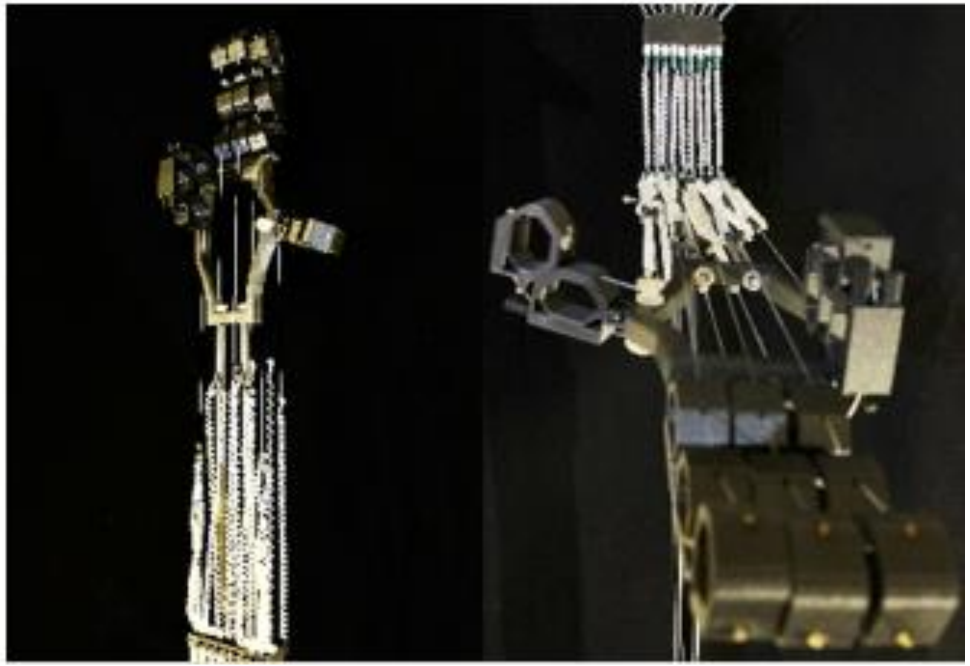

Figure 1: Cavatappi Artificial Hand Prototype [1]

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Project Description

- Soft Robotics, is the field within robotics most involved in human-robot interfaces
  - Each new muscle technology in the field has the potential to enhance the human experience in a number of ways
  - In order to get bigger stakeholders interested in technology there has to be demonstrated uses
- Our Project:
  - Aims to demonstrate the scalability of the cavatappi actuator in terms of size
  - Design a small actuating "hand like" device
    - Can pick up a small flat object from a flat surface.
    - Has multiple independent degrees of actuation
- Stakeholders include Dr. Michael Shafer and Diego Higueras-Ruiz.

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Literature Review

- Higueras-Ruiz DR, Shafer MW, Feigenbaum HP. "Cavatappi artificial muscles from drawing, twisting, and coiling polymer tubes" [1]
- The team is referencing the research article that our stakeholders have published. This article is utilized by all members of the team.

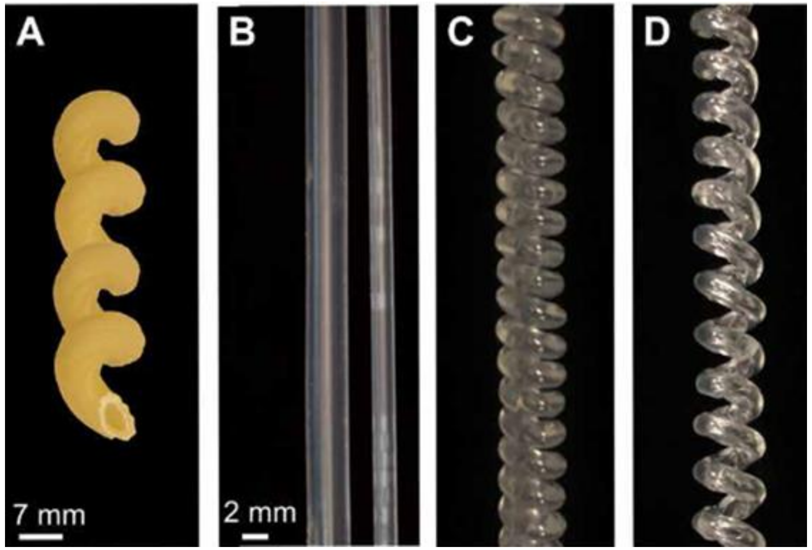

Figure 2: Cavatappi pasta (left) and PVC Cavatappi manufacturing steps (right) [1]

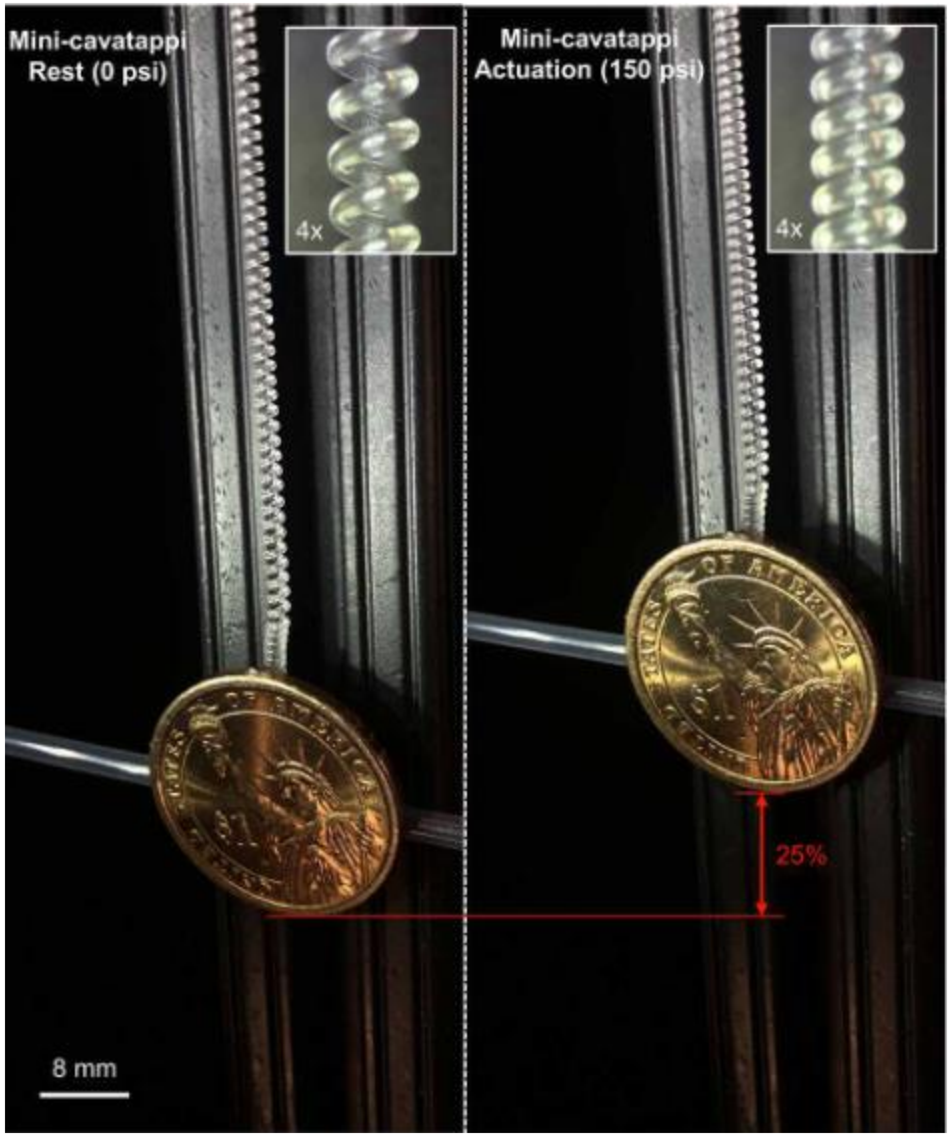

Figure 2: Micro-Cavatappi tubes lifting a US $1.00 coin at 0.0 and 150 psi [1]

Background/ Benchmarking: Muscles

- Current State of the Art:
  - Most currently known soft artificial muscles run into a combination of problems between them:
    - TPA's (Thermally Activated Twisted Polymers), Thermal activation can be inconsistent.
    - McKibben Actuators, too many points of energy loss and failure, difficulty running in parallel due to radial expansion
    - HASELs (Hydraulically Amp. Self-Healing Electrostatic Actuators) require upwards of 5kV to deliver useful mechanical energy.
- Cavatappi utilizes a hybrid mechanism that combines the properties of twisted polymer actuators (TPAs) and McKibben actuators. [1]

Literature Review: ctn'd

Table 1: Comparisons of Soft Actuators [1]

Metric	Cavatappi (37–40)	TPA (1)	PPAM (5, 6, 41)	HASEL (14, 15)	OV-PAM (12, 13)	FOAM (11)	Human muscle (42, 43)
Avg/peak specific power* (kW/kg)	0.8 / 1.42	27 / 50	1 / –	0.36 / 0.59	– / 0.02	~1 / ~2	0.05 / 0.28
Specific work (kJ/kg)	0.11–0.38	2.48	1.1	0.07	0.19	~0.25	0.04
Maximum actuation Strain (%)	~50	49	38	~60	>90	90	>40
Maximum actuation stress (MPa)	~0.70	~100	0.67	0.3	0.04	~0.6	0.35
Lifetime (cycles)	$>10^{4}$†	$>10^{6}$	$>10^{5}$	$>10^{5}$	–	$>10^{4}$	$>10^{9}$
Actuator efficiency (%)	~9‡§ and ~45‡‖	–	~57‡‖	–	~99‡§	23‡§ and 59‡‖	–
Total system efficiency (%)	10–22‡‖	~1	~5‡‖	21‖¶	16‡§	2–5‡§	~20

*This value is limited to the energy rate provided by the energy source. †This was the maximum number of cycles tested, not an upper limit on lifetime. Cavatappi showed no signs of degradation. ‡Actuators' energy conversion contractile efficiency (without energy recovery). §Pneumatic. ‖Hydraulic. ¶Full-cycle analysis of actuator efficiency (includes energy recovery).

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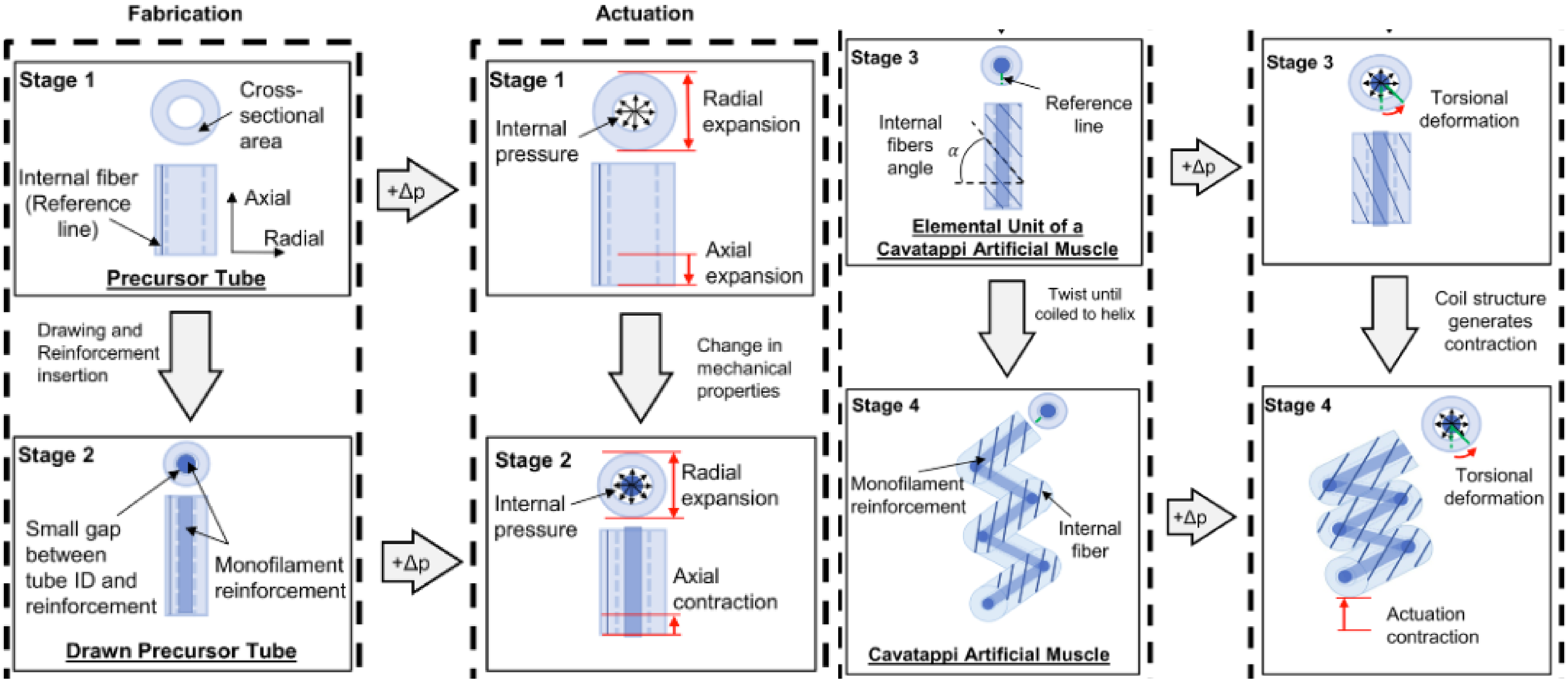

Figure 4: In-Depth look at Cavatappi muscle manufacturing process [1]

Background/Benchmarking: Tools

- Current MIS/ laparoscopic tools are usually stiff, steel rods with interchangeable heads to perform different operations. [2]
- Scissor-like actuation with one mode of control allows for simple force application
- Forceps can be semi-rigid or fully-rigid, depending on the use.

Figure 5: Common modern forceps (wolf style grip) [2]

Customer Needs and Engineering Requirements*

Customer Needs

- Manufacture system for muscle fabrication
- Scalability (Will it work at the intended size?)
- Generally low cost
- Reliable/ consistent production quality
- Actuated by user's hand via glove
- Utilize bundles of muscles
- "Hand" must be 1cm x 1cm maximum
- Flexible
- Dexterous enough to pick up a coin from a flat surface.
- Fewer failures in the muscle strands
  - Failure along twisting plane
  - Fluid leaks

Engineering Requirements

- Maximize force output/ minimize size needed
- Minimize manufacturing cost
- Mech. input => Proportional hydraulic output
  - Input reduction, 0 – 150 psi
  - Minimal loss compared to "full size" cavatappi
- Minimize device size
  - < 1.0 cm^3 final dimensions for "hand"
- High Factor of Safety
- Maximize user control sensitivity

*CNs and ERs may change during the project

Customer Needs and Engineering Requirements ctn'd

Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit) / Functional Requirements	Maximize Force Output	Minimize Muscle Size	Minimize Muscle Manufacturing Cost	Mech Input/Hydraulic Output	"Hand" Size	High Factor Of Safety
7	9	Manufacture System For Muslce Fab	○	○	●	○	○	●
10	9	Scalibity	●	○	●	●	●	▽
4	9	Reliable	▽	▽	○	▽	○	●
7	3	Conistent Production Quality	○	○	▽	○	▽	○
9	9	Acuated in a "glove-like" mechansim	▽	●	▽	○	○	▽
7	9	Utilize bundled muscles in paralell	●	●	●	●	▽	▽
10	9	1cm x 1cm maximum size of "hand"	○	●	▽	▽	●	▽
5	3	Flexible	○	▽	▽	○	▽	▽
6	9	Reduce leaks in muscle	●	○	○	●	▽	●

Target	>=0.38kJ/kg	d<=1.5mm	TBD	<=50 N	<=1cm^3	>=1.5 FS
Max Relationship	9	9	9	9	9	9
Technical Importance Rating	472.31	512.31	426.15	469.23	407.69	330.77
Relative Weight	18%	20%	16%	18%	16%	13%

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Schedule and Budget

This Semester

- Manufacturing muscles
  - Automating some of the production steps
    - Drawing, Twisting & Coiling, and Heating
  - Striving for consistency and quality in the manufacturing process.
- Stress testing
  - Repeated actuation
  - High force actuation

Budget

- Currently uncapped for materials
  - Many materials are already purchased, no need for more right now
- $200.00 for miscellaneous expenses
  - Presentation material
  - Test material (final product)

Next Semester

- Manufacturing the medical tool/muscles
  - Prototyping
    - Bundling
- Design testing
  - Prototype trials
    - Different forms of actuation
- Application of Manufacturing
  - Automation
    - Drawing, Twisting & Coiling, and Heating

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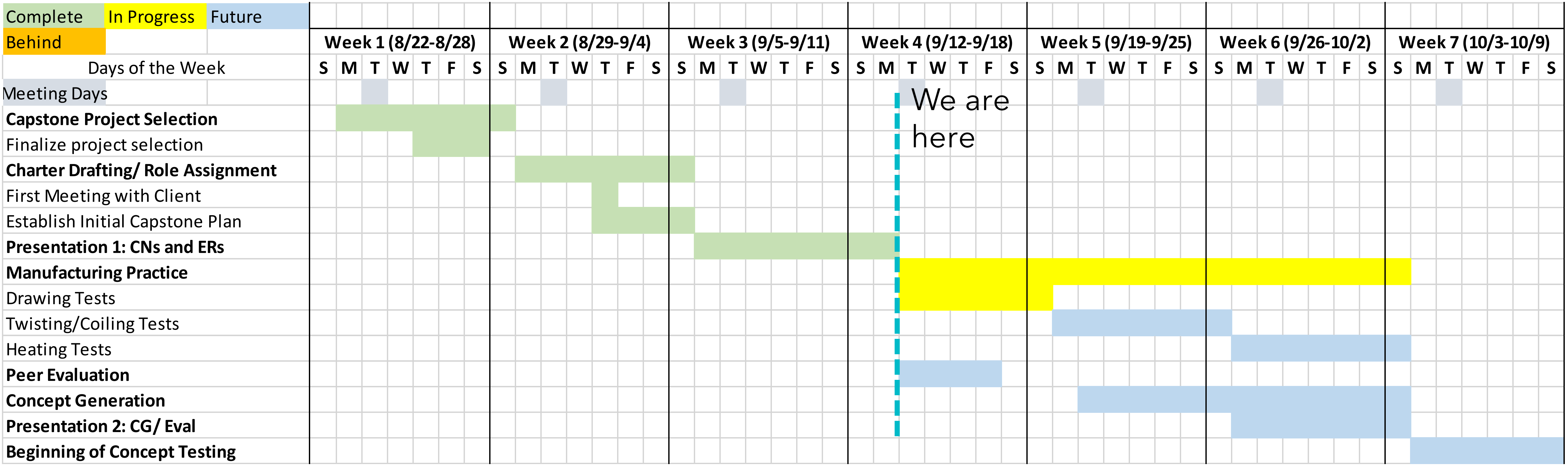
Semester 1 Current Project Timeline



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Bennett, Team Cavatappi, Sept. 13th, 2021

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, p. 1 to 12, April 2021. Available: ScienceRobotics, https://www.science.org/doi/10.1126/scirobotics.abd5383. [Accessed: 01, Sep. 2021].

[2] "5 fr 34cm Semi Rigid Biopsy FRCPS WOLF STYLE," Surgical Instruments. [Online]. Available: https://www.surgicalinstruments.com/browse-by-type/product/8547-5-fr-34cm-semi-rigid-biopsy-frcps-wolf-style. [Accessed: 11, Sep. 2021].

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