Material Analysis and Design for a Rotator Cuff Tendon Repair Scaffold

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Background/Motivation

- Rotator cuff damage afflicts millions of people annually, particularly the older demographic.
- The body has a difficult time repairing tears in this tissue naturally
- Current cell therapies, while helpful, are not ideal

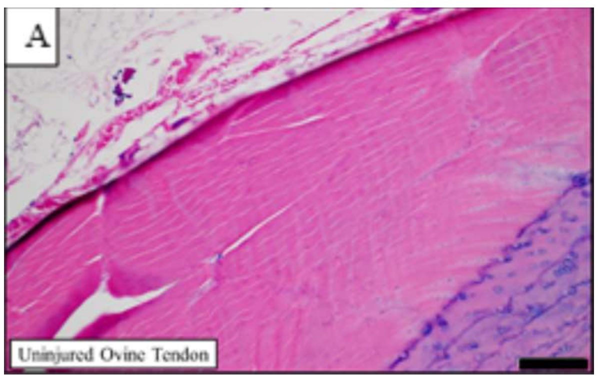


Figure 1: Histology image of healthy tendon tissue. Image sourced by Jimmy Johnson within CSU's Orthopedic Bioengineering Research Laboratory

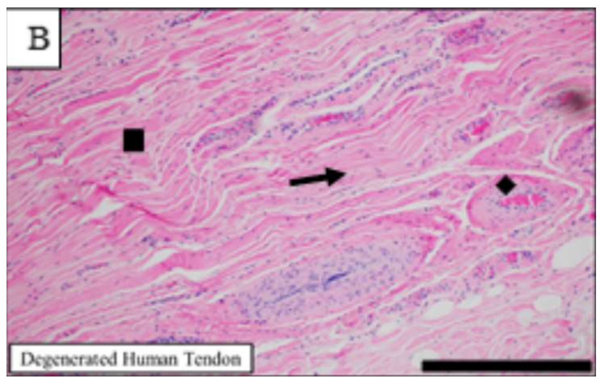


Figure 2: Histology image of degenerated tendon tissue, also sourced by the CSU OBRL's Jimmy Johnson

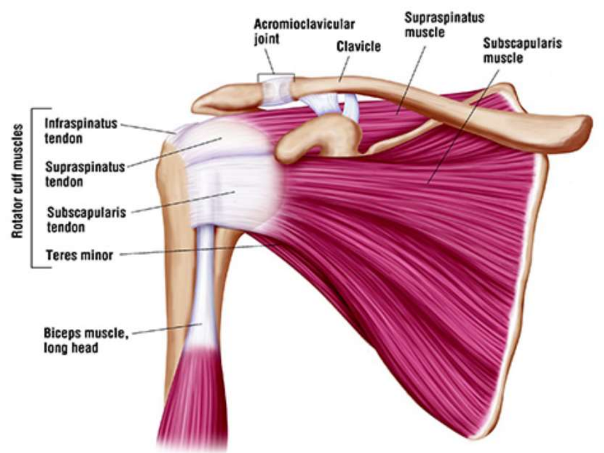


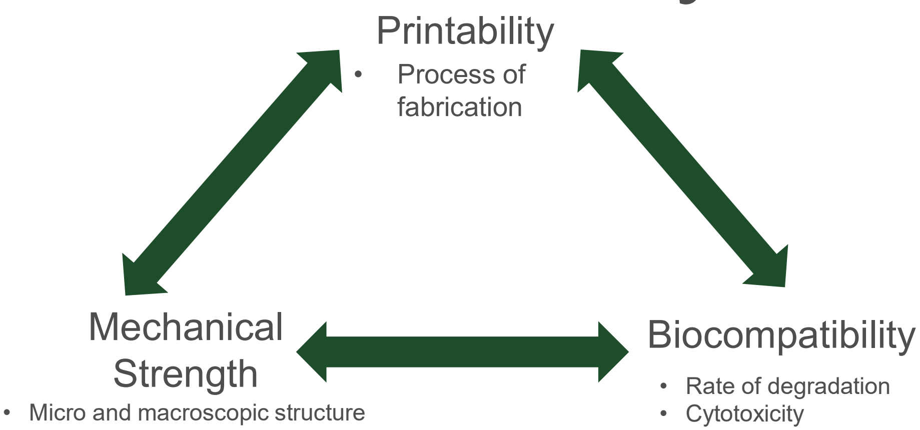
Figure 3: An anatomical diagram of the rotator cuff and its associated tendons. From "Rotator Cuff" by the Illinois SportsMedicine Orthopaedics & Stem Cell Center. Retrieved from ismoc.net/rotator-cuff.html

Background/Introduction

Figure 1: A simple example graphic of how a scaffold/ patch can be employed to help facilitate healing of the rotator cuff. Adapted from "Patch the Shoulder" by the Journal of Arthroscopy, received from arthroscopyjournal.com

- Common material for these patches is a polymer called Polycaprolactone (PCL)
- Subject to various shortcomings:
  - Fatty infiltration
  - Poor tendon to bone adhesion
  - Decreased muscle tissue quality
  - High retear rates
- My project focused on the <u>material</u> of this patch, in hopes of generating a more ideal treatment for rotator cuff damage

Material Analysis/ Investigation



Considerations are highly interconnected; focus was placed on printability

Of the following materials I researched, I selected two of the brightest candidates:

- Aliphatic Polyester-poly(D,L-lactide)-polyaniline (S-HAP-PLA-PANI)
- Aliphatic Polyester'; polyglycolide (PGA)
- Polyactide (PLA)
- Polyphosphazenes
- "Polyurethanes
- Silk Fibroin(SF)
- Callogen and Chitosin (80%:20%)
- PNAGA/CMC-Fe hydrogels
- Decellularized Tendon Scaffold (DTS)
- "nanotopographic" scaffolds
- PLCL copolymer (Polyl-lactic acid [PLLA] and PCL)
- Collagen and Silk Blend
- Chitosan
- Polyethylene Terephthalate (PET)
- Multiphasic PCL/TCP with gelatin methacrlate
- PLGA (poly(l-lactide-co-glycoside))
- HA (Hyaluronic acid) Hydrogel
- PLA/ HA Composite
- HA/PCL Composite
- Collagen

Material Analysis/ Investigation

The following were some of the reasons that these two candidates were ultimately chosen:

Type 1 Collagen

>Same fiber that predominates in native tendon tissue
>Highly 'biocompatible' and mechanically appropriate
>Difficult but feasible to print in our lab
>Properties vary slightly depending on sourcing

Silk Fibroin (SF)

>Impressively high tensile strength
>Difficult to process the raw material;
    -Harvested from the cocoons of silkworms
>Lack of publication of printing protocols

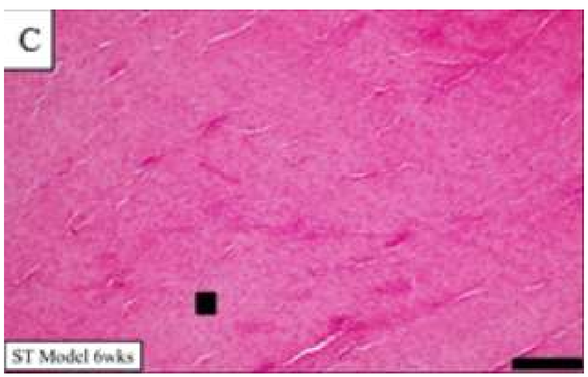


Figure 1: Histology of tendon tissue in which native collagen fibers can be easily seen predominating. Sourced by Jimmy Johnson in the CSU OBRL

We saw more potential for the Collagen scaffold, and decided to proceed with its experimentation

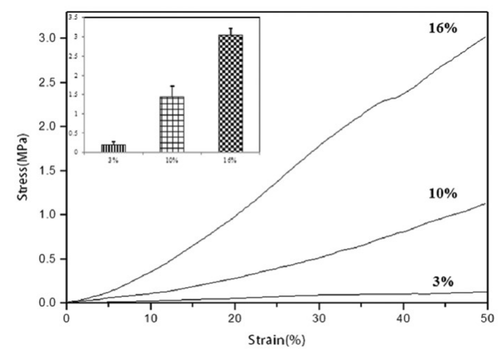


Figure 2: Stress vs strain relationship of Silk Fibroin Scaffolds, demonstrating their high tensile strength. Adapted from "Fabrication of Microporous Three Dimensional Scaffolds from Silk Fibroin for Tissue Engineering" by Hyun Jung Park, received from ResearchGate.net

J1 J2

Methods/Experimental Setup

Conventional Printing Process (As in PCL):

Canister is loaded with polymer in powder form → Polymer is heated by the printer until it becomes a malleable, printable liquid (~80° C) → Printing is executed per the programed G-code → The polymer cures (hardens) as it **cools down** to room temperature

Compiled Printing Protocols for Collagen, (distinct and a bit more complicated):

The Collagen solution is prepared and mixed with a buffer solution → The cartridge is loaded with the prepared collagen solution → The collagen solution is a workable liquid when it is cold (5-10° C), so everything is cooled down, and kept cold → Printing is executed per the programed G-code → The polymer cures (hardens) as it **heats up** to room temperature

** The printing environment is kept sterile, and either during or after printing, host cells can be 'seeded' (introduced) into the scaffold

Slide 6

J1 Jackson,Jason, 4/21/2021

J2 Jackson,Jason, 4/21/2021

Outcomes and Future Work

- ☑ Material Investigation
- ☑ Selection of ideal material candidates
- ☑ Learned 3d Printing Principles
- ☑ 3d Printing Training
- ☑ Compilation of printing protocols
- ☑ Material sourcing
- ❑ Printing of collagen scaffold — Pending…
- ❑ Mechanical Testing — Pending…
- ❑ Cell Response Testing — Pending…

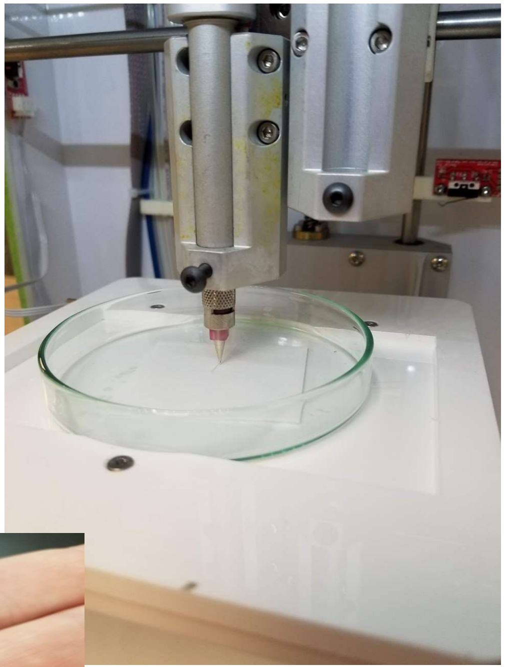


Figure 1 (Top Right): A setup of the in-lab Inkredible+ printer 3d printing the first layer of a scaffold prototype

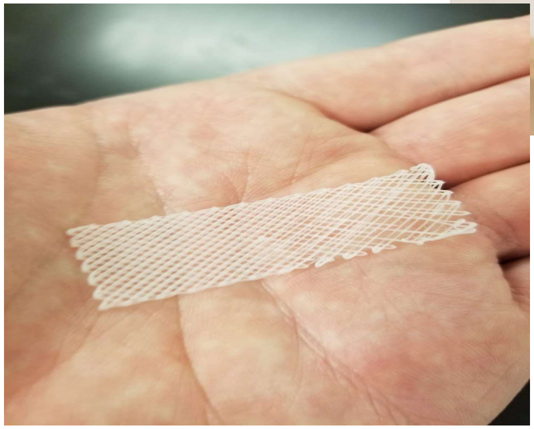


Figure 2 (Bottom Left): In lab, I was able to train myself in the printing process with normal PCL polymer

Discussion

- Material analysis can aide greatly in the future development of novel tendon-repair scaffolds.
- The collagen printing process will still need to be refined
- Several simple hybridizations of the scaffold I proposed could also be created and tested
- Silk Fibroin was explored enough that it could also be looked at for incorporation into future scaffold designs.
- Results of the mechanical, histological, and in-vivo testing of the scaffold will be paramount in directing future research efforts.

Conclusions

- Project was able to suggest the feasibility of using various materials with potential merit. Specifically, that of collagen and its composites.
- Cannot determine my scaffold's efficacy, seeing as I couldn't physically print it
- We have a good idea and the skillset to continue this work in the future

What benefits did you get from you SURE experience?

- ❑ Hands on experience in an Orthopedic Research Laboratory
- ❑ Connections to faculty and graduate students
- ❑ Specialized training relevant to my field (3d printing and basic laboratory techniques/policies)
- ❑ Exposure to professional research resources and practices
- ❑ Application of content learned in relevant engineering courses

References & Acknowledgements

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Thank you

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