

Parametric Prosthetics

By: Ashlyn Schafer
Carroll Middle School
Fort Wayne

Problem

The Reason
Behind
Project

I am interested in biomedical engineering as a career path.

Prosthetics are complex with many mechanical parts to learn about.

Optimizing a prosthetic device requires systematic testing of geometry and material parameters.

Creating a 3D printed hand is a quick way to learn about prosthetics.

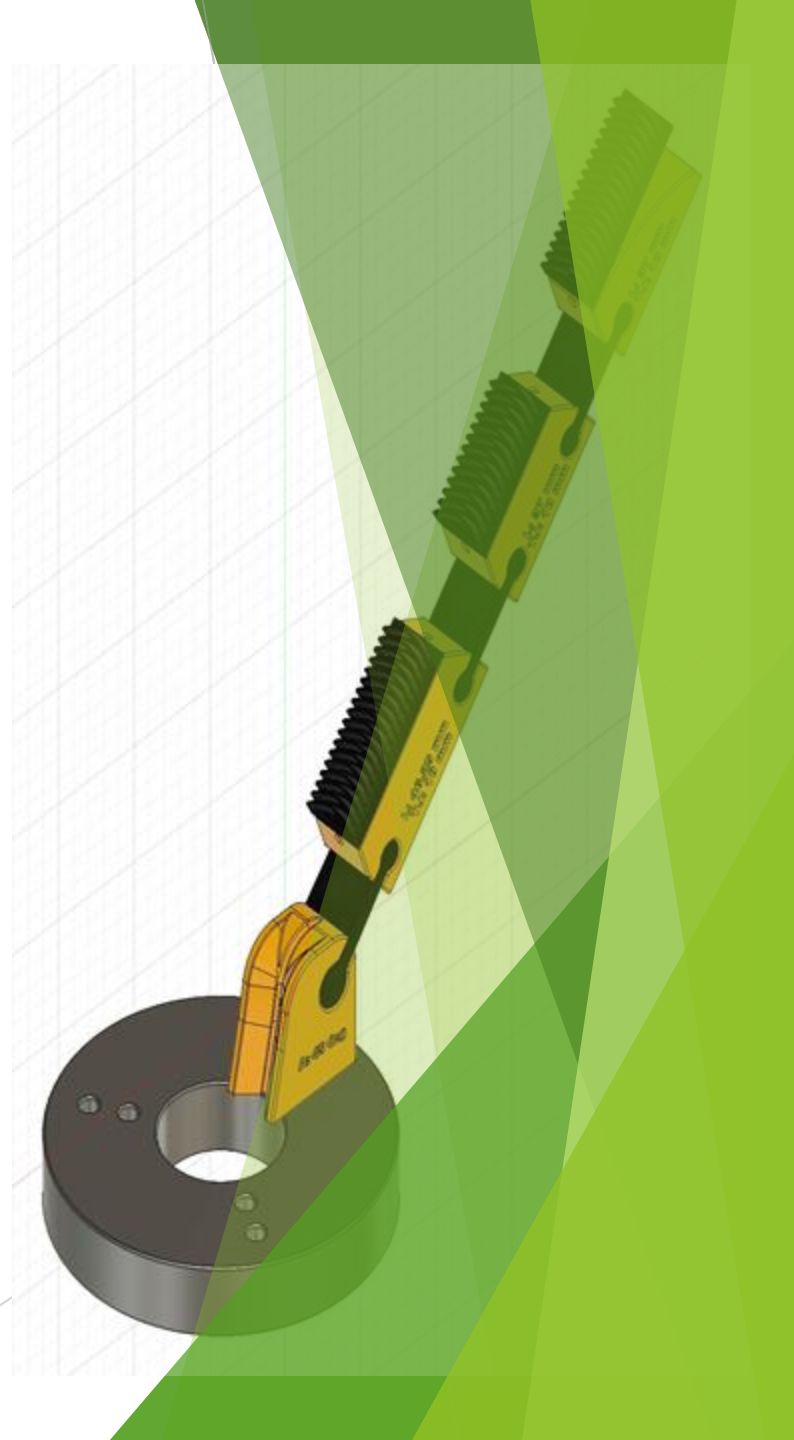
Question and Hypothesis

Question / Engineering Goal

- Can a low-cost, modular, tendon-based prosthetic gripper be designed and 3D printed to help test different configurations efficiently and quickly?

Hypothesis

- The distance between the tendon and joint changes the mechanical advantage, so increasing this distance should reduce the closing force required. Increasing the depth of the flexible grip pads should also increase the ability to grip objects.
- I believe the best design will have a 15mm tendon to joint distance and a 4mm pad depth.



Materials

Software and Testing Devices

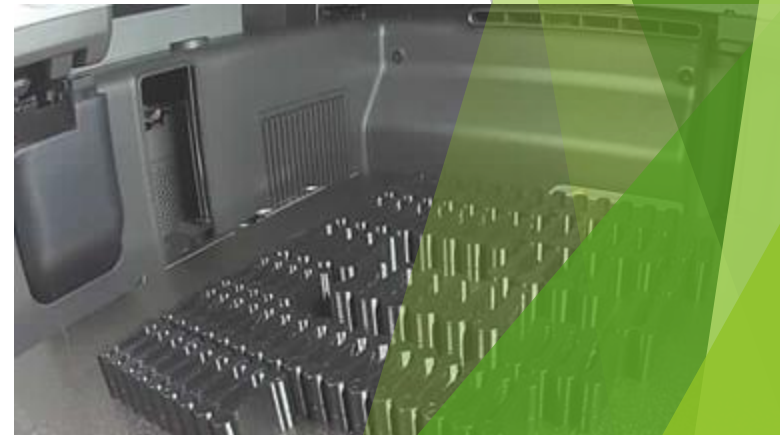
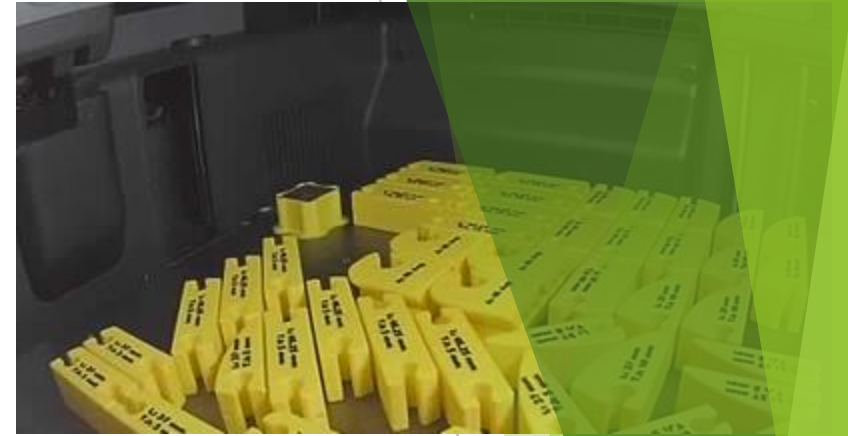
- 3D modeling software (TinkerCad, Autodesk Fusion)
- 3D printing software (Bambu Studio, Orca Slicer)
- A spreadsheet to document the results
- Force Gauge with hook to measure closing force requirements
- Household objects to test grip dexterity ex: ball, hat, cup, cube, and glasses



Materials

Prosthetic Hand

- 3D Printer that can print PLA, TPU, and PETG
- Filament: PLA, TPU 90A, and PETG-CF
- 40lb Braided Fishing Line for tendons
- Metal Snap Rings to attach all tendons together in one pulling location
- Heatset inserts, soldering iron, and screws to attach fingers to base
- Bench vice
- General Supplies: Scissors, super glue, and cutting board.



Setup

- Create a software model of a segmented tendon driven prosthetic hand. Use parameters to quickly change the distance between the tendon and joint, and the thickness of the finger pad.
- Print all the joints using TPU 90A, the finger sections with PLA, and the base with PETG-CF
- Assemble the fingers in sets of three with the fishing line tendons connected to one snap ring.
- Add heatset inserts into metacarpal section and screw them to each base.
- Create spreadsheet to record testing data.



Testing Procedure: Closing Force

- Set the Force Gauge to measure in kilograms and peak load.
- Install the one of the hand designs on the circular base plate.
- Place base plate on the slightly opened jaws of a bench vice with the tendons and snap ring hanging between the jaws.
- Put the hook of force gauge on the snap ring.
- Slowly pull the force gauge straight down until all the fingers almost touch.
- Record the peak force just applied and zero out the current reading.



Testing Procedure: Dexterity

- Choose 5 household objects: tennis ball, cup, hat, glasses, and cube.
- Install one of the hand designs on the rectangular base plate.
- While holding the hand vertically,
 - attempt to pick up each household objects 10 times, and
 - record the success rate.
- While holding the hand horizontally,
 - attempt to pick up each household objects 10 times, and
 - record the success rate.
- Repeat both tests this for every hand design.



Analysis

- TPU 90A was chosen for full testing over TPU 95A because on average TPU 90A required 57% less closing force.
- The 15mm tendon to joint distance on average had a
 - 49% lower closing force than the 10mm, and a
 - 166% lower closing force than the 5mm.
- The 4mm pad was 10% more dexterous than the 2mm pad.
- The 15mm tendon to joint distance on average was
 - 29% more dexterous than the 10mm, and
 - 60% more dexterous than the 5mm.

Vertical Dexterity Test

Tendon/Joint Distance (mm)	5	10
Pad Length (mm)	2	4
Cube	0	0
Tennis Ball	1	2
Cup	1	2
Hat	2	3
Glasses	2	3
% Success Rate	12.0%	20.0%
% Change		40.0%

Horizontal Dexterity Test

Tendon/Joint Distance (mm)	5	10
Pad Length (mm)	2	4
Cube	0	2
Tennis Ball	1	2
Cup	4	2
Hat	2	3
Glasses	4	3
% Success Rate	22.0%	20.0%
% Change		-9.1%

Overall Dexterity Test

Tendon/Joint Distance (mm)	5	10
Pad Length (mm)	2	4
Cube	0	2
Tennis Ball	1	2
Cup	4	2
Hat	2	3
Glasses	4	3
% Success Rate	22.0%	20.0%
% Change		-9.1%

Analysis

Test Data for Closing Force and Overall Dexterity

Avg Closing Force: TPU 95A vs TPU 90A

Filament	TJ-5mm	TJ-10mm	TJ-15mm	
TPU 90A	2.47	1.39	0.93	
TPU 95A	4.54	2.23	1.18	Avg
% Change	-83.9%	-60.8%	-27.7%	-57.5%

Closing Force Test

Force required to close the grabber (kg)

Filament	TPU 90A (2 walls, 15% Gyroid infill)		
Test #	TJ-5mm	TJ-10mm	TJ-15mm
1	2.59	1.36	0.92
2	2.49	1.35	0.94
3	2.38	1.38	0.94
4	2.50	1.36	0.92
5	2.49	1.44	0.92
6	2.44	1.36	0.91
7	2.48	1.38	0.91
8	2.36	1.36	0.92
9	2.50	1.42	0.96
10	2.43	1.45	0.93
Average	2.47	1.39	0.93
% Change		-77.9%	-49.5%
			-166.0%

Overall Dexterity

Tendon/Joint Distance (mm)	5		10		15		% Success Rate	by Tendon/Joint Distance			by Pad Length	
	2	4	2	4	2	4		5	10	15	2	4
Cube	0	2	8	7	9	6	27%	5.0%	37.5%	37.5%	28.3%	25.0%
Tennis Ball	2	5	8	11	9	12	39%	17.5%	47.5%	52.5%	31.7%	46.7%
Cup	5	6	10	11	13	12	48%	27.5%	52.5%	62.5%	46.7%	48.3%
Hat	4	6	11	17	17	17	60%	25.0%	70.0%	85.0%	53.3%	66.7%
Glasses	6	8	14	13	16	14	59%	35.0%	67.5%	75.0%	60.0%	58.3%
% Success Rate	17.0%	27.0%	51.0%	59.0%	64.0%	61.0%	93.0%	22.0%	39.0%	55.0%	44.0%	49.0%
% Change		37.0%		13.6%		-4.9%			43.6%	29.1%		10.2%
										60.0%		

Conclusion

- My hypothesis was mostly correct.
 - Yes, the longer the tendon to joint distance, the lower the closing force and greater the dexterity. The 15mm distance was the best.
 - Yes, the greater depth the finger pad had, the better overall dexterity. The 4mm pad was overall the best.
 - No, the best specific configuration was 15mm tendon to joint distance with a 2mm finger pad simply because the 4mm finger pad did so poorly on the vertical dexterity test.