High speed production of stretched collagen microfibers comprised of aligned collagen fibrils for creating artificial tendons

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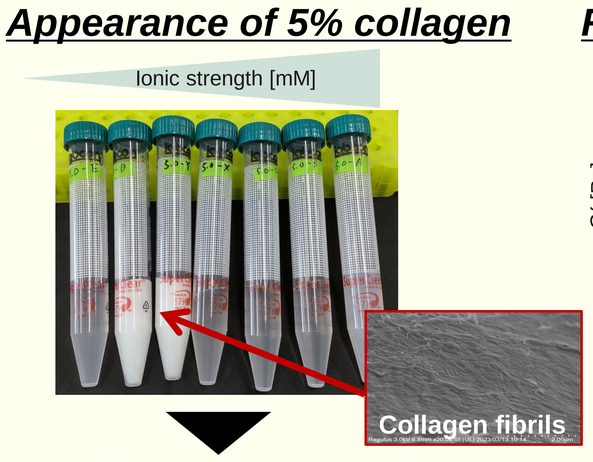
Summary

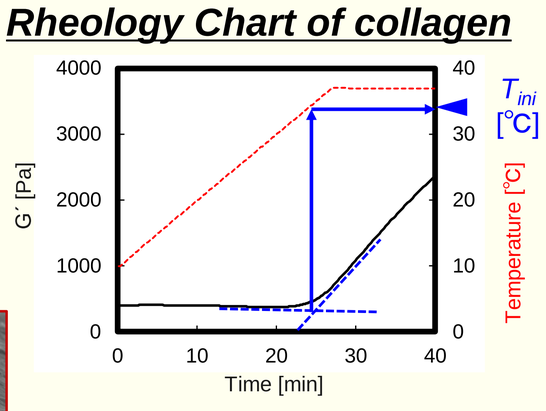
- Spinning method: Wet spinning of collagen fibers involving stretching of collagen fibrils (stretch ratios > 3.0)
- Advantages: (A) Productivity (spinning speed ≥171 m/h), (B) Narrow microfibers (approximate diameter 20 μm), (C) Tendon-like fibrillar alignments, (D) Highest mechanical properties of dry microfibers (Young's modulus > 4 GPa)
- Bundles of microfibers exhibited excellent mechanical properties under wet conditions:
  a) Tangent modulus (137 ± 7 MPa), b) Stress at break (13.8 ± 1.9 MPa)
  Those properties were still lower than those of human ACL, but they were within the same order of magnitude.

Critical fibrillogenesis concentration (CFC)

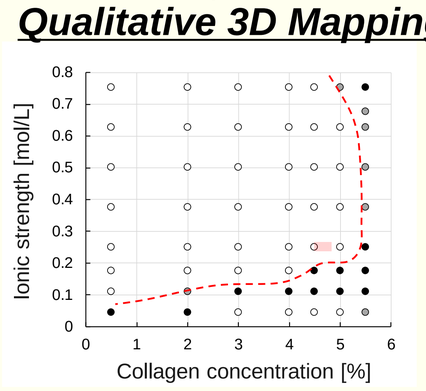
Appearance of 5% collagen



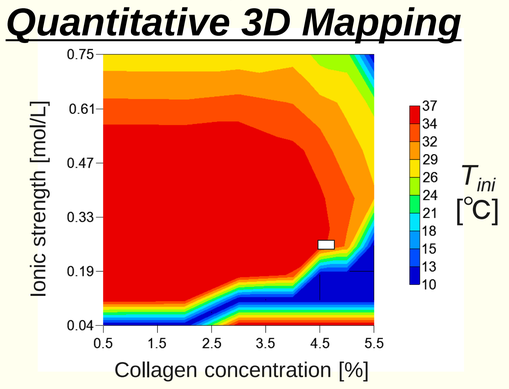
Rheology Chart of collagen



Qualitative 3D Mapping



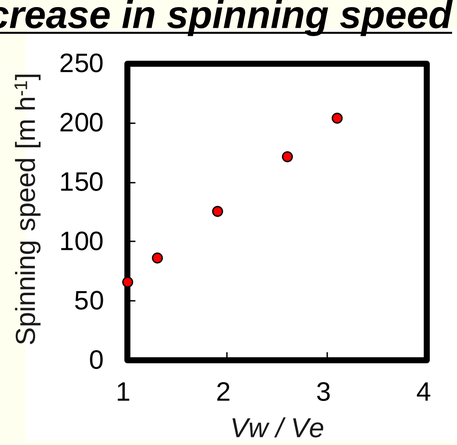
Quantitative 3D Mapping



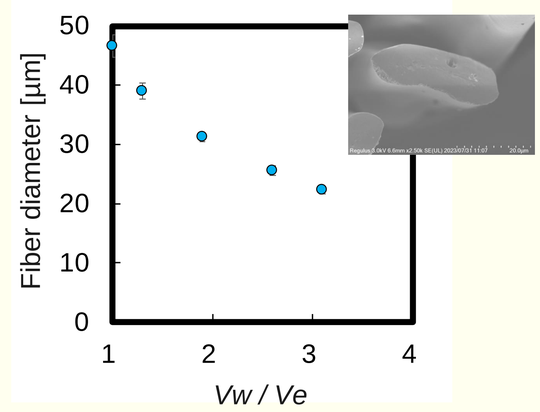
CFC solution:
4.5%–4.8% neutral collagen solution (ionic strength: 0.25 mol/L) has a capacity to cause fibrillogenesis immediately when a portion of the water is removed with ethanol.

Effects of stretching method on spinning and products (collagen microfibers)

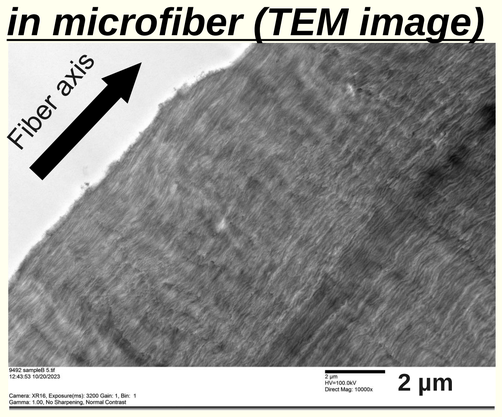
Increase in spinning speed



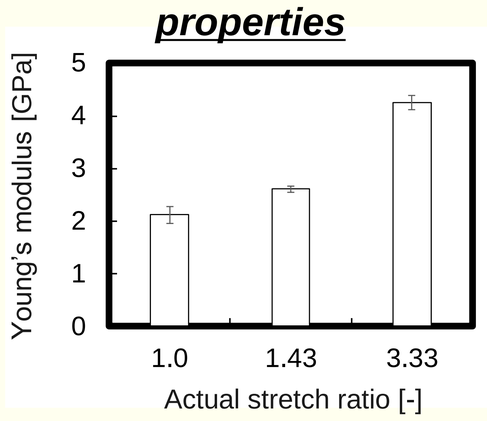
Decrease in fiber diameter



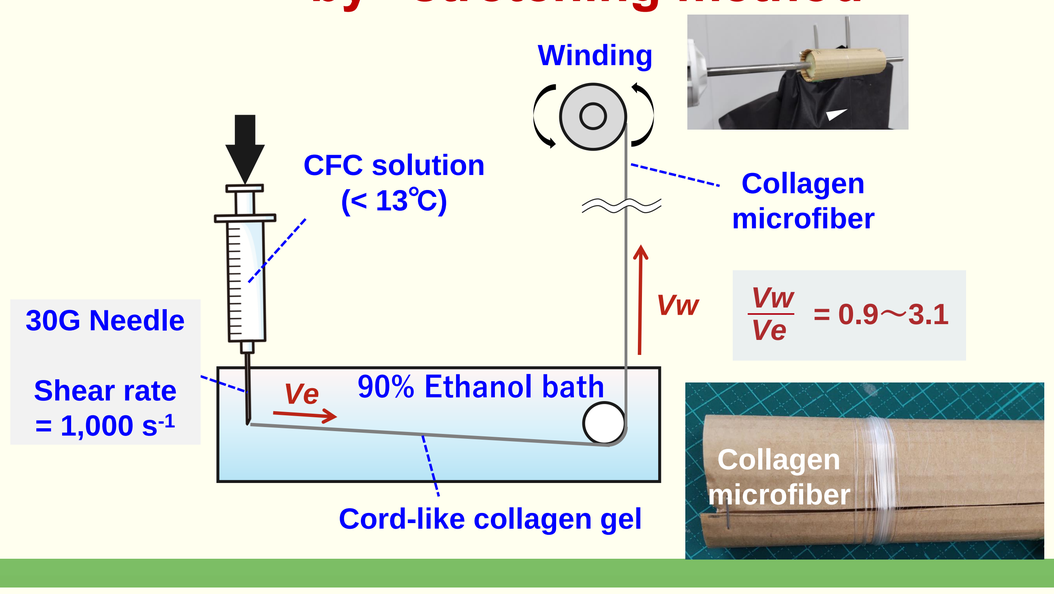
Uniform fibril alignment in microfiber (TEM image)



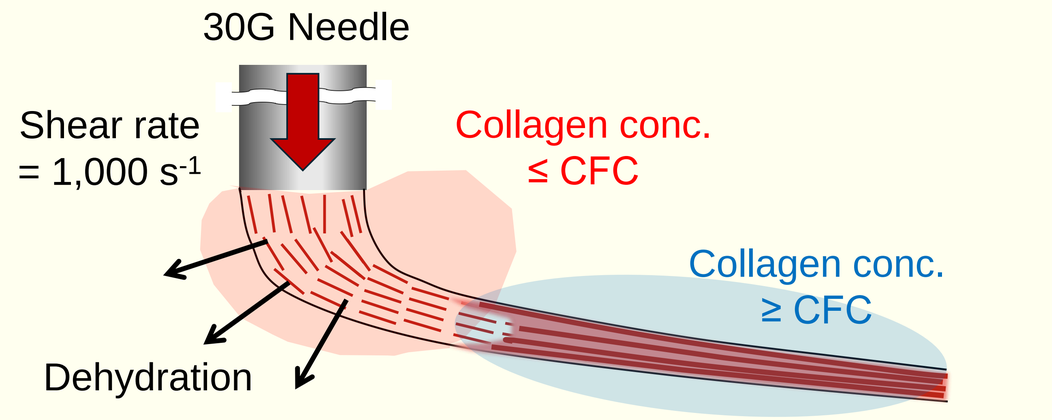
Increase in mechanical properties



Wet spinning from CFC solution by "stretching method"

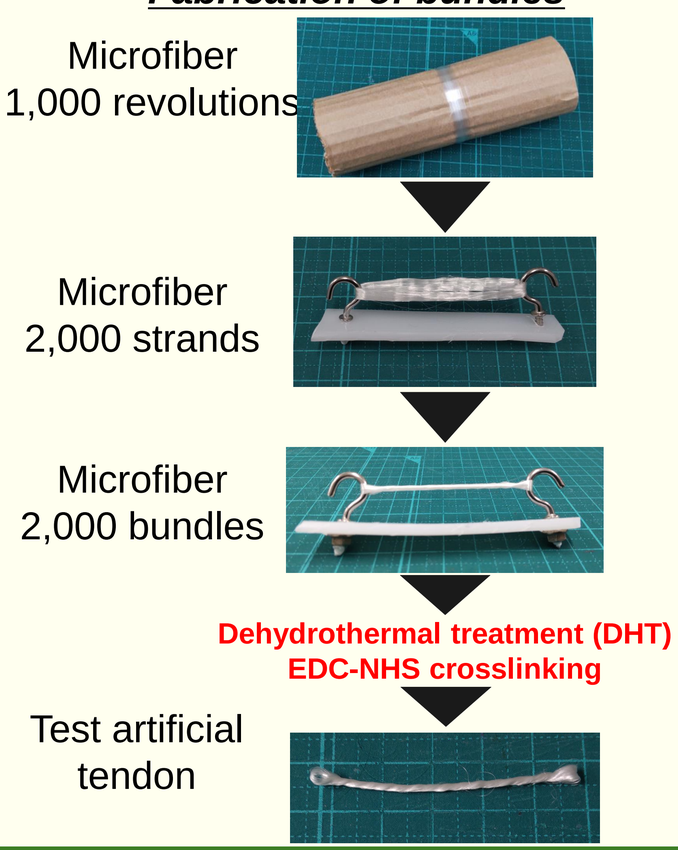


Mechanism of uniform fibril alignment by wet spinning using stretching method

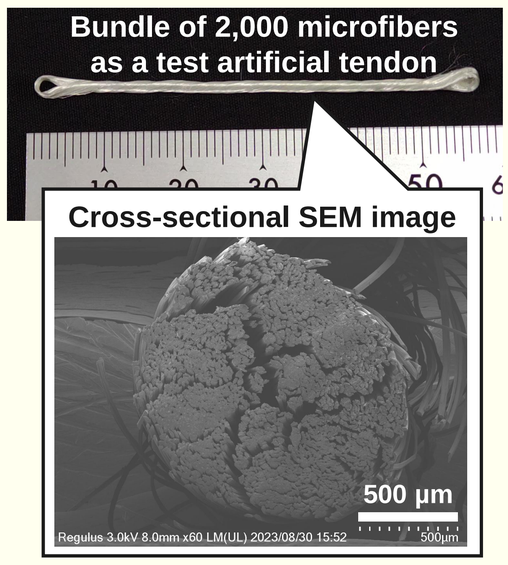


Structure and mechanical properties of bundles of stretched collagen microfibers

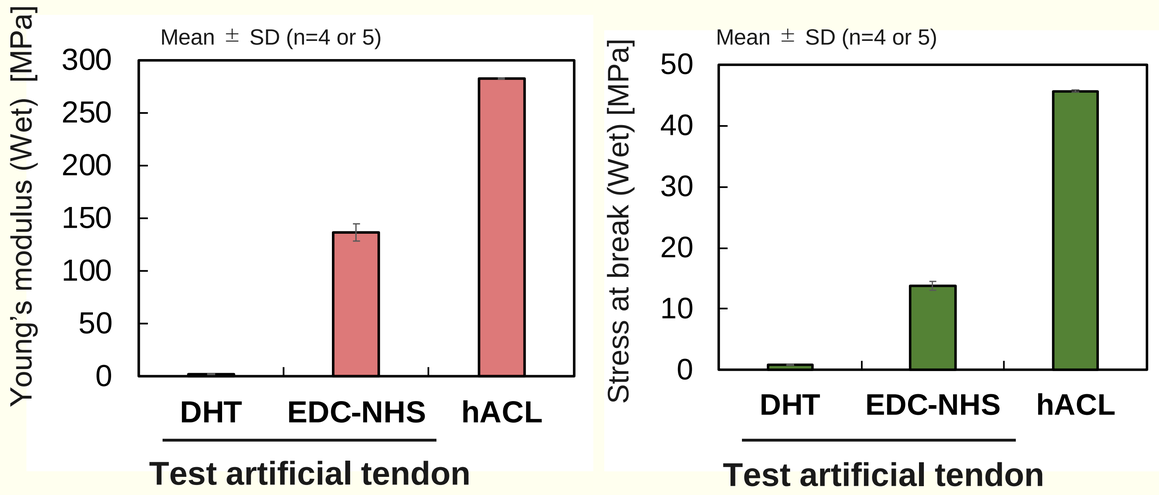
Fabrication of bundles



Interior structure



Tensile mechanical properties under wet condition



Conclusion

We developed a unique spinning technique for collagen microfibers in which the material is stretched in CFC solutions. The excellent mechanical properties of the obtained dry microfibers reflected those of the microfiber bundles under wet conditions. Our spinning method inspires the development of collagen-based synthetic tendons as substitutes for autogenous tendons.