Future horizons: embedding the evolving science of regenerative dentistry in a modern, sustainable dental curriculum

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Key points

Although regenerative therapies can be approached in different ways, they all share basic principles in employing sustainable biological repair, contrasting the usage of dental materials, as a conservative approach.

Future dentists will need to be equipped with knowledge and be able to educate and inform patients and the wider public on new biological treatments.

New dental curricula need to embrace the advancements of basic science, incorporating the vision of translating this knowledge into future dental therapies.

Design and development of innovative dental curriculum will see implementation of novel therapies derived from regenerative dentistry, with embedded principles of sustainability, equipping the new generation of dentists for the future.

Abstract

Regenerative dentistry is an emerging field promising to revolutionise the way we approach and perform clinical therapies. This multidisciplinary field, integrating cellular biology, material science and tissue engineering, aims to restore and maintain biological vitality unlike conventional dental therapies, providing a new approach in achieving sustainability within dentistry. Although this emerging field in dentistry seems futuristic and a distant reality, it is closer than we perceive it, as rapid scientific advances contribute to novel technologies. In this opinion piece we share our views on the emerging field and the need of embedding the scientific knowledge and sustainability within the dental curriculum. We critically discuss challenges and quests ahead of our dental profession facing the future.

Introduction

Unsustainable dentistry and the need to embrace science for the future

Imagine a new world of dentistry without restorative fillings, long pending dental lab work, or unsustainable treatments. Imagine harnessing nature to do all the hard work with a sustainably organised system of dental care. This visionary new approach can be achieved through implementation of the newest scientific advances, embedded in biological approaches of regenerative dentistry while

developing a sustainable system in providing oral health care.

Today, oral diseases such as caries and periodontitis are global health problems, with over (an estimated) 3.5 billion patients affected annually in the world.¹

In a constantly evolving world, modern-day dentistry has arguably seen very little clinical evolution in the last four decades. We might argue that this is surprising, considering the vast advances within the medical field and research. It is not news to dental professionals that current therapies still pose longstanding limitations and issues. Conventional dental therapies lack the physiological and chemical properties of natural tooth structure and undoubtedly, all have a limited lifespan. Many of the used dental materials, such as amalgams and composites, have been put in the spotlight for their environmental impact due to the release of toxic materials or microparticles. Contrasting to the usage of traditional dental materials, the prospect of a new, biological-based dentistry and dental curriculum centring

around the inherent properties of repair and regeneration at the cellular level offers the potential for a more sustainable future.^{2,3,4}

Biology as a tool

Regenerative dentistry is an emerging field, promising to revolutionise the way we perceive and perform clinical dentistry (Fig. 1). This multidisciplinary field, integrating cellular biology and tissue engineering, aims to restore and maintain biological vitality, unlike conventional dental therapies. The regeneration of biological tissues may be defined as the production and replacement of cells within functional tissue constructs. This process is naturally occurring in tissues under diseased and physiological conditions and is utilised for the production of bioengineered replacement tissues. The continuous biological replacement of teeth is seen in nature in examples such as sharks, snakes and other animals. Although the regeneration of whole human bioengineered teeth is still preliminary at research level, other potential approaches in regenerative dentistry

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Fig. 1 Timeline of key developments and advancements within regenerative dentistry through time^{30,31,32,33,34,35,36}

include: the regeneration of the dental pulp tissue; the repair and regeneration of dentine as a biological hard-tissue barrier; the repair of cementum; and the biological repair and regeneration of the periodontium.^{4,5,6} The translation of regenerative research into clinical viable therapies, however, must yet overcome many hurdles and challenges.

The 'makings of a third human dentition' and learning to switch on our 'repair forces'

The regeneration and repair of dental tissues has been described in the literature through one of two approaches: via the intrinsic wound healing capacity of the tissue or via the *de novo* formation using tissue engineering techniques.⁷ The repair and replacement by regeneration of oral tissues aims to restore tissue functionality and vitality, with the ultimate goal of providing the third human dentition.^{2,3,4} Although the concept of regenerative dentistry seems futuristic, regenerative therapies have been utilised in clinical practice from as early as the 1950s, with the recognition of dentine repair using calcium hydroxide in vital pulp therapy.⁸

The intrinsic tissue healing capacity for therapeutic potential has been extensively studied in dentine regeneration in response to damage such as bacterial invasion or injury. The mechanism of this tertiary dentine formation is dependent on the extent of damage to the post-mitotic odontoblast cells.⁹ Extensive damage requires recruitment of pulpal stem cells that will differentiate into odontoblasts, capable of production of reparative dentine. Examples of dentine reparative therapies include the application of materials such as Biodentine and mineral trioxide aggregate.^{3,9} Tissue engineering approaches, including developmental tissue

Fig. 2 Illustration of stem cell populations found within the oral cavity and dental tissues. The landmark discovery of dental stem cells opened new horizons for dental research and provided accessible sources of autologous mesenchymal stem cells capable of self-renewal and multi-lineage differentiation^{2,3,4,5,6}

engineering, use underlying biological mechanisms to stimulate repair of damaged tissue or develop replacement of the organ.^{2,3,4,5,6,9,10}

Dental pulp stem cells (Fig. 2) have been the focus of many research groups, with some relatively recent publications showing that mobilised dental pulp stem cells and human deciduous pulp stem cells have regenerative potential for the generation of whole dental pulp.^{11,12} Further promising results have emerged from Phase I/II clinical trials on safety and efficacy of regenerative approaches in root canal treatments of teeth with apical

lesions using encapsulated human umbilical cord mesenchymal stem cells.¹³

The advancements, such as understanding of tissue structure and disease progression at a molecular level, are now emerging, contributing to potential translation of this knowledge into therapeutic solutions in dealing with periodontal disease.^{14,15}

While promising research data are continuously being published in the literature focusing on the repair and regeneration of the dentine-pulp complex, one of the major challenges is the complexity of enamel structure and its synthesis, requiring a

post-translationally modified protein scaffold for crystal growth and nonlinear prism organisation.^{9,11,12,16} During tooth development, enamel is produced by highly specialised cells, ameloblasts, that undergo apoptosis once completing enamel formation.¹⁷ The absence of ameloblast cells, following the formation of enamel, diminishes the ability for biological enamel repair.^{3,10}

The *de novo* generation of whole teeth focuses on mimicking the natural events of tooth development *in vitro*. The main approaches are based on the capacity of epithelial and mesenchymal cell populations to communicate and initiate the creation of a dental primordium that can further develop in a functional organ.^{2,3,4,10} Nevertheless, an important challenge remains in securing cell sources that maintain the odontogenic signal that will initiate the communication between the types of cells and lead to organ formation.^{4,10,18}

A further challenge for this approach includes the control of crown morphology and full periodontium integration followed by innervation and vascularisation in the oral cavity.⁴

These therapies, proven in principle, no doubt provide an exciting prospect of what the future of dentistry holds. Further translation into clinical therapies, however, face hurdles beyond the research laboratory, as many challenges still remain in translating the biological repair approaches into viable clinical, therapeutic solutions.

Tailoring an innovative dental curriculum

Regenerative dentistry within the dental curriculum

Dental curriculums around the world primarily focus on the clinical aspects of dentistry and skills acquisition. However, the rapid pace of innovative advancements in the field of regenerative dentistry will pose the need of reinforcement of knowledge of basic sciences and biological processes that underline the processes of repair and regeneration among the new generation of dentists, equipping them with knowledge ready for future advancements.

Currently, regenerative dentistry is taught on a postgraduate level. Pioneered by King's College London, the postgraduate taught programme in regenerative dentistry was launched in 2013 and has later been followed by few other schools in the world.¹⁹

When evaluating the knowledge of undergraduate dental students regarding regenerative dentistry, questions usually focus on knowledge of: stem cells; sources of knowledge; interest in continuous education; interest in pursuing graduate education in regenerative dentistry; and clinical applications of stem cells.^{19,20}

This tendency can be seen in some multicentre studies, for example final year dental students expressed a 'poor' level of knowledge with respect to stem cells and 80% of dental students expressed an interest in pursuing continuing education to explore the possibilities of translation of stem cell knowledge into clinical applications in regenerative dentistry.²¹ Other studies reported similar tendencies of indicating poor knowledge on dental stem cells; here, 70% of students were only able to provide a definition of stem cells.²²

While these studies are not evaluating comprehensively students' knowledge of the biological mechanisms that are the cornerstones for regenerative dentistry approaches, they can still be considered indicative to the level of incorporation of the new advancement of knowledge in the biomedical field within the dental curriculums.

The need of reviewing the content of biological and biomedical sciences (BMS) taught within the dental curriculum with a scope of defining a core curriculum has been the focus of a Special Interest Working Group within the Association for Dental Education in Europe, with representatives from across Europe, to develop a consensus BMS curriculum for dental programmes.²³

Modern regenerative dentistry is based on the biological principles and the continuous revision of BMS content will address the fast-paced advancement of the field. Further development of delivery methods within the curriculum of pre-clinical and clinical years should include a modular approach or incorporate sub-themes of regenerative dentistry within existing non-clinical and clinical modules.

Sustainability within the dental curriculum

Current delivery of dental care has a considerable environmental footprint, from aspects of travel, time and usage of resources, to products used in dental practices and therapeutic dental materials.

The most appropriate material system is chosen to manage each particular clinical

situation in the most effective manner. But, concerns were raised through the years regarding the usage of amalgam, one of the most commonly used dental materials, for its environmental impact due to releasing mercury. Therefore, its usage has been limited in recent years, in accordance with the recommendation of the Minamata Treaty. The recommendations include a planned phase-down of the use of dental amalgam with an anticipated complete phase-out by 2030.²⁴

The environmental impact of other restorative dental materials, such as composites, also deserves further consideration. It is necessary to consider the waste products released from resin-based composites, such as microparticles and monomers into our environment. Bisphenol A and methacrylate are just two of the chemicals associated with resin-based composites that have been shown to have an effect on human development.²⁵

Policies to support sustainability within the healthcare system are not recent and legislation to support it has been introduced within Europe and beyond since mid-1990.²⁶

While the graduating European dentist needs to 'have a comprehensive knowledge of and the skills to comply with the regulatory system of the country which they have trained', a more systematic and global approach is needed.^{26,27}

Following the publication of the United Nation's Sustainable Development Goals, higher academic institutions started looking closely at providing a more sustainable workplace for students and staff and developing a 'programme level approach' to further address the issue. Several dental academic institutions have also put an emphasis on sustainability and embedded 'sustainable developmental guidance' in their teaching.^{26,28}

In a new, constantly developing, innovative and inclusive dental curriculum, the need to address sustainability in dentistry is evident.²⁹

Several areas that will need to be evaluated and addressed through the dental curriculum in regard to sustainability concepts should include: oral health promotion and prevention with patient education; employing therapeutic strategies with lower environmental impact, such as regenerative dentistry approaches; and sustainable management and leadership in delivering dental care, working closely with professional bodies and governmental policy makers.

Although regenerative dentistry is only one of the many segments and parts of the important puzzle in promoting the concept of

sustainability, its scientific development within an innovative dental curriculum is pivotal in shaping the dental practitioners of the future.

Ethics declaration

The authors declare no conflicts of interest.

Author contributions

Kiri Paul, Abida Islam and Ana A. Volponi were involved in drafting the manuscript and revising it. Abida Islam created the figures. Ana A. Volponi contributed to the conception of the work. All authors approved the final version and agreed to be accountable for the work.

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