

Background

Click-chemistry bioadhesives offer promising regenerative treatments due to their biocompatibility and tunable properties. Click-chemistry bioadhesives are injected and rapidly cross-link creating a tissue engineered scaffold that can combat many diseases or injuries. However, the paradox is that this rapid polymerization can cause needle occlusion making delivery difficult for providers. Traditional single barrel or pre-mixed delivery systems are insufficient for arthroscopic application. We engineered a multi-chamber arthroscopic applicator designed to keep reactive precursors stable until point of tissue contact. This study validates the device using an animal model demonstrating scalability.

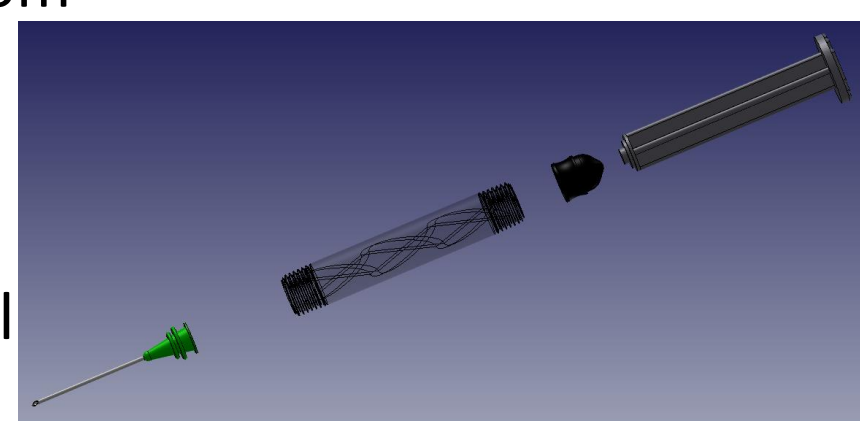


Hypothesis

We hypothesize that an **integrated multi-chamber applicator** can prevent premature needle occlusion by isolating reactive precursors until the point of contact, thereby enabling the **controlled, site-specific polymerization** of a PDGF-loaded bioadhesive within a fluid-filled joint environment to significantly enhance tendon healing.

Methods

Applicator Fabrication: A custom dual-chamber arthroscopic cannula was designed using SolidWorks to isolate reactive click-chemistry precursors until the point of extrusion.

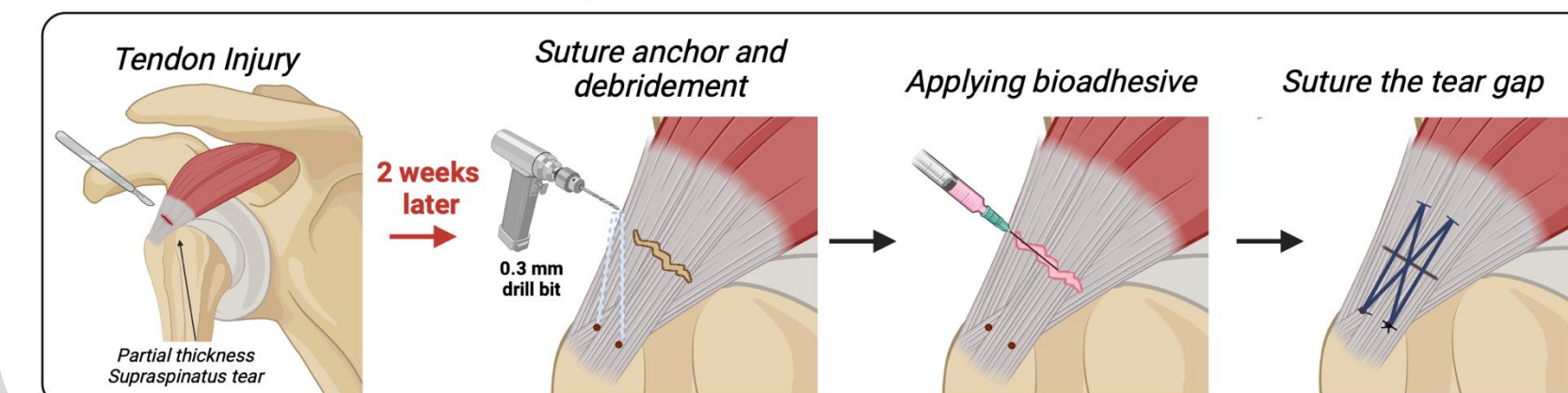


Prototypes were manufactured using 3D printing (ABS).

Mixing Geometry: A miniaturized static mixing nozzle was integrated into the distal tip to for rapid, homogenous cross-linking upon injection.

Interrupted Injection Testing: To simulate surgical delays, extrusion was paused at intervals of 10 or 30 seconds, followed by resumed injection to confirm the absence of premature polymerization and cannula occlusion.

Chronic Rotator Cuff Surgery Model



Results

Table 1: Key functional and engineering requirements for the multi-chamber arthroscopic bioadhesive applicator.

Class	Functional Requirement
Form Factor	The outer diameter does not exceed 5.5 mm to ensure seamless insertion through standard 6.0 mm arthroscopic syringes.
Working Length	Minimum working length of 150 mm
Volumetric Ratio	Dispense at a precise 1:1 volumetric ratio, with an allowable deviation of no more than $\pm 2\%$
Dispense Volume	Capable of delivering adhesive volume ranging from 0.2 mL to 1 mL
Mixing Efficiency	Minimum of 95% fluid homogeneity
Precursor Isolation	Maintain a hermetic seal capable of preventing precursor cross-contamination

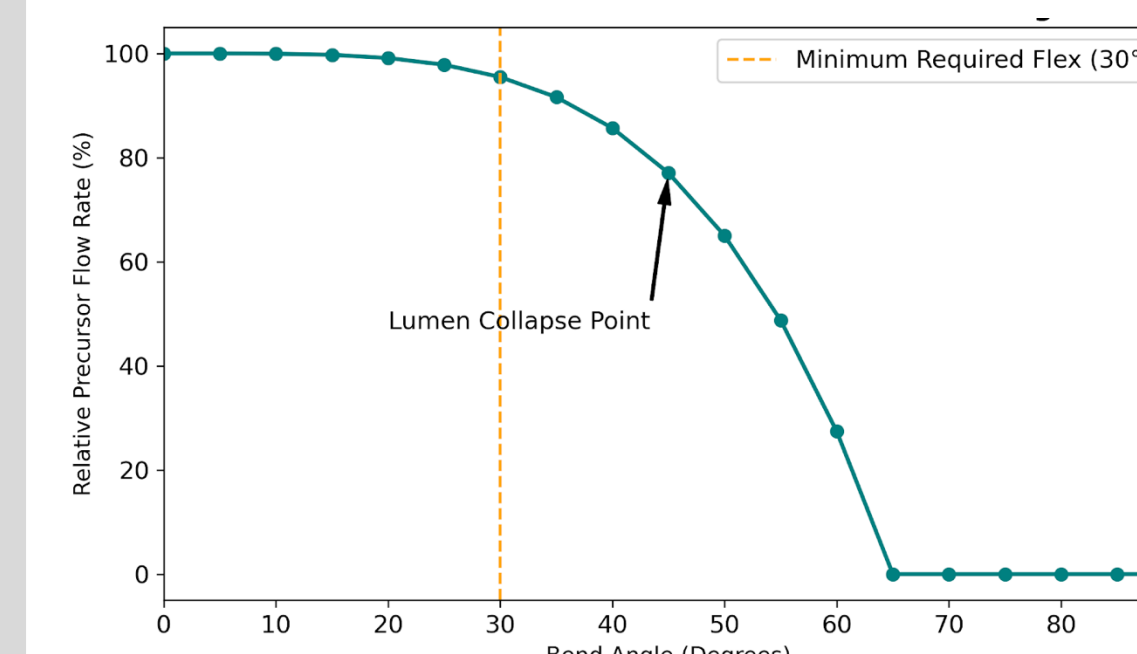


Figure 2: Simulation of the relationship between the cannula bend angle and the relative precursor flow rate.

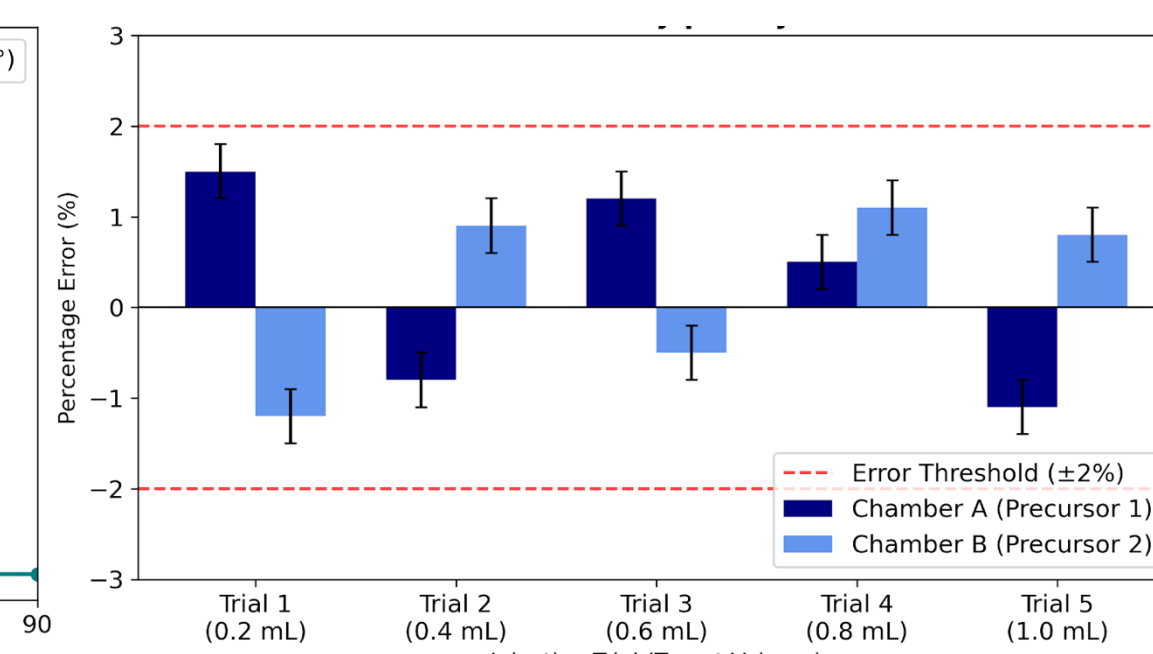


Figure 3: Comparison of the error rate of dispensed volume per injection at varying levels

Mechanical Testing

Finite Element Analysis (FEA) was performed to evaluate the structural integrity of the device under extreme loading conditions. The structural model was subjected to a static exaggerated force of 200 N compressive load.

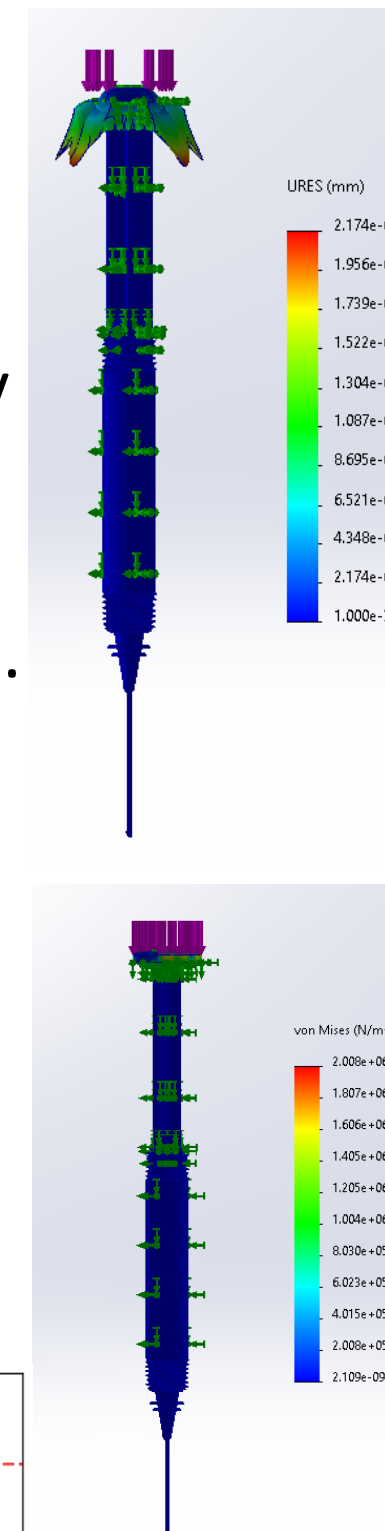


Figure 1: (Top) The von Mises stress distribution and (Bottom) the resultant displacement (URES) plot.

Functional Testing

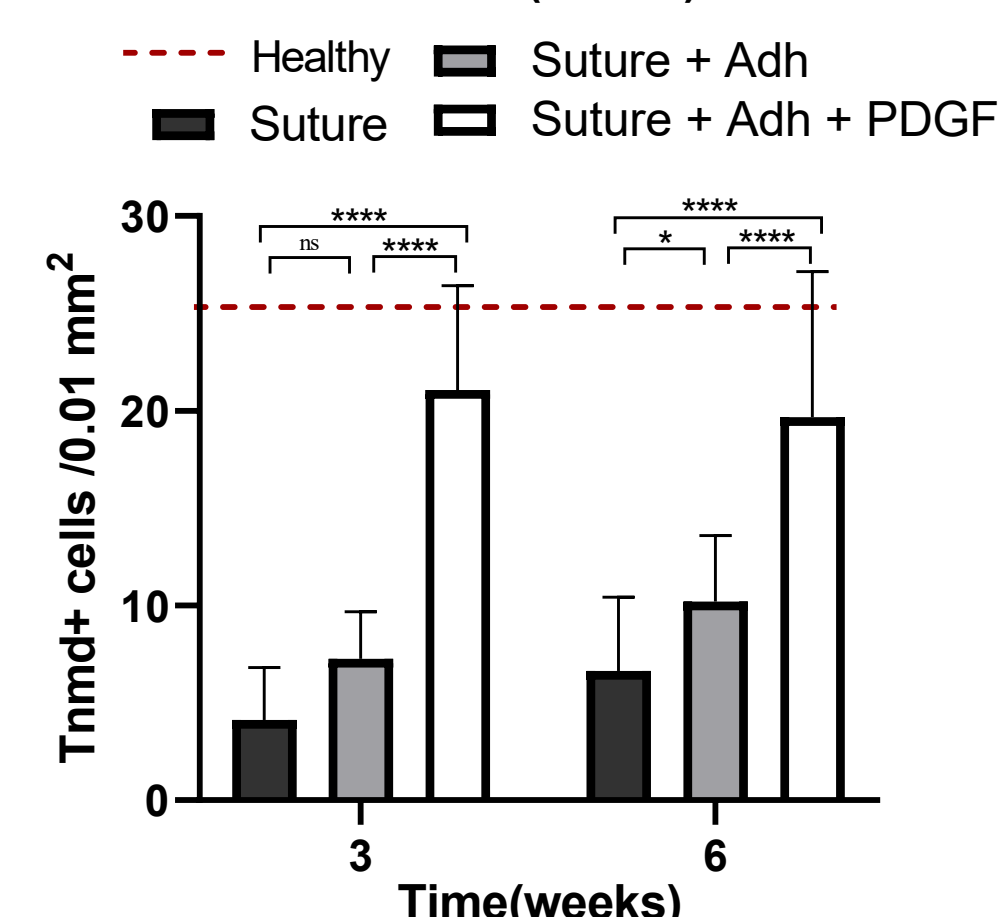
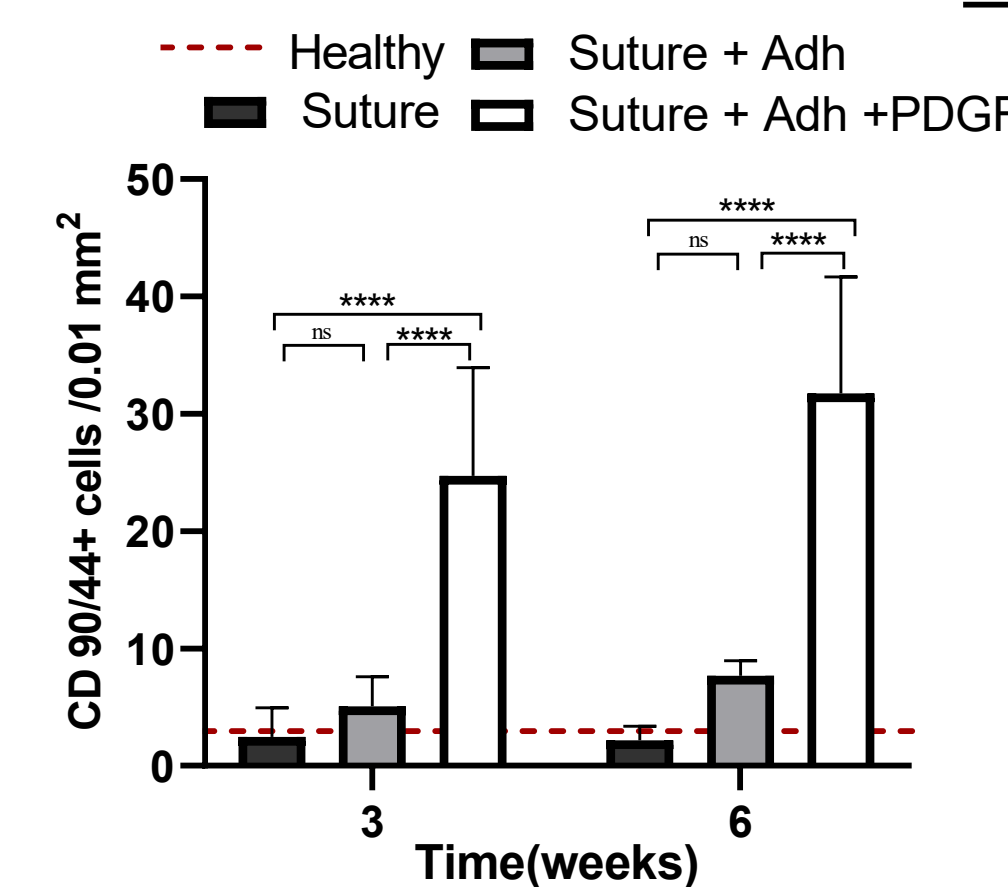


Figure 4: (Top) Progenitor Cell recruitment and (Bottom) mature tenocyte (tendon) marker

Our animal model illustrates that treating the injury with **Suture + Adhesive + PDGF** yields a superior, more regenerative healing profile compared to standard sutures. The combined treatment actively promotes cellular recruitment to the repair site such as progenitor cells (CD 90/44+), promotes the formation of healthy tendon cells (Tnmd+) back toward healthy baseline levels, and actively suppresses scar tissue formation (fibrocytes).

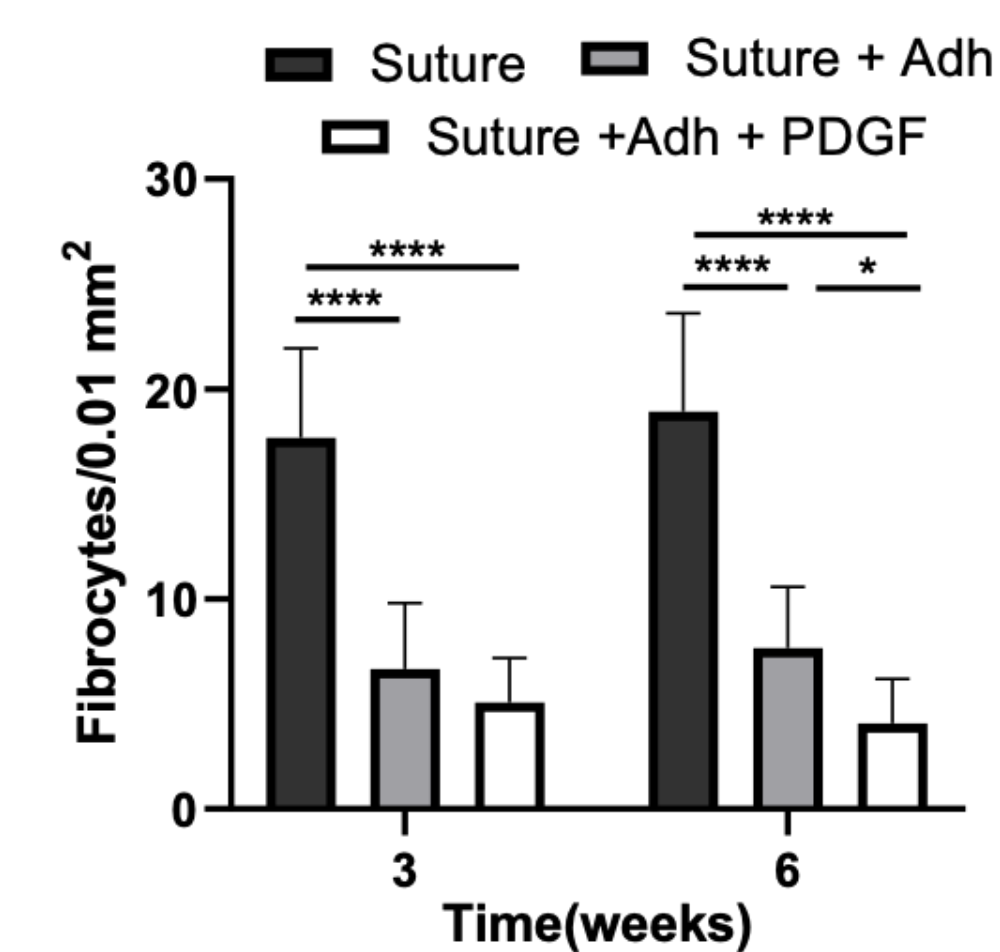


Figure 5: Quantification of fibrocyte cells, associated with fibrosis and scar tissue formation

Results

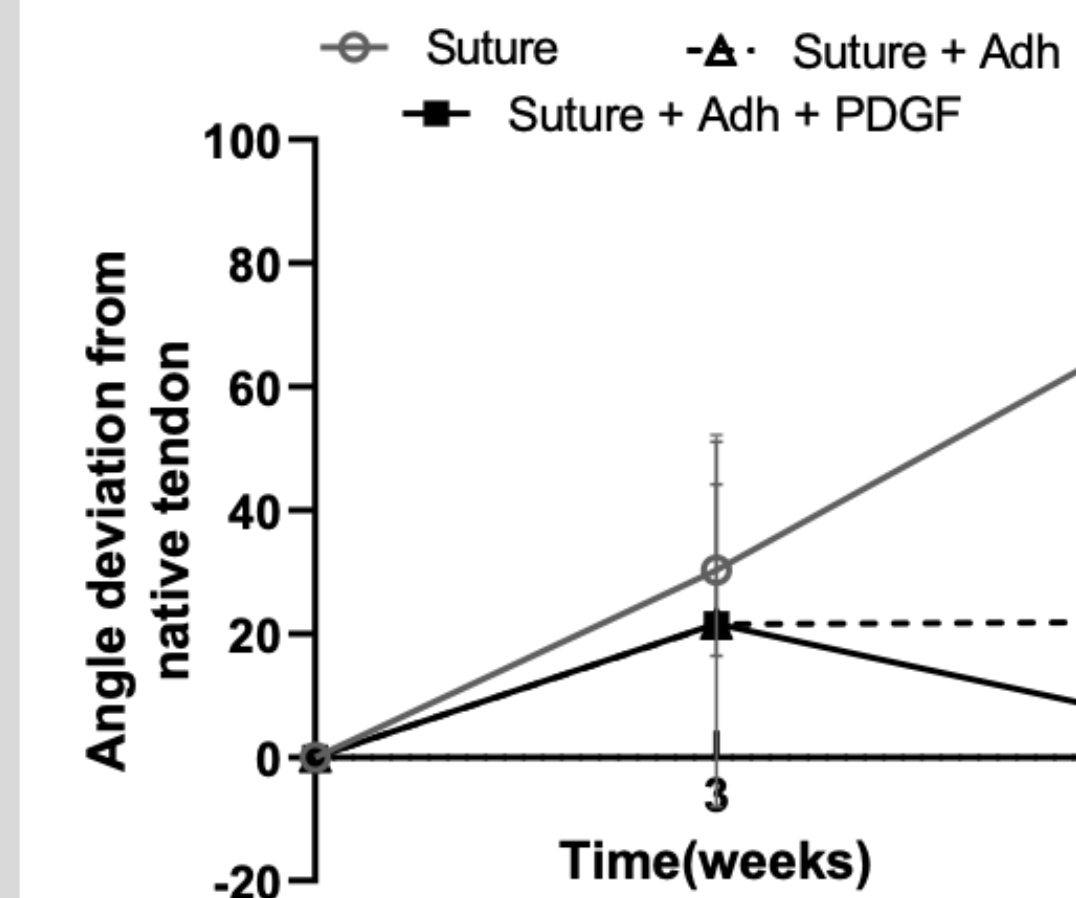
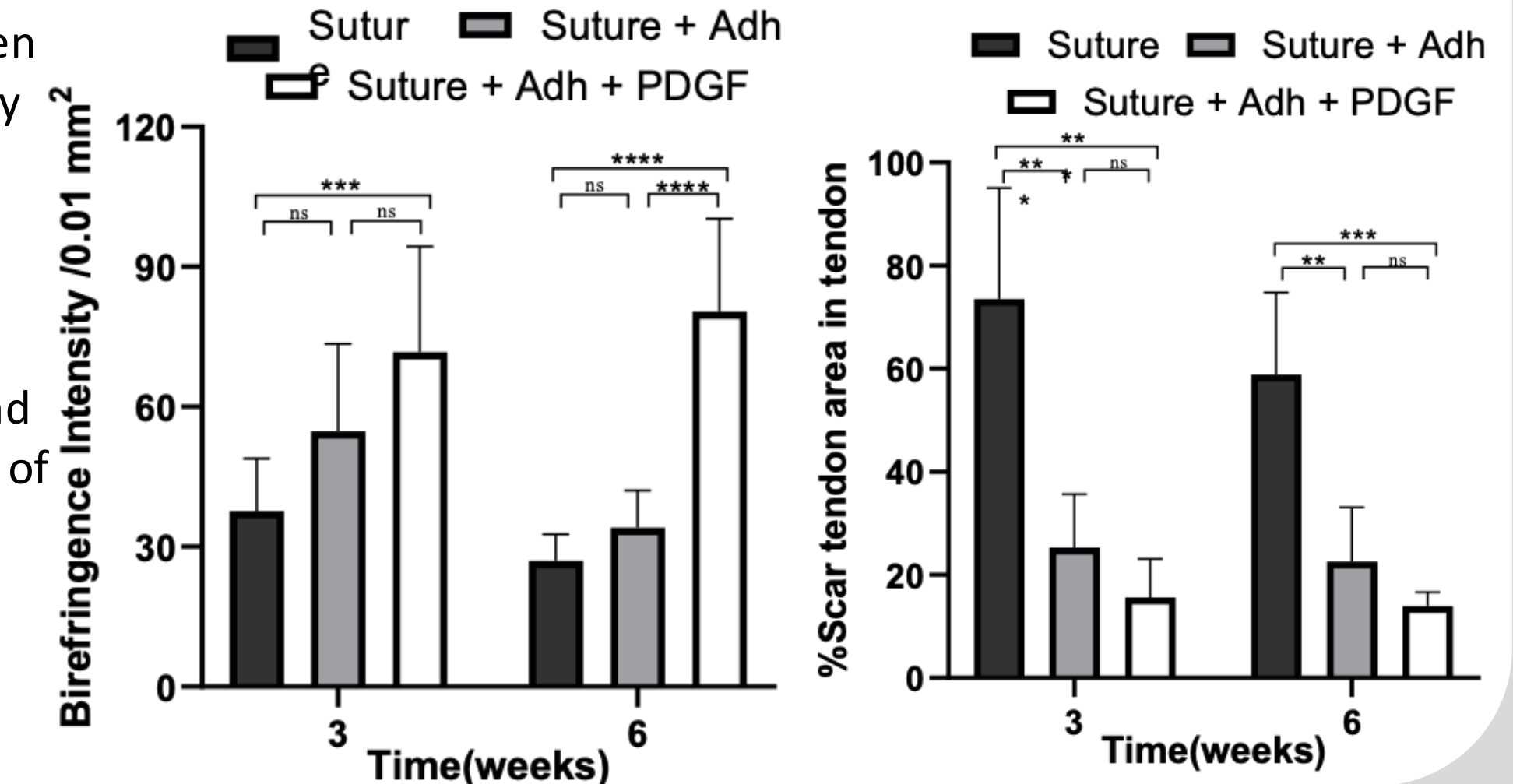


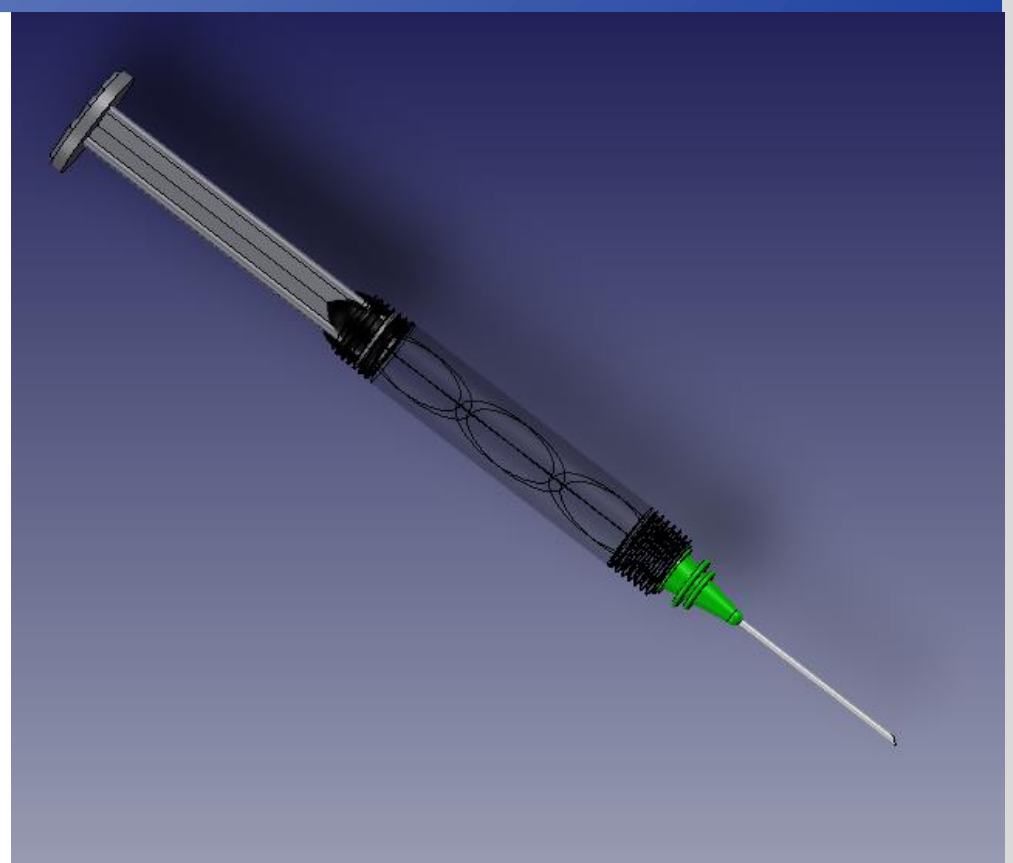
Figure 6: Deviation of collagen fiber angle relative to healthy tissue

Figure 7: (Right) Birefringence of collagen fibers and (Left) percentage of repair area composed on unorganized scar tissue



Conclusion

Our device prevents clogging without sacrificing the quality of the bioadhesive. The application of the bioadhesive, particularly when combined with PDGF, significantly enhances tendon regeneration and healing quality compared to standard suturing alone. *In vivo* analysis demonstrated that the **Suture + Adhesive + PDGF** treatment effectively minimizes scar tissue formation, evidenced by substantially reduced fibrocyte density and overall scar area, while preserving native structural alignment. The adhesive promotes superior collagen maturation and organization by six weeks post-operation. Collectively, these findings validate the bioadhesive as a highly promising therapeutic adjunct for improving structural and functional outcomes in arthroscopic tendon repair



References

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- Current clinical standard delivery systems, such as the Vivo stat Endoscopic Applicator