Collagen-based inks reinforced with hydroxyapatite nanoparticles for 3D printing: a rheological study comparing bovine and fish sources

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June 17, 2022
Introduction: why collagen-based inks?

Bone

Osteons

Fiber patterns

Fibers

- Bone
- Osteons
- Fiber patterns
- Fibers

[~ cm]

[~ 100 μm]

[~ 50 μm]

[~ 5 μm]

Macro-scale

Atomistic Scale

Hydroxyapatite (≈60%)

Tropocollagen (≈30%)

Water (≈10%)

Mineralized fibrils

[~ 500 nm]

[~ cm]

[~ 100 μm]

[~ 50 μm]

[~ 5 μm]

[~ Å]
Introduction: why collagen-based inks?
Introduction: why collagen-based inks?

- Balanced resistance/toughness at the macro scale
- Improved rheology
- Stabilization after the printing process
- *In vitro*
  - Cell adhesion
  - Osteogenesis (ECM, phenotype)
- *In vivo*
  - Osteoconductivity
  - Fast absorption
Introduction: why collagen-based inks?

- Human source
- Marine source
- Bovine source

Collagen peptide

3D Printing

Prosthetic device

Hydroxyapatite
Objective

Correlation between rheology and printability of animal-based collagens for bone tissue replacements
Materials and methods

**Materials**
- Collagen peptide
  - \( M_w \approx 2 \text{kDa} \)
- Hydroxyapatite
  - \( D < 1 \ \mu\text{m} \)

**Preparation**
- \( \omega = 50 \ \text{rpm} \)

HA-COL-AA ratio of 1.7:1:1
Materials and methods

Rheometer with a plate-plate configuration

Expected outcomes

- $G'$ -> elastic modulus
- $G'_0$ -> elastic modulus with no strain
- $G''$ -> viscous modulus
- $\tan \delta = G''/G'$
- Yield stress $\bar{\sigma}$
- Yield strain $\gamma$

Graph showing the relationship between stress ($\sigma$) and strain ($\gamma$).
Amplitude sweep
Amplitude sweep

HA/Water

HA/Water/Silk

HA/Water

HA/Water/Silk

HA/Water

HA/Water/Silk
Frequency sweep

- Bovine - day 1
- Bovine - day 6
- Fish - day 1
- Fish - day 6

Graphs showing complex viscosity, storage modulus, loss modulus, and stress against frequency for different samples.

Diagram illustrating the structure of the ear with labels for Malleus, Incus, and Stapes.
Deposition tests

Now under hood for a complete solidification before the mechanical tests.
Next steps

- **Mechanical characterization** of the samples and **assessment of the main mechanical properties** (i.e., stiffness, compressive strength, toughness)

- **Fabrication of simple geometries and assessment of the printing quality** using specific comparative benchmarks (e.g., surface flatness)

- **Correlation between mechanical properties and printability**

**Final results expected by the end of July 2022**
Thank you for your time!

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