

Letter to the Editor

The future pulp: Should pulp regeneration aim to be smart and self-healing?

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Dear Editor,

Emerging trends in endodontics are rapidly shifting from traditional repair-oriented approaches to advancing themes of pulp tissue regeneration. This evolution encourages the pursuit not just of replacement, but of smart, self-healing pulpal tissues capable of both maintaining vitality and participating in natural repair.^[1] The concept of “smart pulp” involves designing regenerated tissues that can sense, respond, and adapt to environmental cues – similar to native pulp. Stimuli-responsive scaffolds and materials are being engineered to mimic the microenvironment, modulate inflammation, and release bioactive agents in response to potential of hydrogen, temperature, or infection, supporting both regeneration and immune defense.

A critical milestone for pulp tissue engineering is the use of biomimetic, self-healing scaffolds incorporating bioactive molecules and growth factors. Examples include composite membranes, injectable hydrogels, and nanofiber scaffolds that enable stem cell homing, vascularization, and *in situ* tissue repair. Recent studies confirm that scaffolds embedded with growth factors or extracellular vesicles facilitate endogenous cell recruitment, promoting a regenerative and self-repairing microenvironment.^[2] While autologous dental pulp stem cell transplantation has shown promise, issues such as limited donor tooth availability, immune rejection, and complex cell-handling protocols limit clinical scalability. Therefore, there is increasing interest in cell-free approaches, utilizing extracellular vesicles, decellularized matrices, or gene delivery systems, which offer more practical and less ethically complex options.

Despite these advances, translating such innovations into clinical practice remains challenging. Consistent protocols and standardization are elusive, with key hurdles including controlling the inflammatory response, ensuring

vascularization, and achieving predictable integration with host tissues. Sustained interdisciplinary research is essential to advance smart, self-healing pulp regeneration from the laboratory to widespread clinical practice.

Regenerative endodontics has progressed from revascularization to scaffold-based cell-homing protocols. While these methods can be effective in immature teeth, they remain largely passive and lack real-time adaptability, immune surveillance, or genuine functional integration. This limitation raises a fundamental question: Should pulp regeneration be reconceptualized as a dynamic and intelligent process rather than static tissue replacement?

At present, no clinically deployable scaffold integrates sensing, feedback, and physiological adaptation. Treating all tooth types with a standard construct fails to account for critical differences in vascularity, occlusal load, and anatomical morphology, further highlighting the need for a new generation of tailored, smart pulp constructs.^[3]

Several promising approaches may guide this transition. Biosensor-enabled scaffolds could detect bacterial metabolites or inflammatory markers and trigger the controlled release of antimicrobials or anti-inflammatories. Piezoelectric matrices, capable of converting masticatory forces into bioelectric signals, may stimulate localized pulp–dentin regeneration.^[4]

The incorporation of Clustered regularly interspaced short palindromic repeats (CRISPR)/Cas9-based gene-modulating vectors offers opportunities to upregulate odontogenic pathways and fine-tune host–microbe interactions.^[5] Personalization by tooth class should be enabled through advanced three dimensional (3D) bioprinting and artificial intelligence-based modeling, allowing for the design of constructs tailored to the distinct demands of molars, premolars, and anterior teeth.

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The translational pathway is not without difficulty. Ensuring the sterilization and standardization of hybrid scaffolds without compromising biosensor or gene-vector functionality is a significant technical challenge. Biocompatibility requires rigorous validation, particularly for integrated bioelectronic or gene-editing elements. Ethical and regulatory clarity are also imperative before clinical adoption. Cost-effective fabrication also remains essential if these advanced technologies are to reach routine practice.^[3] Nonetheless, early steps could focus on *in vitro* biosensor-scaffold prototypes and tooth-class-specific 3D bioprinted models, followed by large-animal validation as proof-of-concept.

In summary, by moving toward intelligent and self-healing constructs, regenerative endodontics could shift from passive tissue repair to establishing a responsive, functional, and personalized pulp. This vision offers a realistic translational roadmap by blending nanotechnology, gene modulation, and regenerative tissue engineering, ultimately aligning with the clinical goals of durability and predictability.^[1]

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REFERENCES

1. Li XL, Fan W, Fan B. Dental pulp regeneration strategies: A review of status quo and recent advances. *Bioact Mater* 2024;38:258-75.
2. Hong SH, Huh J, De R, Park R, Yang SM, Choi H, *et al.* Smart bioelectronic materials and systems for regenerative tissue engineering. *Biomaterials* 2025;323:123427.
3. Quigley RM, Kearney M, Kennedy OD, Duncan HF. Tissue engineering approaches for dental pulp regeneration: The development of novel bioactive materials using pharmacological epigenetic inhibitors. *Bioact Mater* 2024;40:182-211.
4. Li J, Zhao X, Xia Y, Qi X, Jiang C, Xiao Y, *et al.* Strontium-containing piezoelectric biofilm promotes dentin tissue regeneration. *Adv Mater* 2024;36:e2313419.
5. Garhnayak M, Rath S, Garhnayak L, Panda S. CRISPR in dentistry: A boon or bane. *Microbes Infect Dis* 2023;4:1178-82.

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