Modeling Mechanical Properties of Fibrous Polymer Scaffolds as a Function of Fiber Alignment

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Background

According to OSHA over 600,000 musculoskeletal injuries occur in the US each year[1]. Treatment for these injuries, such as a torn rotator cuff, can be invasive and involve surgeries which may fail to completely restore original tissue functionality. This can lead to chronic pain and reduced mobility that may last a lifetime. Therefore, more effective treatments need to be developed which are capable of fully restoring native tissue function.

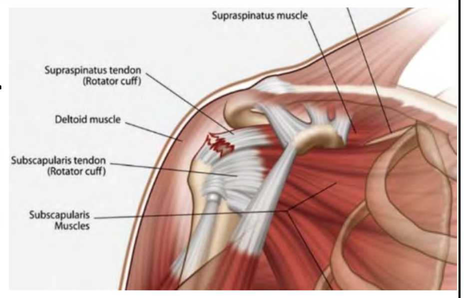


***Figure 1:** Diagram of a Torn Rotator Cuff[2]*

Motivation

In the US, the greatest cause of chronic pain besides cancer is from musculoskeletal injuries[3]. Tissue scaffolds could offer a treatment option that results in better healing and fewer lasting conditions. These scaffolds can be implanted in an injured patient and serve as guides for native cells to restore damaged tissue. In order to effectively do so, enough tissue must be restored before the scaffold degrades so that regrowth can continue. Creating scaffolds with mechanical properties that closely match the targeted tissue is known to induce proper tissue regeneration. Furthermore, many musculoskeletal interfacial tissues, such as the tenon-bone junction, consist of a complex extracellular matrix with gradients in fiber alignment and chemistry that impact mechanical properties[4].

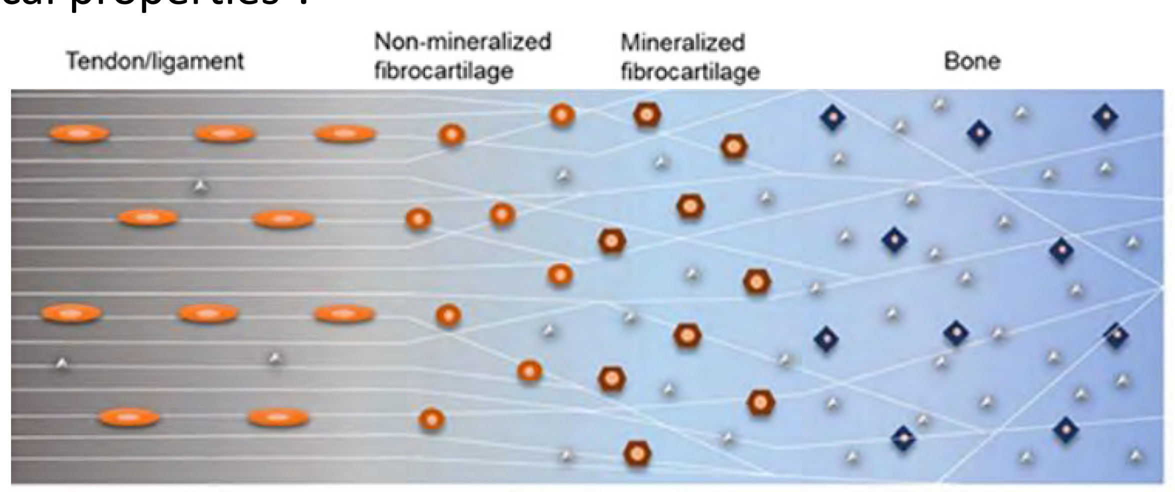


***Figure 2:** Diagram of changing fiber alignment at tendon-bone junction[5]*

Altering fiber alignment within an electrospun scaffold is known to change the bulk mechanical properties. However, models which predict the mechanical properties of scaffolds as a function of fiber alignment do not yet exist. The development of such a model could allow for targeting of specific fiber alignments that will yield the desired mechanical properties which match those of a targeted tissue.

Results

Using a rotating mandrel controls electrospun fiber alignment

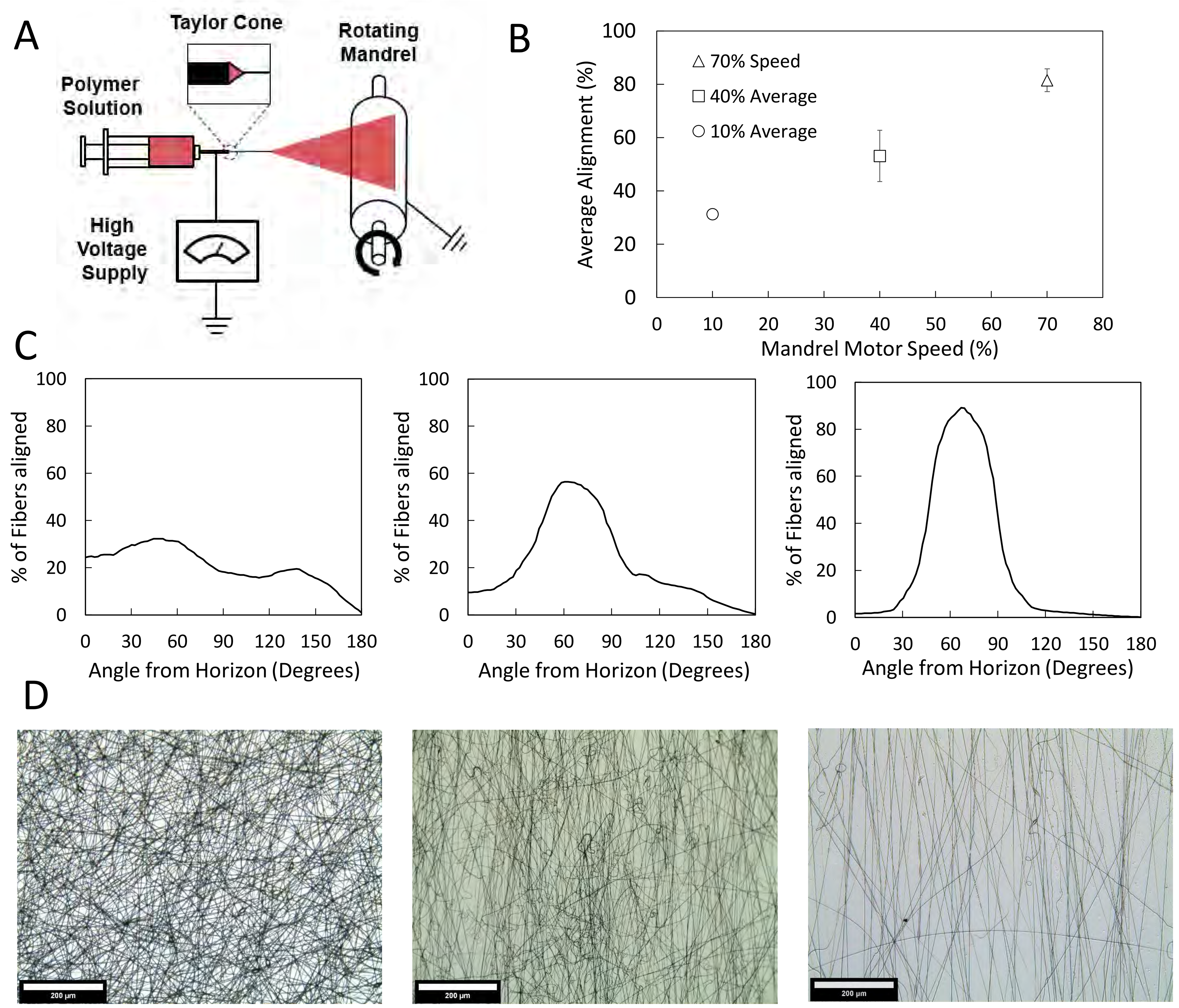
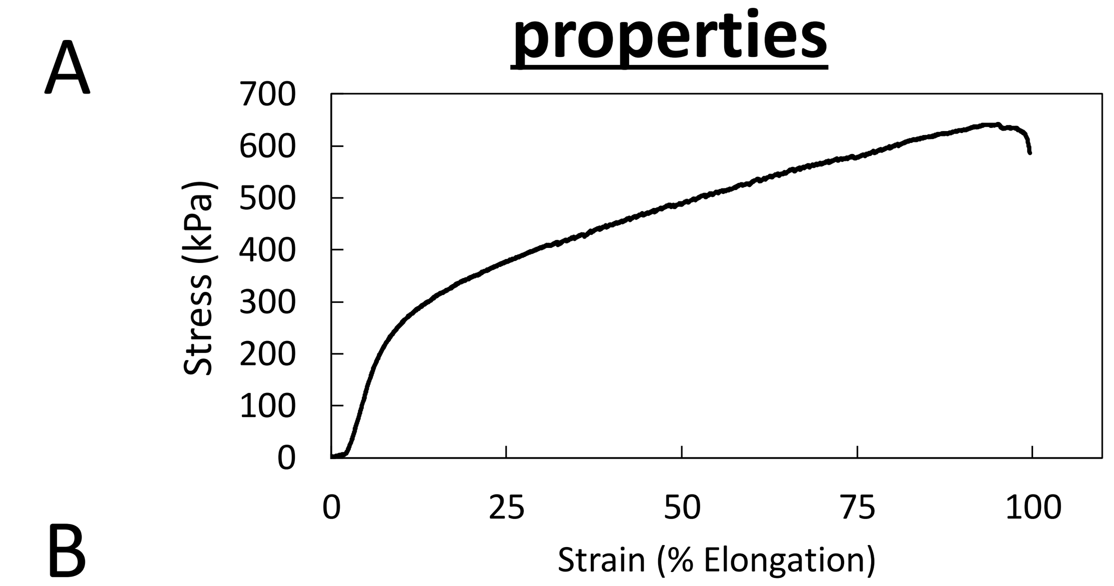


***Figure 3:** Alignment of electrospun fibers can be controlled by electrospinning onto a rotating collector. (A) Electrospinning apparatus with rotating drum. (B) Fiber alignment as a function of mandrel velocity confirming fibers are more aligned as mandrel speed increases. (C) Distribution of fiber alignments for 10, 40, and 70% motor speed (left to right). (D) Brightfield images (scale 200μm) of scaffolds for 10, 40, and 70% motor speed (left to right).*

Tensile tests determines scaffold mechanical properties



B

Sample	Thickness (mm)	Strain at break (%)	Tensile Strength (MPa)	Modulus (MPa)
1	0.30	99.4	0.64	4.2
2	0.34	92.1	0.49	2.7
3	0.32	111.5	0.68	3.9
4	0.30	108.3	0.71	3.5
5	0.34	110.9	0.65	3.8
Avg	0.32	104.4	0.63	3.6
Std Dv.	0.02	7.5	0.08	0.5

***Figure 4:** (A) Stress-strain curve for a scaffold spun at 10% mandrel speed. (B) Five samples at 10% speed were tested. Average Young's modulus was found to be 3.6 ± 0.5 MPa, the tensile strength was found to be 0.63 ± 0.08 MPa, and the strain at break was found to be 104.4% of the original length.*

Conclusion and Future Work

The results of this experiment demonstrate how a rotating mandrel can be used to control the alignment of electrospun fibrous polymer scaffolds. Future work will include mechanical testing of the more aligned fibers. During initial testing these samples all suffered from grip failure, so another approach is needed to acquire this data. Additionally, development of a predictive mathematical model is still ongoing and will need to be validated by comparing its output to experimental data.

Acknowledgements

I would like to acknowledge Dr. Julianne Holloway for this amazing opportunity to be a part of her team as well as the Fulton Undergraduate Research Initiative for funding this endeavor. I would also like to thank my PhD mentor R. Kevin Tindell for all his help.

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