Biodegradable scaffold design framework: guiding the future of oncological maxillofacial reconstruction

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Background/Aim

Large mandibular bone defects resulting from oncologic resections remain a major reconstructive challenge, as bone beyond a critical size loses its intrinsic regenerative capacity. Current graft-based approaches are limited by donor site morbidity, infection risk, and poor integration, while metallic implants lack bioactivity and often lead to long-term complications such as exposure or fibrous encapsulation.
Therefore, there is a growing need for bioactive, biodegradable solutions capable of supporting functional bone regeneration.

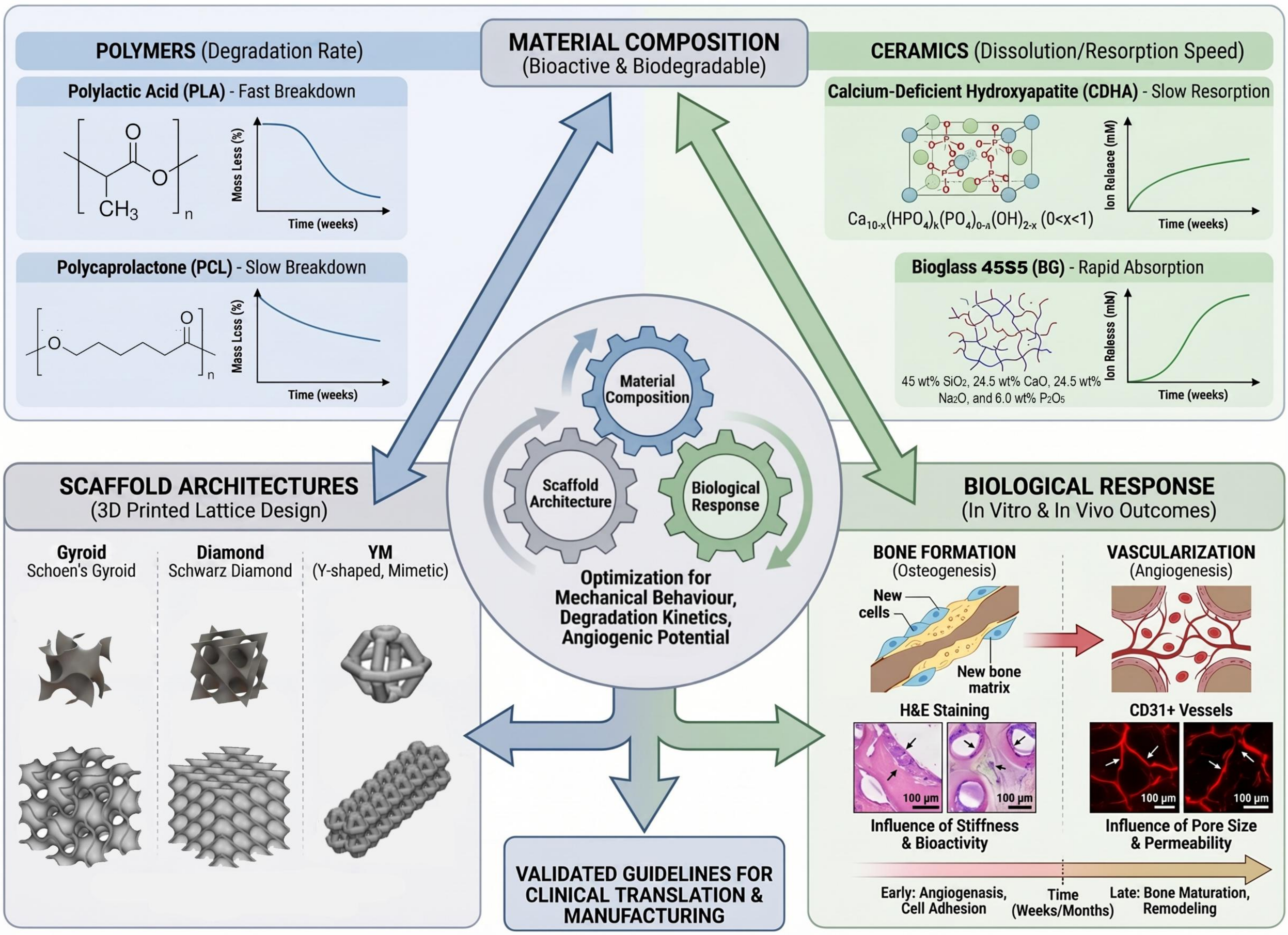
Research gap

Biodegradable scaffolds (BS) offer a promising alternative; however, their performance depends on a complex interplay between degradation kinetics, mechanical stability, and vascularization. However, the optimal relationship between degradation rate, mechanical behaviour, and vascular ingrowth remains largely unexplored.

Aim

To establish design guidelines for biodegradable scaffolds tailored for large maxillofacial bone reconstruction by systematically investigating the interplay between material composition and lattice architecture.

Concept



Methodology

Biodegradable scaffolds will be developed by systematically combining polymers and bioactive ceramics with distinct degradation profiles and fabricating them into controlled µ-lattice architectures using 3D printing. Material formulations will be optimized to ensure printability and mechanical performance, followed by detailed structural characterization and mechanical testing to define scaffold properties.
The influence of lattice geometry and material composition on mechanical behaviour and degradation kinetics will be evaluated through long-term *in vitro* studies, including degradation in simulated body conditions and assessment of cell–scaffold interactions. In parallel, scaffold performance will be validated *in vivo* using critical-size bone defect models, where scaffold degradation, bone regeneration, and tissue integration will be assessed at defined time points using imaging, mechanical testing, and histological analysis, enabling evaluation of regeneration processes in relation to scaffold degradation progression.
To further understand and predict scaffold behaviour, computational modelling based on finite element analysis will be employed. These models will integrate experimental data to simulate time-dependent changes in mechanical properties, degradation, and tissue regeneration, enabling iterative optimization of both µ-lattice architecture and implant-scale design. This combined experimental and computational approach provides a systematic framework for developing scaffolds that balance mechanical stability, controlled degradation, and biological performance.

Expected outcomes

It is expected that systematic variation of material composition and lattice architecture will enable the development of biodegradable scaffolds with tunable degradation behaviour and mechanical properties. By analysing scaffold performance at defined time points, the study will provide insights into how scaffold degradation influences bone regeneration and vascularization, allowing identification of conditions under which tissue formation progresses in coordination with material resorption.
The combined experimental and computational results are anticipated to reveal optimal relationships between material properties, structural design, and biological response, supporting the development of scaffolds that maintain mechanical stability while promoting efficient tissue regeneration. Ultimately, this work will establish design guidelines for next-generation biodegradable implants for large maxillofacial bone defects.

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