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.

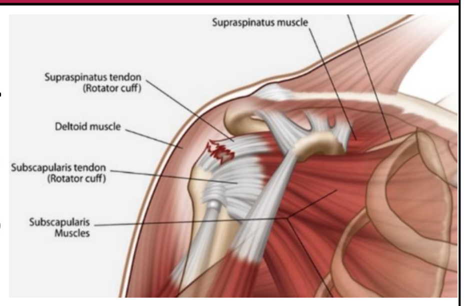


Figure 1: *Diagram of a Torn Rotator Cuff[2]*

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].

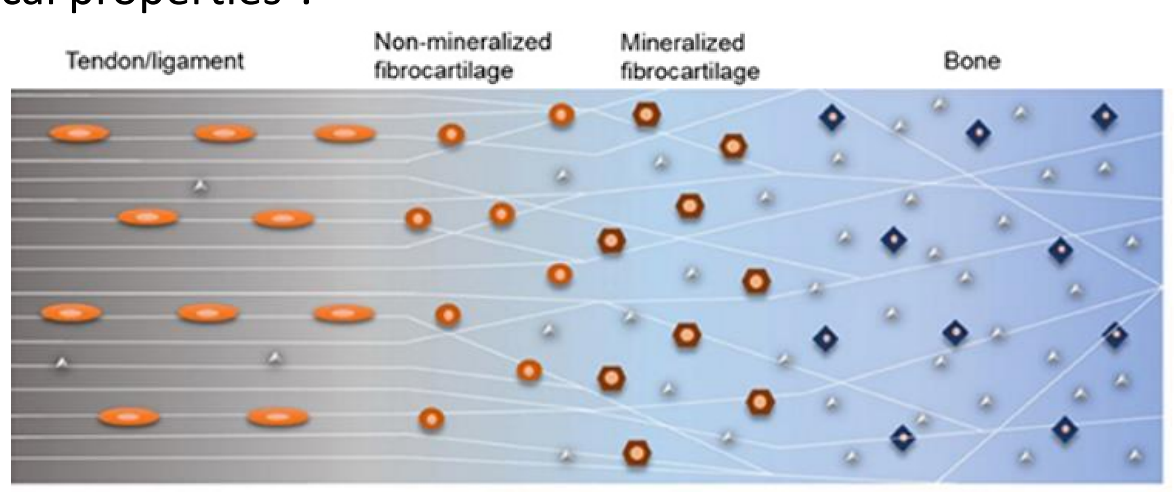


Figure 2: *Diagram of changing fiber alignment at tendon-bone junction[5]*

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

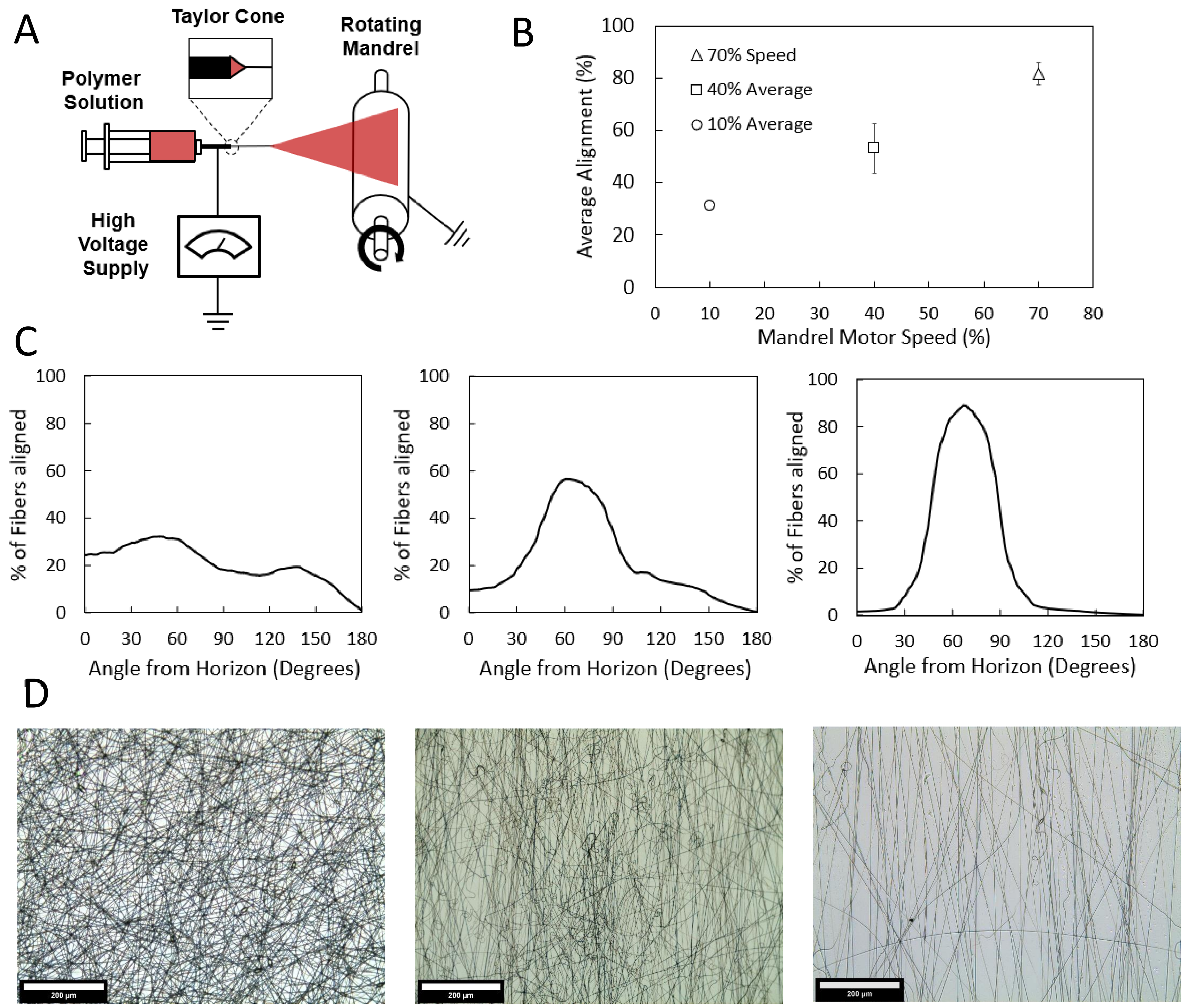
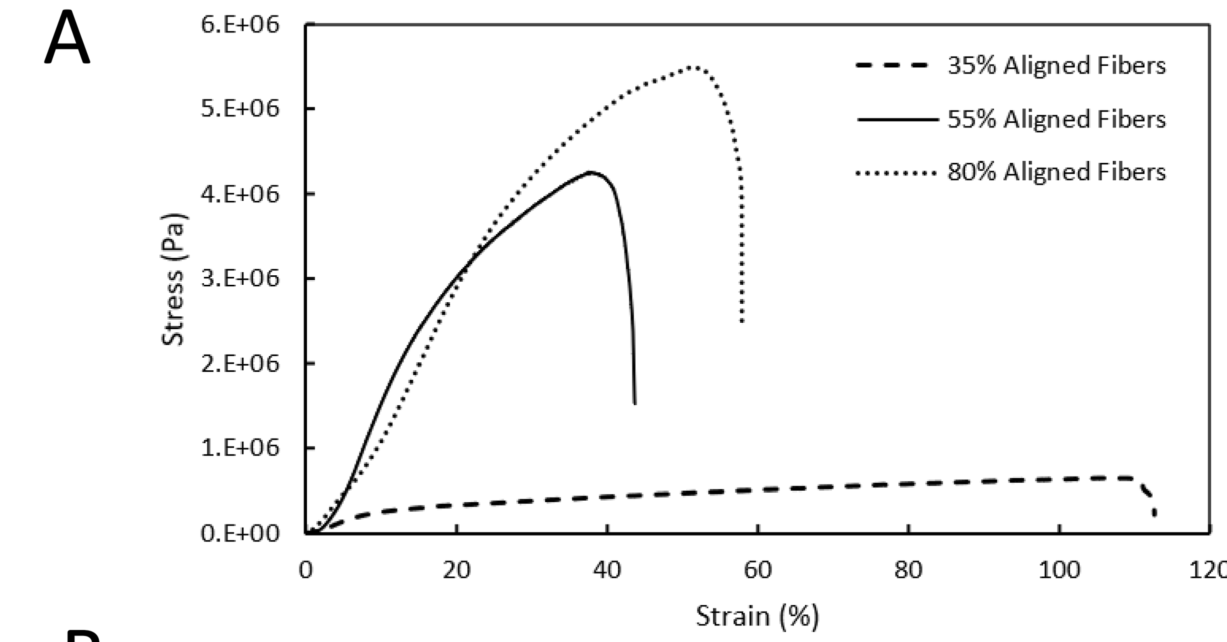


Figure 3: *Alignment of electrospun fibers can be controlled by electrospinning onto a rotating collector. (A) Electrospinning apparatus with rotating drum. (B) Fiber alignment as a function of mandrel velocity confirming fibers are more aligned as mandrel speed increases. (C) Distribution of fiber alignments 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 and Predictive Model



B

$$\widehat{Y_{Factior}} = \overline{Y_{Factor}} + Effect_{Factor} * x - Error(x)$$

$$Strain\ @\ Fail = (-150x + 63.1) - (-784x^2 + 881x - 306)$$

$$Max\ Tensile\ Strength = (8.3x + 2.6) - (18x^2 - 20.6x + 9.9)$$

$$Youngs'\ Modulus = (8.3x + 3.7) - (8.3x + 3.8)$$

Figure 4: *(A) Stress-strain curves for scaffolds spun at 10, 40, and 70% mandrel speed. (B) Predictive models for various material properties. General structure follows an average output value plus a factor effect multiplied by the percent alignment minus error. Error was determined to be a function of percent alignment and functions to estimate said error were implemented.*

Conclusion and Future Work

This experiment serves as a good baseline for establishing procedures to build a model for predicting mechanical properties of fibrous tissue scaffolds. Future work could focus on exploring varying other parameters, such as the molecular weight of the polymer or diameter of spun fibers, to incorporate those effects into a model. The basis for developing the model in this experiment comes from general six sigma knowledge, which could be used to expand this model to incorporate further factors or levels.

Acknowledgements

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References

[1] UNITED STATES DEPARTMENT OF LABOR. (n.d.). Retrieved November 01, 2020, from https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_id=4481

[2] Formini, N. Rotator Cuff Tear. http://www.doctornate.com/rotator-cuff-tear (accessed March 27, 2019).

[3] Relieving pain in America: A blueprint for transforming prevention, care, education, and research. (2011). Washington, D.C.: National Academies Press.

[4] Li, W., Mauck, R. L., Cooper, J. A., Yuan, X., & Tuan, R. S. (2007). Engineering controllable anisotropy in electrospun biodegradable nanofibrous scaffolds for musculoskeletal tissue engineering. Journal of Biomechanics

[5] Bayrak, E., & Huri, P. Y. (2018). Engineering Musculoskeletal Tissue Interfaces. Frontiers in Materials, 5. doi:10.3389/fmats.2018.00024

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