Preclinical Study of 3D-Printed Glass-Hydrogel Dressings: Continuous Moisturizing for Burn Wound Healing

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Introduction

Burn injuries pose a significant challenge to both civilians and military personnel:

- Each year approximately 1.1 million civilians are admitted to US hospitals, and 60% of them are diagnosed with second-degree burn wounds.
- Burns-related procedures accounted for 6% of the operative workload during natural disasters and 11% in conflict zones.

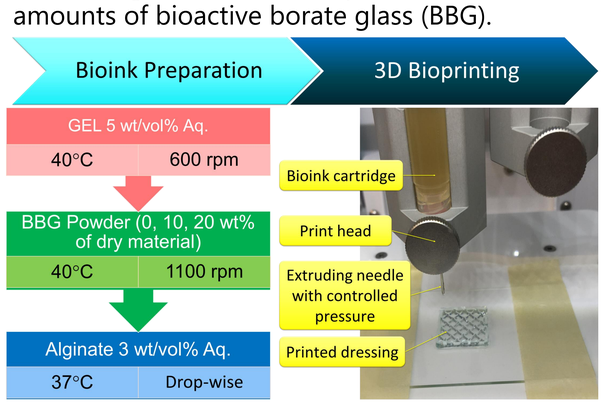
Advanced hydrogel materials have garnered significant attention for their soothing and moisturizing properties in the treatment of burn wounds. However, their us in burn wound management is limited by shortcomings such as prolonged healing, pain, traumatic removal, and severe scarring.

Post-burn scarring pose major rehabilitative challenges due to functional, aesthetic, and psychosocial consequences, leading to a shift in burn wound care, moving from acute treatment to scar management, driven by advances in wound care research, pain management, , and a growing array of commercialized products.

Existing dressings can cause pain, secondary trauma, and sever scarring to burn wounds.

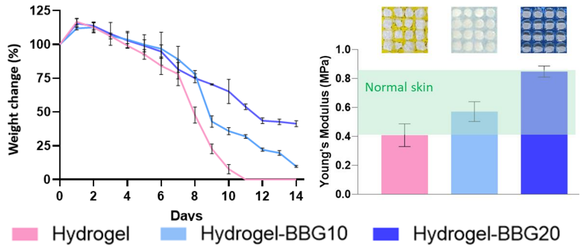
Materials and Methods

3D-printed dressings were fabricated using an extrusion-based 3D printer with natural hydrogels composed of gelatin (GEL) and sodium alginate (ALG) incorporated with various amounts of bioactive borate glass (BBG).

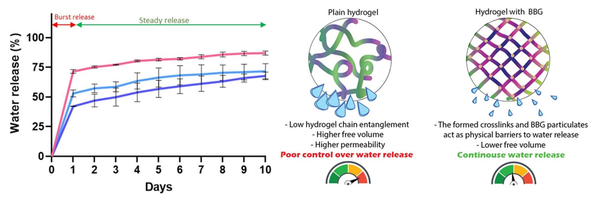


Results and Discussion

3D-printed dressings with higher BBG contents showed higher **Young's modulus** and lower **degradation rate**.



Samples with 10 and 20 wt% BBG exhibited Young's modulus in the range of normal skin (0.42-0.85 MPa), which is a favorable mechanical stiffness to cover the wound and adapt to the surrounding tissue without pain and limiting body movement.

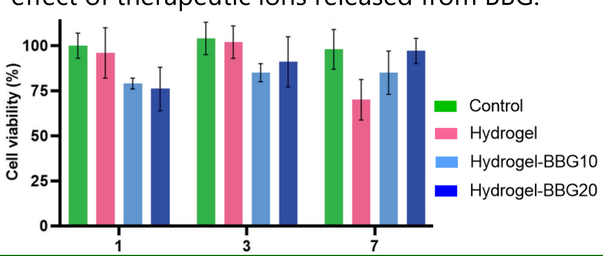


The 3D-printed dressings without BBG showed burst release of water at early hours, while 3D-printed dressings with 20 wt% BBG showed **continuous water release** for up to 10 days, which is a key feature for treatment of second-degree burn wounds.

BBG enhanced the kinetics of water release by (1) providing physical barriers against water molecules and (2) reducing the diffusion and degradation rates.

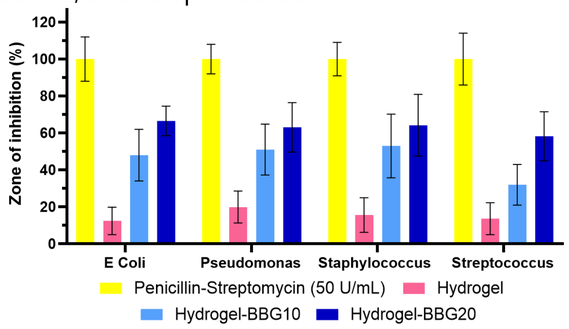
In Vitro Biocompatibility

Hydrogel samples showed higher viability of human dermal fibroblasts on days 1 and 3, with a decline on day 7. While BBG improved the cell viability at day 7, which indicates the long-term effect of therapeutic ions released from BBG.



Antibacterial Activity

BBG improved the antibacterial activity of the 3D-printed dressings against E coli, pseudomonas aeruginosa, staphylococcus aureus, and streptococcus.



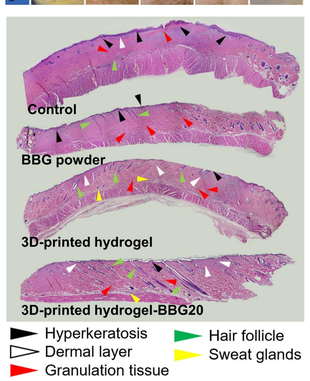
The observed lower antimicrobial activity in our dressings compared to penicillin-streptomycin, is well-aligned with the intention for use on non-infected second-degree burns. Our dressings are designed to provide effective protection against potential pathogens, while avoiding unnecessary antibiotic treatment to minimize the risk of antibacterial resistance.

In Vivo Wound Healing (Rat Model)

The *in vivo* wound healing functionality of the dressings was investigated in a rat model with second-degree burn wound in the dorsal area. Petrolatum gauze and BBG powder were included in the test as control groups (n=6).

Our dressings with 20 wt% BBG promoted moist wound healing with faster wound closure, and non-traumatic dressing removal.

Histology analysis showed the positive effect of the BBG on uniform re-epithelization, dermal regeneration, and regeneration of skin appendages (e.g., hair follicles and sweat glands) compared to the plain hydrogel, and the control groups.

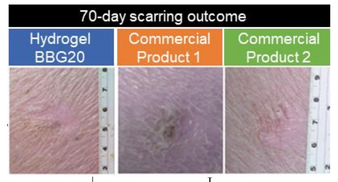


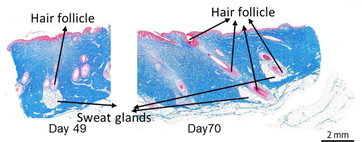
Scar Prevention (Porcine Model)

The anti-scar activity of the 3D-printed dressings was investigated in a porcine model with second-degree burn wound in the dorsal area. Contact dressings from Smith&Nephew and Convatec were included in the test as standards of care (n=6).

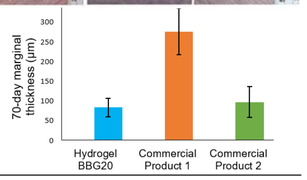
Our sample with 20 wt% BBG showed superior scaring outcome:

- Lower new/old collagen fiber ratio
- Lower Ki67 activity → lower fibrosis and scar





Regeneration of skin appendages in Hydrogel BBG20



Samples	Scar prevention score (1-4)	Basket-weave pattern (%) (compared to parallel fibers)
Hydrogel BBG20	**3.33 ± 0.81**	**21**
Commercial Product 1	2.5 ± 0.83	10
Commercial Product 2	3.16 ± 0.75	**17**
Normal Skin	4	No parallel pattern

Conclusion

Our findings provide proof of concept for the synergistic effect of bioactive formulation and 3D printing technology on continuous water release and antimicrobial activity to enhance the outcomes of second-degree burn wound treatment.

Our product can be applied on second-degree burn wounds for instantaneous relief, and preventing scar tissue formation which is a key factor in patient's quality of life.

The outcomes of our study will lead to significant progress in knowledge generation, advancing the current standard of care, and product development for treatment of burn injuries to the next phase: clinical studies towards product commercialization and delivery for both military and civilian use.

Acknowledgement

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