Fabrication and Optimisation of a 3D Printed Polyhydroxybutyrate/Ti-MXene Hybrid Scaffold for Bone Regeneration

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Clinical need

- **Osteochondral defects involve damage to both cartilage and subchondral bone**, and effective restoration of the bone compartment remains challenging.
- **Current treatments, such as autologous bone grafting, are limited** by donor-site morbidity, limited graft availability and inconsistent integration.
- **There is a need for biodegradable 3D-printed scaffolds** that provide mechanical support and promote bone regeneration in the subchondral region.

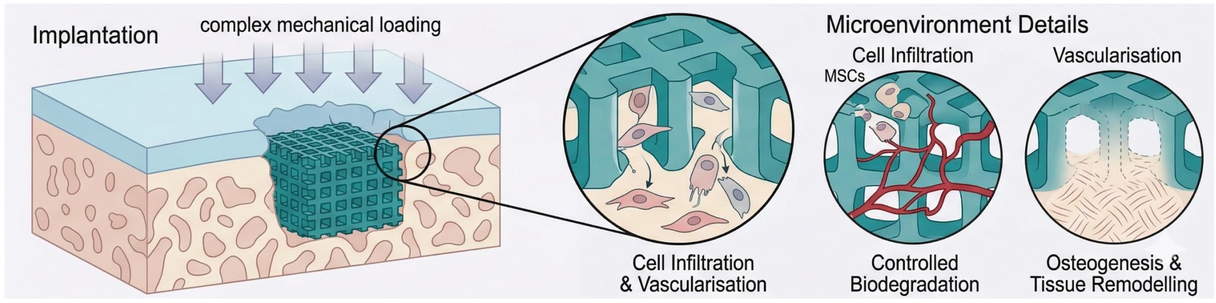


Figure 1. Schematic illustration of the biological mechanisms underlying scaffold-mediated subchondral bone regeneration.

Research strategies

- **PHB** was selected as the main scaffold material because of its biodegradability and biocompatibility, but its intrinsic brittleness limits its use in load-bearing bone repair.
- **PCL** was incorporated to improve the flexibility, toughness and printability of the PHB-based system.
- **$Ti_3C_2T_x$-MXene** was introduced to enhance surface wettability, bioactivity and osteogenic-related cellular response.

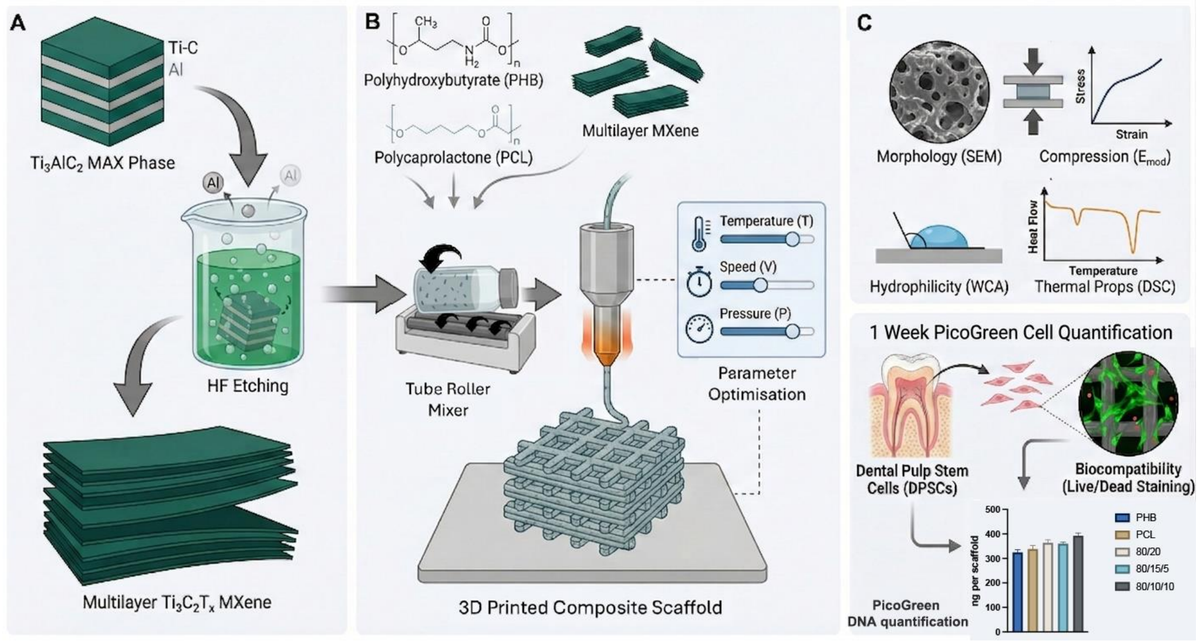


Figure 2. (A) Schematic illustration of $Ti_3C_2T_x$ MXene synthesis, **(B)** composite ink preparation, 3D printing of hybrid scaffolds, and (C) their physicochemical characterisation and biological evaluation.

Results

Scaffold printing setup and printability

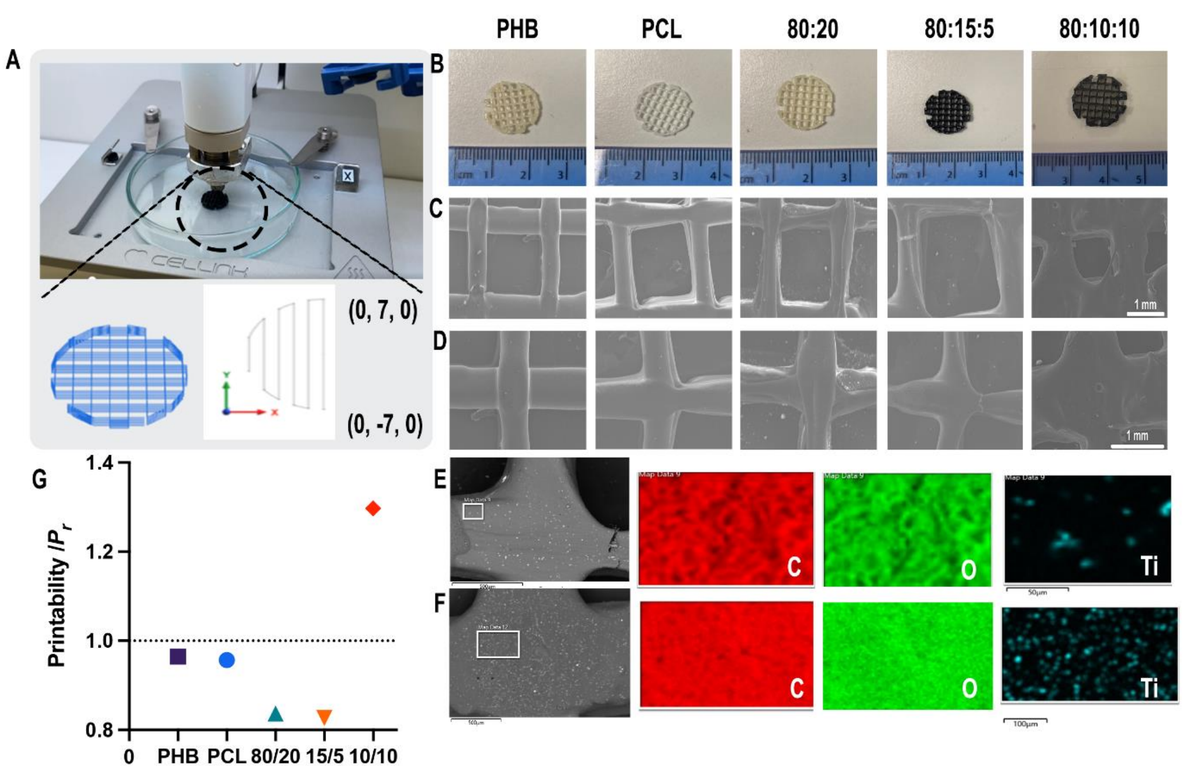


Figure 3. (A) Schematic illustration of the printing path and layer arrangement. **(B)** Photographs of printed scaffolds. **(C, D)** Representative SEM images. **(E, F)** elemental mapping images of C, O, and Ti. **(G)** Printability *(Pr)* of scaffolds prepared from different formulations.

In vitro mineralisation

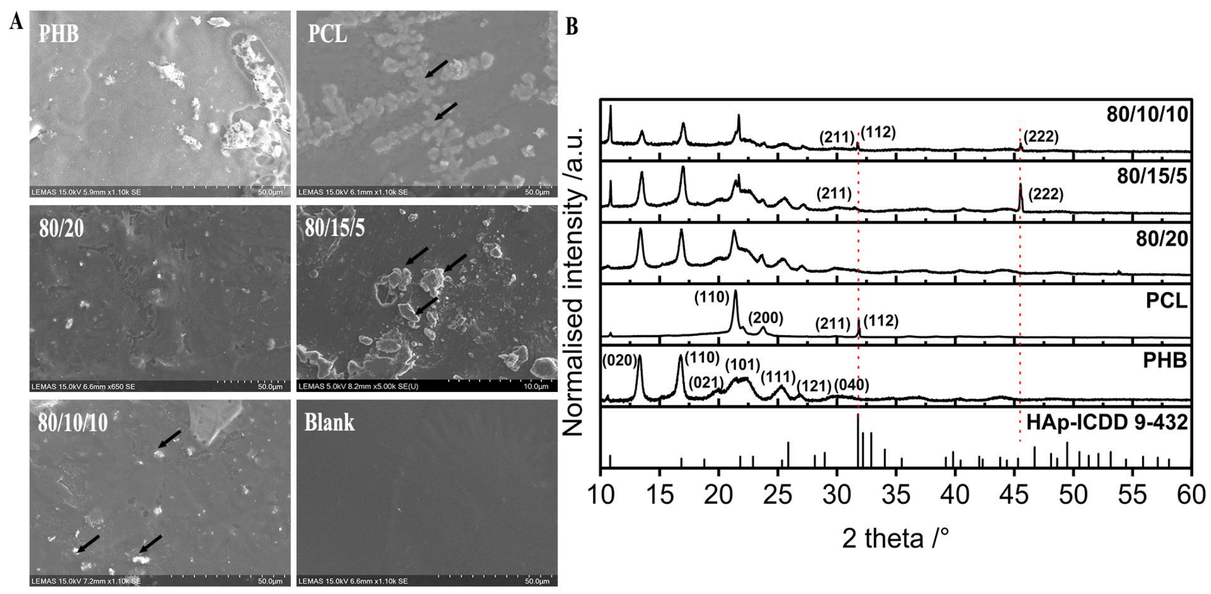


Figure 4. In vitro mineralisation behaviour of the different scaffold groups following immersion in SBF for 14 days at 37 ° C. **(A)** SEM images **(B)** Corresponding XRD patterns of the mineralised scaffolds.

In vitro cell response

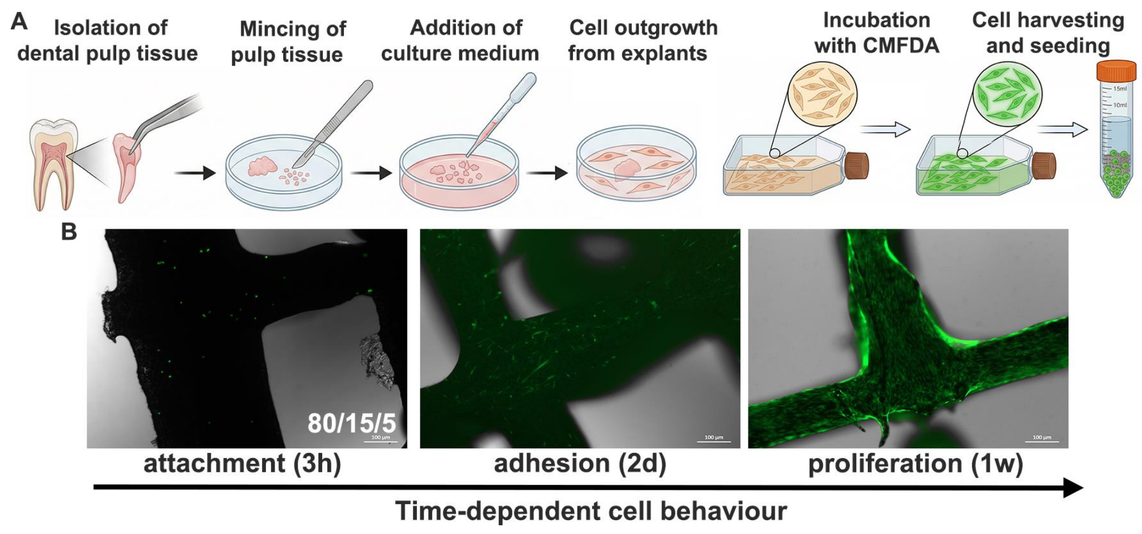


Figure 5. (A) Isolation of DPSCs and CMFDA labelling, **(B)** time-dependent cell behaviour.

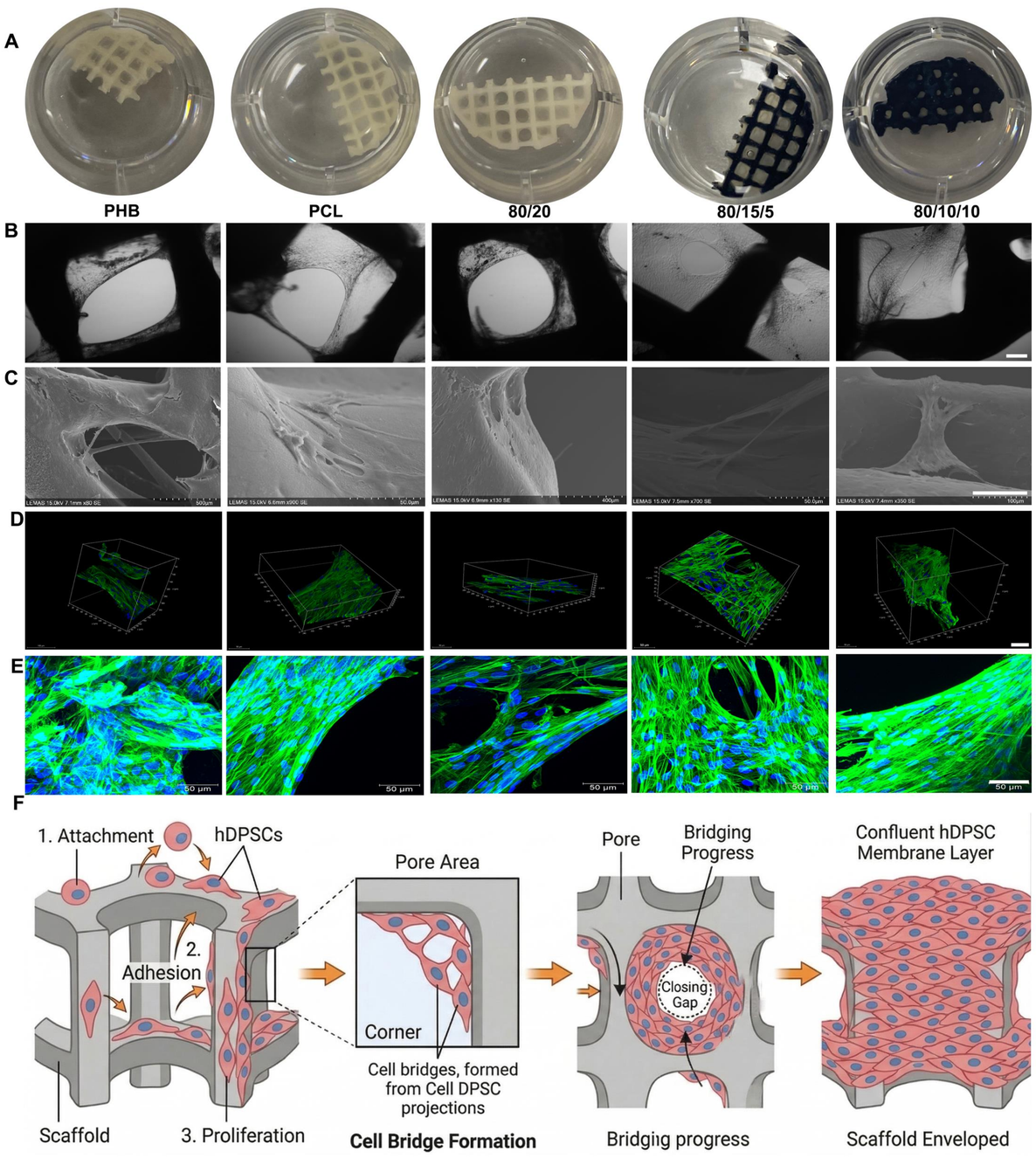


Figure 6. Representative photographs and microscopic images showing cell attachment, spreading, and growth on different scaffold formulations.

Conclusion

A PHB/Ti-MXene hybrid scaffold was successfully fabricated by extrusion-based 3D printing, exhibiting favourable printability, physicochemical properties, and support for cell attachment and spreading. These findings suggest that the developed scaffold is a promising candidate for subchondral bone regeneration in osteochondral defect repair.

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