Multifunctional Injectable Foams for Hemorrhage Control and Musculoskeletal Regeneration

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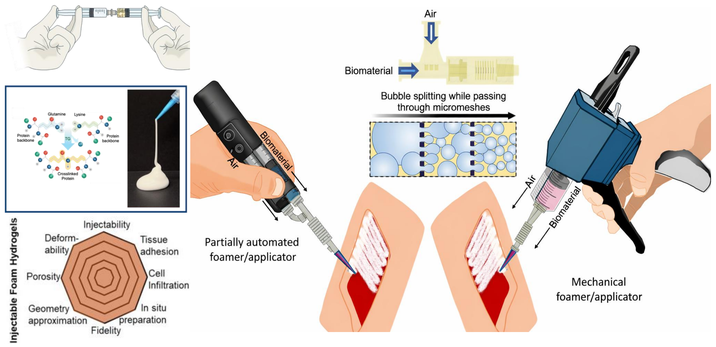
Introduction:

Battlefield trauma can produce both uncontrolled hemorrhage and complex musculoskeletal defects, yet current treatments generally separate immediate stabilization from later reconstruction. We developed a rapidly generated, macroporous gelatin–transglutaminase (Gel–TG) foam that enzymatically crosslinks in situ, conforms to irregular wounds, and can be delivered by injection or spraying[1]. Laponite nanoclay was incorporated to enhance blood–material interactions while providing ion-mediated osteogenic cues. This study evaluated whether a single formulation could balance deployability, hemostatic efficacy, structural integrity, inflammatory compatibility, and musculoskeletal regenerative potential.

Objective:

Identify a single Gel-TG/Lap formulation capable of controlling acute bleeding while also capable of supporting bone repair and regeneration.

Methods of Foam Fabrication:



Results:

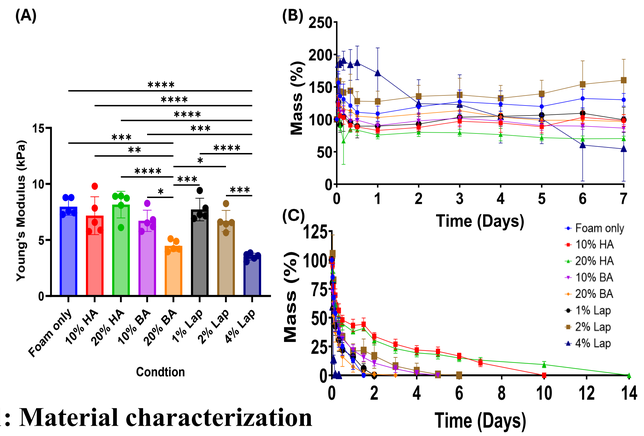


Figure 1: Material characterization
(A) Young's modulus of all foam variations. (B) Swelling of foams over a week. (C) Accelerated enzymatic degradation of foam scaffolds. N = 5 for all experiments.

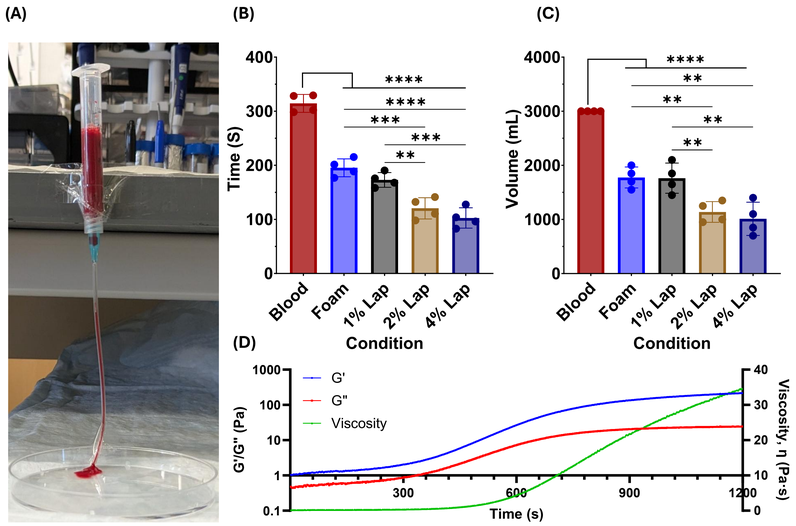


Figure 2: Dynamic In Vitro Bleeding model
(A) Setup of the dynamic in vitro bleed out model using a 3 mL syringe, 22-gauge needle connect to 4 inches of tubing loaded with 98:2 Bovine Blood to 10% CaCl2. (B) Time and (C) Volume until clotting occurred or bled out (n = 4). (D) Hemorheology of the blood sample to get a more accurate depiction and status of the clot kinetics.

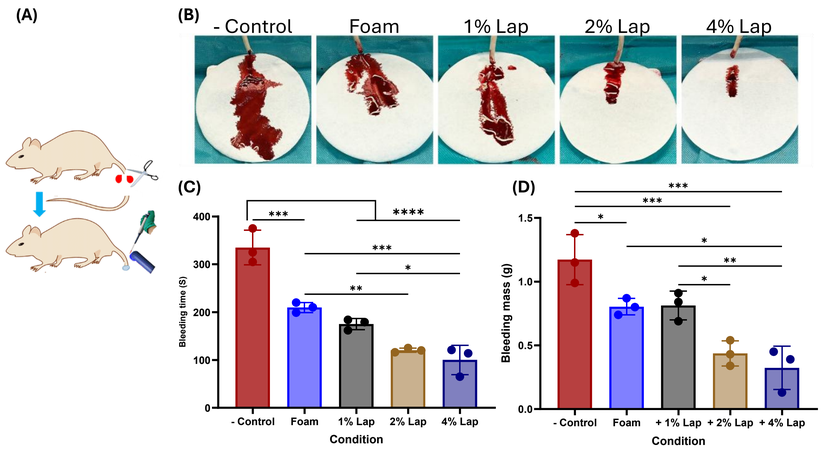


Figure 3: In Vivo Tail Snip Bleeding Model
(A) Schematic representation of the procedure. (B) Representative images of the blood collection from the rat tail snip showcasing the effects of the added hemostatic foam. (C) Bleeding time and (D) collected mass before the clotting occurred.

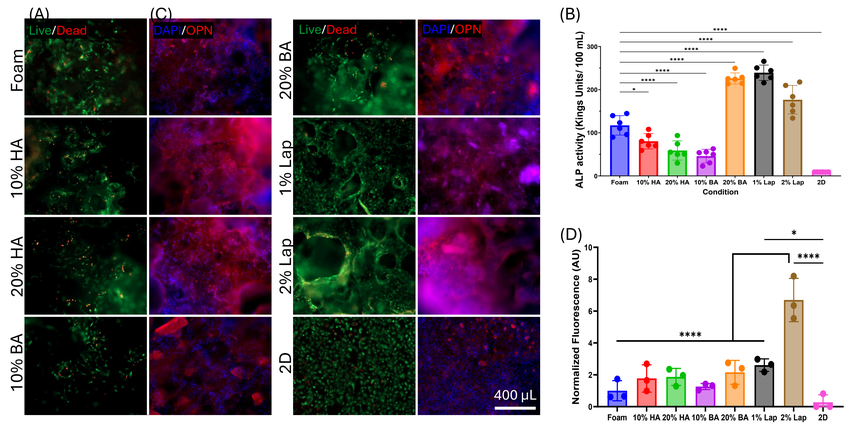


Figure 4: In Vitro Assessments of MC3T3-E1 (A) Live/dead analysis day 1, n=3. (B) ALP activity was monitored day 12 to show early mineralization, n=6. (C) OPN staining was performed on day 28 to evaluate osteogenic potential, n=3, (D) Xylenol Orange was performed on day 35 to evaluate late-stage mineralization, n=3.

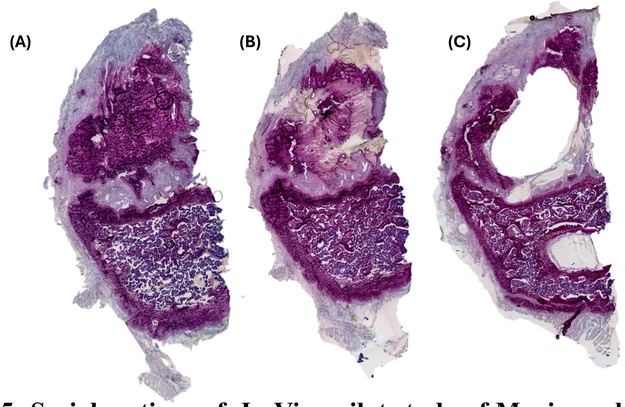


Figure 5: Serial sections of In Vivo pilot study of Murine calvaria defect
n of 5 mice were tested with 2 holes per head with 3.5 mm defects using the 2% Lap condition. For the pilot they were sacrificed after 2 weeks, and then stained with hematoxylin and bluing agent. (A) Most superficial (B) middle and (C) most sections showed revealed a cell-rich, matrix-containing response concentrated near the ectocranial surface, with persistent deeper defect space and no clear full-thickness osseous bridging.

Conclusions:

- Injectable Gelatin–TG–Laponite foams enable rapid, conformal wound treatment.
- 2% Laponite provided the best overall hemostatic, mechanical, inflammatory, and osteogenic profile.
- Pilot histology suggests scaffold-associated tissue formation but requires optimized defect filling and confirmation of bone bridging

1.Saeedinejad, F., et al., *In Situ-Formed Tissue-Adhesive Macroporous Scaffolds Enhance Cell Infiltration and Tissue Regeneration*. Acta Biomaterialia, 2025. DOI: 10.1016/j.actbio.2025.04.049

Acknowledgments
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