Individualized Functional Finger Prosthesis

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Abstract

A prosthesis is a functional replacement of an amputated or missing limb. The biggest tradeoff in prosthetic design is mechanical functionality vs. realistic aesthetics. In general, prosthetics are either purely aesthetic and non-movable, or mechanically actuated but lacking discretion; this tradeoff can lead to patients not using their prosthetics. The purpose of this project is to design a prosthetic for a proximal pointer finger amputation that is both mechanically functional and aesthetically appealing, allowing patients usable and discreet prosthesis. To solve this issue, the team designed a 3D printed semi-actuating finger prosthetic frame that could fit under a silicone sleeve. The prototype was evaluated quantitatively on its strength and lifetime, and qualitatively with a subjective usability test. Testing results showed that failure from a 3 point bend occurred at an average of 282.66 Newtons of force, meeting mechanical strength requirements. Lifetime was short, between 250 and 450 cycles, and limited by screw loosening rather than elastic band fatigue. Subjective evaluation revealed good ease of use but a need for improvement in range of motion. Further work is required to fully meet the design

Introduction

Motivation

- 30-50% of amputees prefer to either not or only periodically use prostheses, due to insufficiencies with aesthetics, movement, and/or sensitivity [14]
- Have to choose between price, aesthetics, and functionality

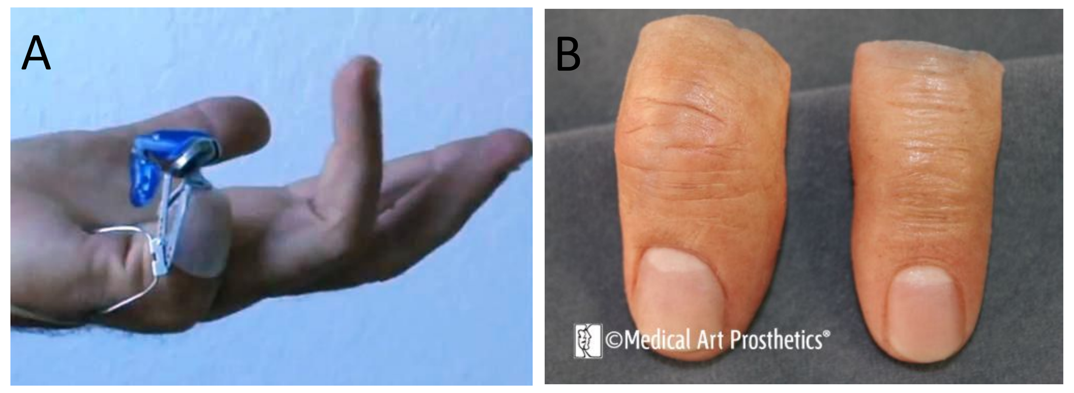

Figure 1. Examples of functional (A) and aesthetic (B) finger prosthetics, illustrating the tradeoff between mechanical functionality and appearance.

Background

- Amputations cause psychosocial/ psychological damage [8]
- Embarrassment over appearance equates to functional disability [9]

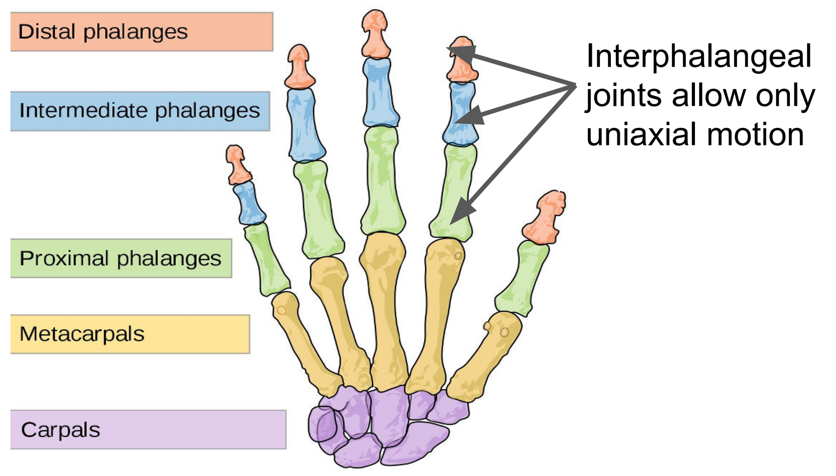

Figure 2. Illustration of hand skeletal physiology[13].

Design Criteria

- Aesthetically indistinguishable from a real finger
- Customizable, 3D printable and convenient to assemble
- Provide mechanical stability to manage small objects (5.3 N for writing)[2]
- At least 1 year lifespan (difficult to judge number of cycles)
- Match dimension and range of motion of index finger PIP and DIP flexion
  - 43 mm, 25 mm and 23 mm length, proximal to distal
- Foam filling between structure and sleeve to allow shaping of prostheses
  - Diameter of 10 mm maximum
- Permit actuation without compromising aesthetics

Design Specifications

- Hinge joints have 3 loose fitting flanges with minimal resistance to movement
- Finger bridge allows actuation by adjacent digit
- Latex bands provide constant extension force
- 10mm maximum diameter allows for optimal foam filling to provide life-like texture
- Aesthetic silicone sleeve to fit over apparatus
- 90° Range of Motion at both joints

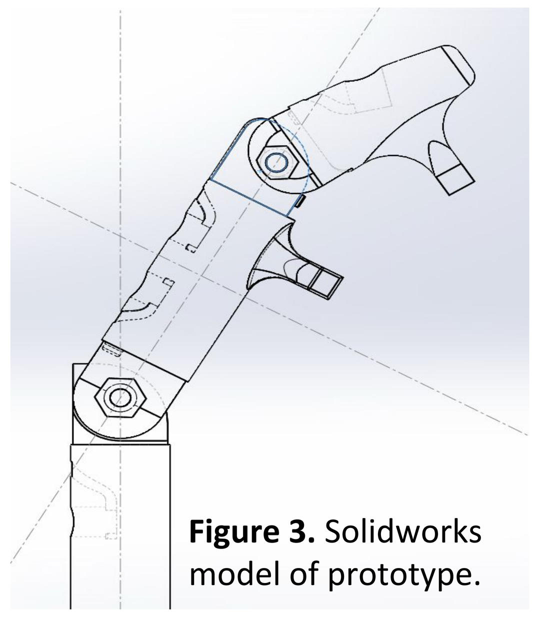

Figure 3. Solidworks model of prototype.

Final Design

Figure 4. Printed prototype; note lack of distal elastic

Fabrication

- 3D printed with photopolymer at 100 µm
  - Printed on Form 2, using resin SLS
  - Biocompatibility not an issue, printed parts will not contact the patient
- 3D printed parts were assembled with M2x16mm screw and hex nut
- ⅜" heavy grade orthodontic bands
  - Held by M4x5mm set screws
- Will be attached to custom fit PMMA residuum cap via press fit during curing.
- Proximal segment to be cut to adjust length

Table 1. Typical forces experienced by a human finger (n = 1).

	Poke [N]	Press [N]	Pull [N]
Human Finger	45.95 ±17.8	43.05 ±18.43	60.09 ±25.24

Testing

Fatigue Test on PIP Joint

- 10 mm/s, 1000 cycles
- Full extension to 90° flexion
- 32mm range of travel
- Primarily interested in lifetime of bands
- Secondary interest in mode of wear at joints

3-Point Bend Test

- Attached a residuum cap onto the base of prototype with PMMA
- Applied force to bond between cap and prototype.
- Determining probability of failure at adhesion to cap

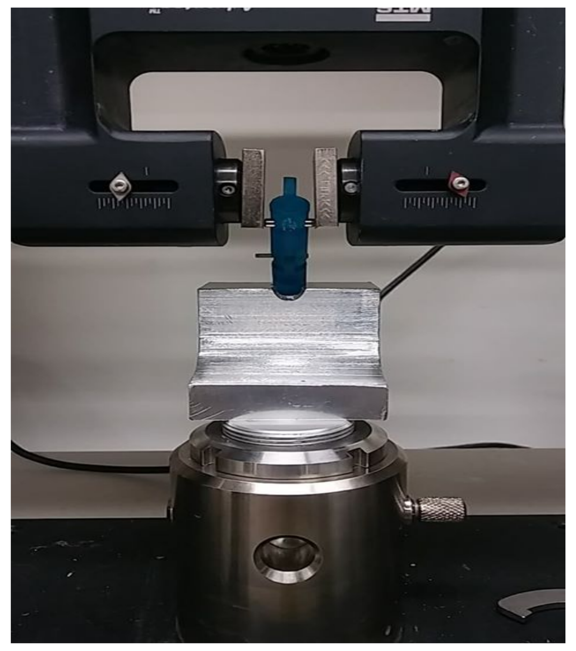

Figure 5. Setup of MTS testing with prototype.

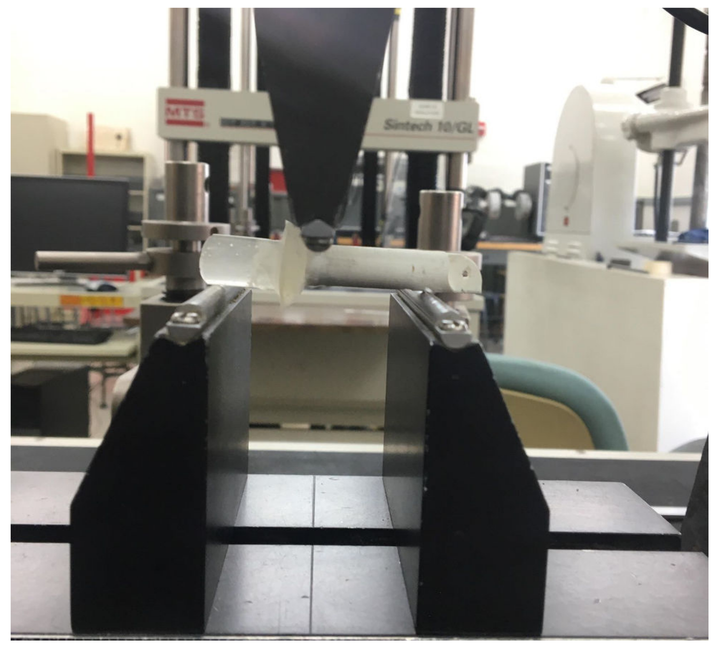

Figure 6. Setup of MTS three point bending test.

Qualitative Test

- Subjective test of comfort and functionality from a non-amputee
- Preliminary; must assess with real patient and fully assembled prosthetic

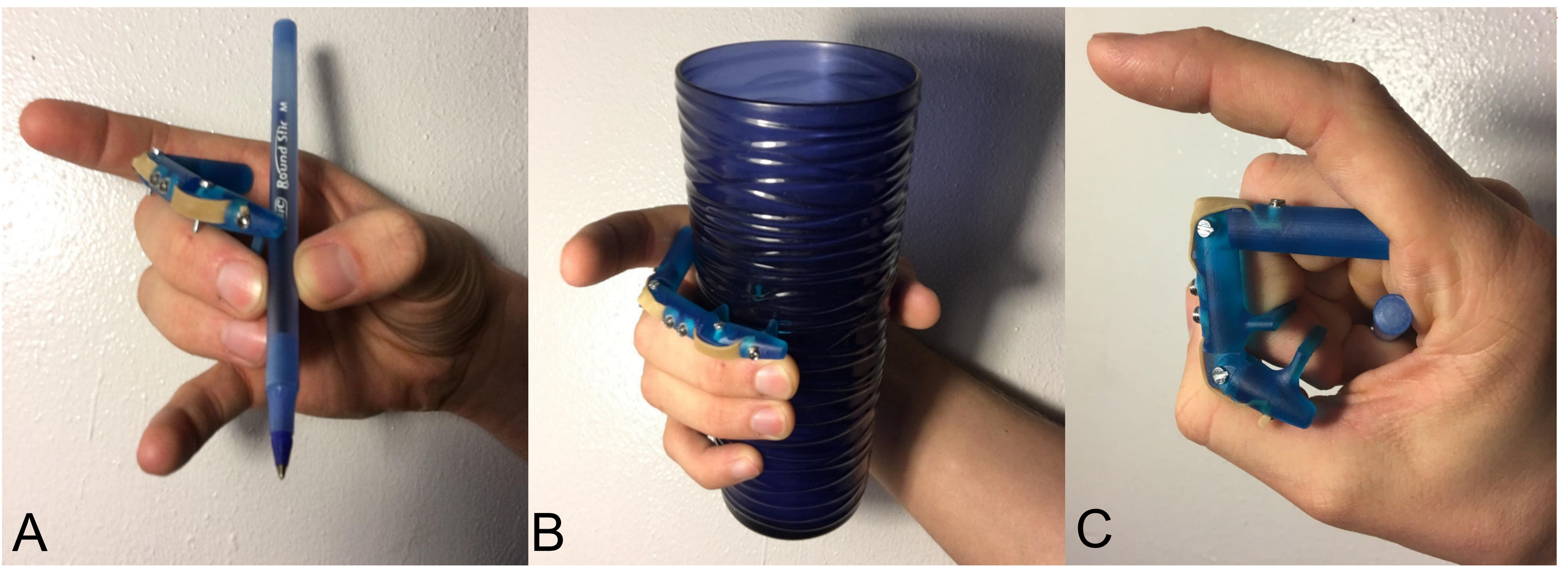

Figure 7. Qualitative testing, showing finger gripping (A), large object gripping (B), and small object gripping (C). An issue with limited joint rotation can be seen in C.

Results & Discussion

Fatigue Test

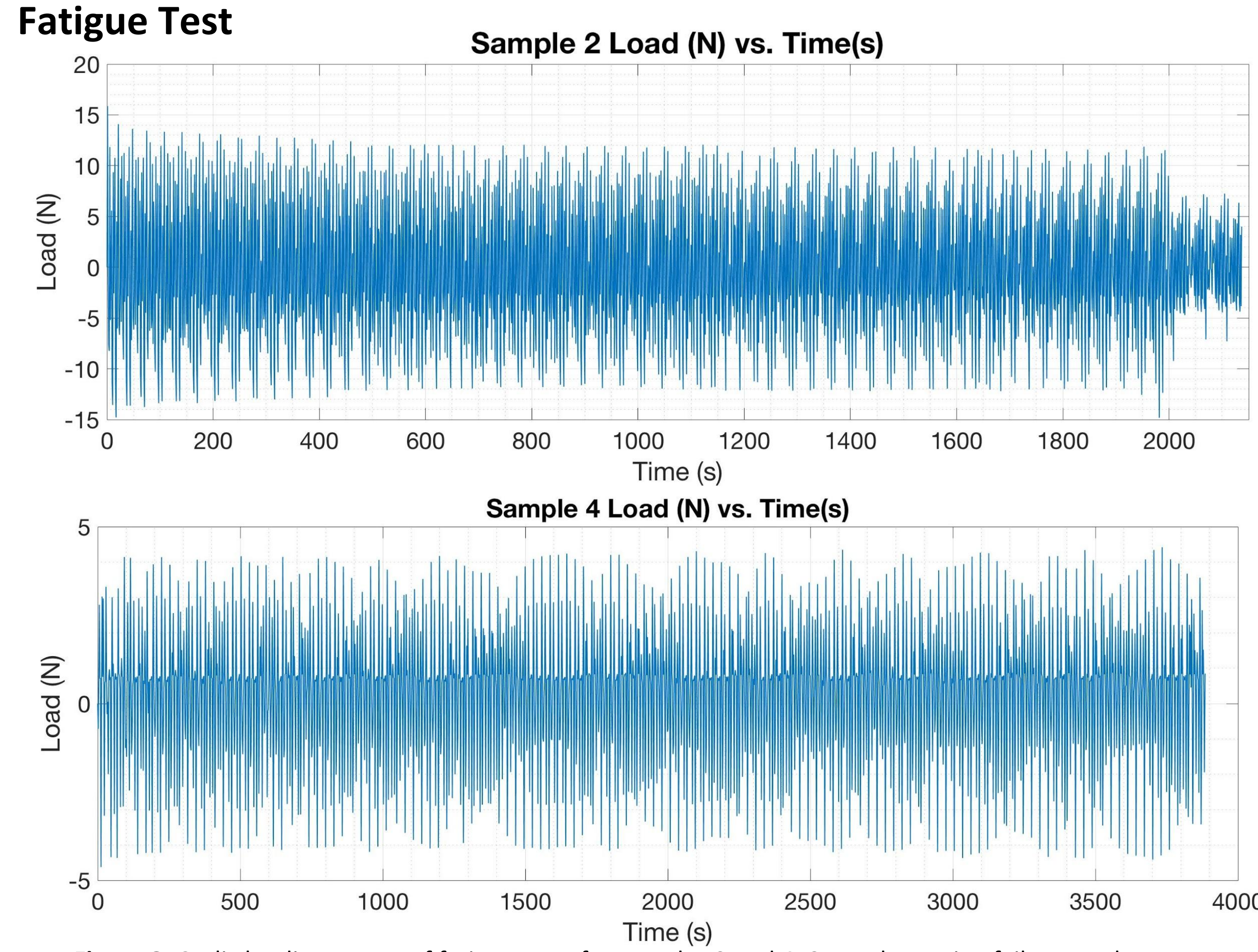

Figure 8. Cyclic loading curves of fatigue tests for samples 2 and 4. Screw loosening failure can be seen at ~2000 s in sample 2 and ~3600 s in sample 4.

- 2 samples experienced screw loosening failure at 250 and 450 cycles
- 1 sample experienced constant amplitude, indicating no fatigue occurred
- Amplitude remains generally constant, indicating minimal fatigue of bands
- Physical inspection shows discoloration of rubber bands indicating slight wear.
- No physical indications of wear at joints in post-test examination

3-Point Bend Test

- Average 282.66 ± 59.20 N force to failure
- Part broke before bond in 4 out of 5 tests
- Normal usage is unlikely to cause failure at interfacial bond

Qualitative Test

- Bridges are easily accessed or avoided, as needed by user
- Recoil is minimal; quiet clicking is present on reset to flexed state
- Limit of rotation to 90° hinders gripping
- Device feels a little "weak" in extension
- Assembly of part is difficult and leads to functional inconsistency

Future Work

Further Design Iterations

- Improve biomimetic ROM
- Implement silicone sleeve and filling
- Refine form of actuation
- Adjust design to ease assembly

Future Analysis

- Determine the force to break at a joint
- Qualitative eval with a potential user
- Assessment of lifetime of silicone sleeve during movement

References/Acknowledgements

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