Bioprinting of Imaging-Derived Bone Geometries: Toward Patient-Specific Alginate Hydrogel Femur Phantoms for Mechanical and Functional Testing

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Background and Aim

Background: Patient-specific bone phantoms have potential applications in surgical planning, education and bone-related biomaterials testing by allowing anatomical models to be generated from clinical imaging data. However, the fabrication of complex bone geometries using soft hydrogel materials is challenging because printed structures can collapse or deform. Freeform Reversible Embedding of Suspended Hydrogels (FRESH) addresses this limitation by printing soft biomaterials within a temporary support bath, enabling the fabrication of complex imaging-derived structures, including alginate femur-shaped constructs.[1,2]

Aim: To propose a CT-derived, FRESH-printed femur phantom platform for comparing alginate-based hydrogel formulations, including mineral-reinforced composites, based on geometric fidelity, handling integrity and basic mechanical performance.

Experimental Workflow

A CT-derived femur geometry will be reconstructed, standardised and converted into printable toolpaths. Using FRESH printing, the same anatomical model will be fabricated with different alginate-based hydrogel formulations to assess whether mineral or composite reinforcement improves functional performance while preserving shape accuracy. Following calcium-mediated crosslinking, the printed constructs will be compared for geometric fidelity, handling integrity and basic mechanical behaviour.[1]

3D CT Femur Data → **Digital Reconstruction & Standaristion** → **Toolpath Generation** → **FRESH Printing of Three Formulations**

Group A	Group B	Group C
Alginate only	Alginate + Hydroxyapatite	Alginate + Hydroxyapatite + Gelatin
Baseline phantom	Mineral-reinforced phantom	Composite phantom

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$CaCl_2$ Crosslinking & Support Bath Removal

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Comparative Evaluation
Shape fidelity • Handling integrity • Mechanical performance

Study principle: The same CT-derived femur geometry and printing workflow will be used across all groups; only the hydrogel formulation will vary.

Expected outcomes

The proposed platform is expected to demonstrate whether reinforcement of alginate hydrogel improves the functional stability of CT-derived femur phantoms without compromising anatomical print fidelity. Compared with alginate alone, mineral-reinforced composite formulations may show improved shape retention during handling and better mechanical behaviour during basic deformation testing.

Key outcomes assessed:

Geometric fidelity – similarity between the digital CT-derived model and printed phantom.
Handling integrity – ability to retain structure during removal and manipulation.
Mechanical performance – response to deformation and elastic recovery.

Expected application: Identification of a promising alginate-based formulation for future bone-related biomaterials testing.

Conclusion and Future direction

- FRESH printing provides a promising approach for producing CT-derived, patient-specific femur phantoms using alginate-based hydrogels. This proposed platform extends existing feasibility work by comparing reinforced formulations for improved functional stability while preserving anatomical fidelity.
- Future optimisation of mineral-containing composite inks may support the development of more bone-relevant phantoms for mechanical assessment, biomaterials testing and evaluation of reinforcement strategies.

References

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