REVIEW ARTICLE

AODMR

Emerging Trends in Oral Health Profession: The Biomimetic - A Review

K. Srinivasan, S. Chitra[1]

Department of Pedodontics & Preventive Dentistry, Adhiparasakthi Dental College & Hospital, Melmaruvathur, Tamil Nadu, India, [1]Department of Anaesthesia, Christian Medical College, Vellore, Tamil Nadu, India.

Address for Correspondence:
Dr. K. Srinivasan, Senior Lecturer, Department of Pedodontics & Preventive Dentistry, Adhiparasakthi Dental College & Hospital, Melmaruvathur, India. E-mail: skskskpedo@gmail.com

ABSTRACT:

Mimicry in the field of science involves reproducing or copying a model, a reference. If we as dentists want to replace what has been lost, we need to agree on what is the correct reference. The accepted frame of reference must be the same for the entire profession, and it should be timeless and unchanging success.

Age, disease and traditional restorations can cause further problems to the existing tooth structure. As teeth do not have natural method of repair, Biomimetic principles should be used to artificially repair the tooth to its natural functions and aesthetics.

Biomimetics is an emerging inter disciplinary field that combines information from the study of biological structures and their function with Physics Mathematics Chemistry and Engineering in the development of principles that are important for the generation of novel synthetic materials and organs.

Biomimetic Dentistry is based on the philosophy that the intact tooth in its ideal hues and shades and, more importantly, its intracoronal anatomy, mechanics and location in the arch, is the guide to reconstruction and the determinant.

In Biomimetic Dentistry there are two aspects .One, the lost or missing dental tissue is restored, leading to the full return of function and aesthetics to the tooth or the material used can regenerate, replicate or mimic the missing dental tissue.

This review will attempt to provide a better understanding of the relative position of the Biomimetic materials in the context of the past and present Dental materials.

Keywords: Biomimetic material, Hydrogel, Mineralization, Peptides, Regeneration.

INTRODUCTION:

Biomimetics is defined as the study of the formation, structure, or function of biologically produced substances and materials and biological mechanisms and processes especially for the purpose of synthesizing similar products by artificial mechanisms which mimic natural ones. A material fabricated by Biomimetic technique based on natural process found in biological systems is called a Biomimetic material.[1]

The main principle of Biomimetics is to return all prepared dental tissues to full function by a hard-tissue bond that allows functional stresses to allowing the entire crown to its final functional biologic and esthetic result.[2]

The subject matter of Biomimetics is known by several names Bionics, Biognosis etc. The concept is very old but the implementation is gathering momentum only recently because the science base can cope with the advanced techniques and our civilization is in ever increasing need of sympathetic technology.[3]

In Dentistry there is no one Biomaterial that has the same, mechanical, physical and optical properties as tooth structure (i.e., dentin, enamel, and cementum) and possesses the physiological characteristics of intact teeth in function. By using Biomimetic therapeutic approaches, Dental professionals can improve and become closer to natural biological structures and their function.[3]

A Biomimetic material should match the part of the tooth that it's replacing in several ways, including the modulus of elasticity and function of the respective areas (e.g., pulp, dentin, enamel, dentoenamel junction).[4]

There are two major perspectives to which the term "Biomimetic" is applied: a purist perspective that focuses on recreating biological tissues and a descriptive perspective that focuses on using materials that result in a mimicked biological effect. Although different, both share a common goal of mimicking biology in restoration.[4]

HISTORY

The name biomimeitcs was coined by Ottoschmit in the 1950s while studying the nerves in a squid. He tried to copy and designs an artificial device that could replicate the same process of synaptic impulse.[3]

The term bionics was coined by Jack E.Steele in 1960 at continence in Dayton. It literally means to mimic life. It is the study of natural structural processes to try to mimic or replicate it artificially in an attempt to restore the same aesthetics or function.[3]

The foundation of this broad new field has ancient roots. Replacing body parts goes back at least 2,500 years ago when bridges made them artificial teeth carved them the bones or oxen. Evidence of crude dental implants dates back to roman population of the first or second century AD and to Pre-Columbian cultures of central and South America.

The first use of Dental amalgam to repair decayed teeth was recorded in the Chinese literature in the year 659 AD.[3]

The middle of 20th century some sophisticated inventions in the heart pacemaker, the artificial heart valve and hip and knee joint replacement historically organ and tissue loss have been treated by surgical reconstruction and more recently the use of mechanical devices such as kidney dialyzers and the transplantations of organs from one individual to another.[5]

The emerging trends of Biomimetic Dentistry in oral health profession are:

1. Biomimetics in Restorative Dentistry: The goal of Biomimetics in Restorative Dentistry is to return all of the prepared dental tissues to full function by the creation of a hard-tissue bond that allows functional stresses to pass through the tooth, drawing the entire crown into the final functional biologic and esthetic results.[2]

• Composites resins are now displaying favorable properties and longevity on par to amalgam. The technique involves minimal preparation decreasing pulpal involvement and decreasing the prognosis of fractures. Therefore it preserves tooth vitality and substance. The bonded composite can prevent fracture of unsupported cusps in primary and permanent molars that were restored with amalgam, and the use of preformed metal crowns was avoided.[6]

• Glass-Ionomer cement is often known as a Biomimetic material, because of its similar mechanical properties to dentine. This, together with the important benefits of adhesion and release of fluoride, render it an ideal material in many restorative situations.[7]

• Glass Ionomer Cements (GIC) is considered to be useful in deep class I or II cavities to fill up the base as lining material.[8] They are also useful as buccal class V cavities. Composites can then be bonded over as a closed sandwich technique. GIC releases fluoride, a bactericidal, stimulates sclerotic dentin and also has properties similar to dentin.[9] Biodentin is a new material that may replace GIC as a liner in deep fillings, but further research is needed. GIC is currently being the main material for advocates of minimum invasive dentistry which is under the umbrella of Biomimetic Restorative Dentistry.[10]

2. Biomimetic principles applied to Cosmetic Dentistry: Biomimetic Dentistry is based on the philosophy that the intact tooth in its ideal hues and shades and, more importantly, its intracoronal anatomy, mechanics and location in the arch, is the guide to reconstruction and the determinant of success. This approach is conservative and biologically sound and in sharp contrast to the porcelain fused-to-metal technique in which the metal casting with its high elastic modulus makes the underlying dentin hypo functional.[9]

3. Biomimetics Endodontics: Minimally invasive Biomimetic Endodontics which new technology, is photon-induced Photo acoustic streaming (PIPS).Reciprocating hand pieces and sonic devices were introduced with the idea of saving precious tooth structure, but further research is needed.[11]

4. Biomimetic approaches for Regeneration (Bioengineered tooth):

a) Stem cell therapy: Stem cell therapy is an emerging technique which is being translated into treatment of degenerated tissues. The simplest method to administer cells of appropriate regenerative potential is to inject the postnatal stem cells into the disinfected root canal system. Among the eight different post natal dental stem cells Stem cells from human exfoliated deciduous teeth (SHED), Dental pulp stem cells (DPSCs) and Stem cells from the apical papilla (SCAP) were more commonly used in the field of regenerative Endodontics.[12]

DPSCs are the stem cells isolated from human dental pulp. The most important feature of DPSCs is their ability to regenerate a dentin-pulp-like complex that is composed of mineralized matrix with tubules lined with odontoblasts and fibrous tissue containing blood vessels arranged as that of dentin-pulp complex found in normal human teeth.[13]

Stem cells from Human Exfoliated Deciduous teeth (SHED) have become a captivities alternative for dental tissue engineering.

The use of SHED for tissue engineering is more advantageous than the use of stem cells from adult human teeth because: (a) SHED have higher proliferation rate compared with stem cells from permanent teeth, which might allow the expansion of these cells in vitro before replantation. (b)

SHED cells are taken from exfoliated deciduous teeth that is "disposable" and readily accessible in young patients. It also has an advantage of painless stem cell collection with minimal invasion and abundant cell supply.[14,16]

A recent finding is the presence of a mesenchymal stem cells residing in the apical papilla of incompletely developed teeth. They are called stem cells from the apical papilla (SCAP). It is hypothesized that DPSCs are likely the source of replacement odontoblast cells, whereas SCAP appear to be the source of primary odontoblast cells that are responsible for the formation of root dentin.[15] These cells are able to survive even during the process of pulp necrosis, as these cells are present in apical papilla which has collateral circulation.[15]

A Biomimetic approach is proposed to construct an artificial microenvironment by Engineering its components, such as soluble factors, ECM, cell–cell interaction and external mechanical stimulation. Advances in materials science, Micro-/ Nano-fluidics, Micromanipulation, Nanofabrication and Multi-scale modelling will facilitate the design and creation of a well-controlled Biomimetic three-dimensional microenvironment, which enables the elucidation of the mechanisms governing stem cell activities. Ultimately, such a microenvironment will benefit stem cell science to be successfully translated into the clinical treatment for tissue repairing.[16-18]

b) Pulpal implantation: In pulp implantation, pulp tissue is produced by tissue Engineering triad and is transplanted into cleaned and shaped root canal system. Rebecca et al had developed Dental pulp like tissue by using the tissue engineering triad, the Dental Pulp Stem Cells (DPSCs), Dentin Matrix protein 1 and a Collagen Scaffold, after subcutaneous transplantation in mice. Collagen was the scaffold, and dentin matrix protein 1 (DMP1) was the growth factor. The result concluded that the tissue Engineering triad of DPSCs, DMP1 and a collagen scaffold, can induce an organized matrix formation similar to that of pulp tissue, which might lead to hard tissue formation.[4,19]

The potential problems associated with the implantation of sheets of cultured pulp tissue is that it requires specialized procedures for proper adherence to the root canal walls. As sheets of cells lack vascularity, only the apical portion of the canal systems will receive these cellular constructs, with coronal canal systems filled with scaffolds capable of supporting cellular proliferation.[20]

c) Root canal revascularization: Use of intracanal Irrigants (NaOCl and Chlorhexidine) along with the placement of antibiotics (e.g., a mixture of Ciprofloxacin, Metronidazole, and Minocycline paste), for several weeks, is a critical step, as it effectively disinfects the root canal systems and increases revascularization of the avulsed and necrotic teeth. The revascularization process offers negligible chances of immune rejection and pathogen transmission, as regeneration of the tissue takes place by the patient's own blood cells.[6,20]

d) Injectable scaffold delivery: This procedure will allow tissue engineered pulp tissue to be administered in a soft three-dimensional scaffold matrix. Among the Injectable Biomaterials investigated so far, hydrogels are more attractive in the field of tissue engineering. Hydrogels are Injectable scaffolds that can be delivered by syringe and are noninvasive and easy to deliver into root canal systems. In theory it is stated the hydrogels may promote pulp regeneration by providing a substrate for cell proliferation and differentiation into an organized tissue structure. Earlier hydrogels had limited control over tissue formation and development, but recent advances in formulation have dramatically improved their ability to support cell survival.[21]

e) Gene Therapy: Gene therapy is a method of delivering genes with the help of viral or non-viral vectors. The gene delivery in Endodontics would be to deliver mineralizing genes into pulp tissue to promote tissue mineralization. Viral vectors are genetically altered to eliminate ability of causing disease, without losing infectious capacity to the cell. At present Adenoviral, Retroviral, Adeno associated virus, Herpes simplex virus, Lentivirus are being developed. Nonviral delivery systems use plasmids, peptides, cationic leptosomes, DNA-ligand complex, gene guns, electroporation, and sonoporation to address safety concerns such as immunogenicity and mutagenesis.[22]

Numerous growth factors normally expressed during primary odontogenesis , members of the transforming growth factor beta (TGF-beta) super family, including several members of the bone morphogenetic protein family (e.g. BMP-2, BMP-7), and insulin-like growth factor-1 (IGF-1) appear to play a key part in the induction of odontoblast-like cell differentiation from progenitor pulpal cells. A number of these growth factors are incorporated into the developing dentin matrix during initial tooth formation, forming a reservoir from which they can be released following dentin breakdown.[7]

5) Biomimetic approaches for oral maxillofacial surgery: Uses in Oral Maxillofacial Surgery for craniofacial reconstruction Stem cells have been used in the tissue engineering of a human-shaped temporomandibular joint and used MSC-derived cells encapsulated in a poly{ethylene glycol} diacrylate hydrogel that was molded into an adult human mandibular condyle in stratified yet integrated layers of cartilage and bone.[20]

6) Biomimetic mineralization (BIMIN): Biological mineral synthesis, in contrast to conventional mineral processing techniques, generates materials of very highly controlled size, habit, texture, composition, and structure.[23] A recently introduced technique of guided formation of an enamel-like fluorapatite layer on a mineral substrate has the potential to enable remineralization of superficial enamel defects and/or exposed dentin. The technique, BIMIN, utilizes the diffusion of calcium ions from solution into a glycerine enriched gelatin gel that contains phosphate and fluoride ions. When the conditioned gel is in direct contact with the exposed tooth surface, within 8 h, a firmly adhering mineral layer is formed on the tooth surface.[24]

7) Biomimetic remineralization of dentin has been investigated with different methods using ion-containing solutions or ion leaching silicon-containing materials. Recently reported the use of bioactive “smart” composites containing reactive calcium-silicate.[25]

Some researcher used Agarose gel containing Na_2HPO_4 that covered an acid-etched dentin sample. Comparable to a sandwich-technique, the gel was then covered by a layer of Agarose without phosphate ions, masked by a $CaCl_2$ solution. The system was immersed in a water bath at 37◦C, replenished on multiple occasions, and resulted in densely packed hydroxyapatite crystals that covered the dentin surface and occluded the dentinal tubules after 10 days of Biomimetic mineralization.[26]

8) Biomimetic self-assembling peptides: P11-4 is a rationally-designed self-assembling peptide. Self-assembling peptides undergo well-characterized hierarchical self-assembly into three-dimensional fibrillar scaffolds in response to specific environmental triggers, offering a new generation of well-defined biopolymers with a range of potential applications.[27]

P11-4 switches from a low viscosity isotropic liquid to an elastomeric pneumatic gel at pH <7.4 and in the presence of cations, conditions assumed to be found within a caries lesion. In a number of in vivo and in vitro experiments, the assembled P11-4 fibers were shown to be highly biocompatible with low immunogenicity. Following P11-4 self-assembly, the anionic groups of the P11-4 side chains would attract Ca++ ions, inducing de novo precipitation of hydroxyapatite.[27]

The earliest clinical sign of enamel caries is the appearance of a 'white spot' lesion on the tooth surface. At this stage, clinicians generally elect to monitor lesion appearance, possibly after the use of topical fluorides, to determine whether the lesion will progress or not, in which case a restoration would then be placed. Non-surgical intervention promoting defect biomineralization or regeneration at the white spot lesion stage would remove the need to 'wait and see' and avoid the ultimate excavation of the tooth to place a restoration.[27]

Infiltration of early ('white spot') caries lesions using low viscosity monomeric P11-4 would result in triggered self-assembly within the lesion, generating a subsurface bioactive scaffold capable of recapitulating normal histogenesis by inducing mineral deposition in situ.[27]

Peptide treatment significantly increased net mineral gain due to a combined effect of increased mineral gain and inhibition of mineral loss.[27]

9) Biomaterials Synthetic Polymer: The polymer can be biodegradable or non degradable. Biodegradable polymers include polylactic acid and polyglycolic acid and co polymers. These polymers are used as suture materials but are also being examined for usage such as bone, skin and liver substitutes. These polymers are broken down in the body hydrolytically to produce lactic acid and glycolic acid. Newer biomaterials are Polyanhydrites, Polyphosphazenes, Polymethyl Meth-acrylate (PMMA), Polytetrafluoroethylene (PTFE) and Polyhydroxyethylmethacrylate (PHEMA) may be described as alloplastic, synthetic, Non biodegradable polymers. PMMA used for dentures and as cement for many orthopedic prosthesis. PTFE used for augmentation and guided bone regeneration.[28]

10) Biomimetic Principles in Ceramics: It is used in dental applications and are being examined for bone tissue engineering application. Two common ceramics used in Dentistry and hip prosthesis are alumina and hydroxyapatite. Alumina has excellent corrosion resistance, high strength, high wear resistance. Hydroxyapatite is a calcium phosphate based ceramic and it is a major component of inorganic compartment of bone.[28]

11) Biomimetic Principles in Dental Implant: Ceramics such as the calcium phosphate hydroxyappatite and various types of aluminum oxides are proved to be

bio compatible and they are coated to implant which increases osteointegration.[28]

CONCLUSION

Replacement of diseased or lost tooth structure with Biocompatible restorative materials is currently the technique of today but each of these procedures has their own limitations and drawbacks. Regeneration of the lost tooth structure rather than replacement will ensure better prognosis and high success rate. Hence the future Dentistry would involve the use of Biomimetic materials which could successfully replace lost enamel, dentin, cementum and even the pulp tissue.

Just as harnessing steam in the 19th century fueled industrial growth, and controlling electrical energy heralded the modern world of the 20th century, deciphering and interpreting the genome of humans and all other living organisms will be seminal event of the 21st century. Armed with this knowledge, molecular biologists will be able to understand and adjust chromosomal function to create optimal cellular performance. As Dentistry relies with great gusto on the technology, it will be affected profoundly. In short "Future is coming, it will be amazing".

Future advances in this field will require materials and computer scientist, physicists, bioengineers, clinicians, biologist and industries working together towards a shared vision rather than pursuing their separate objectives.

REFERENCES

1. Kottoor J. Biomimetic Endodontics. Barriers and Strategies'. Health Sciences 2013; 2(1).

2. McMahon S.M, Evron E. Biomimetic principles applied to cosmetic dentistry 2011; 4(7).

3. Deepak et.al. Biomimetics in Dentistry – a review. Indian Journal of Research in Pharmacy and Biotechnology 2014:2321-5674.

4. Haldia A, Acharya J, Meena D. Review article stem cells: an emerging and regenerative future in dentistry. Journal of science and technology 2015;1(4):90-4.

5. Ikeda E, Morita R, Nakao K, Ishida K, Nakamura T, Takano-Yamamoto T et al. Fully functional bioengineered tooth replacement as an organ replacement therapy, Proc Natl Acad Sci U S A 2009; 106:13475-80.

6. Eidelman E. Dr. Odont. American Academy of Pediatric Dentistry Pediatric Dentistry 1999;21:2.

7. Tyas VMJ. Clinical evaluations of glass-ionomer cement restorations. Oral sci 2006;14:10-3.

8. Magne P, Composite Resins and Bonded Porcelain: The Post amalgam Era? CDA Journal 2006; 34(2).

9. Mount GJ, Ngo H. Minimal Intervention: Advanced lesions, Quintessence Int 2000; 3(9):621-9.

10. Ngo H, Donitz M. Biological properties of Glass-Ionomers. An atlas of glass-ionomer cements 2002: 43-55.

11. Malteru DM. Minimally invasive Biomimetic Endodontics: the future is here. General Dentistry 2013; 61(1):1-10.

12. Garcia-Godoy F, Murray PE. Status and potential commercial impact of stem cell-based treatments on Dental and Craniofacial regeneration, Stem Cells Dev 2006;15: 881-7.

13. Gronthos S, Brahim J, Li W, Fisher LW, Cherman N, Boyde A, et al. Stem cell properties of human dental pulp stem cells, J Dent Res 2002;81:531-5.

14. Miura M, Gronthos S, Zhao M, Lu B, Fisher LW, Robey PG, et al. SHED: stem cells from human exfoliated deciduous

teeth. Proc Natl Acad Sci USA 2003; 5:807-12.

15. Bakopoulou A, Leyhausen G, Volk J, Tsiftsoglou A, Garefis P, Koidis P, et al. Comparative analysis of in vitro osteo/odontogenic differentiation potential of human dental pulp stem cells (DPSCs) and stem cells from the apical papilla (SCAP). Arch Oral Biol 2011;56:709-21.

16. Zhang H, Dai S, Bi J, Liu K. Biomimetic three-dimensional micro-environment for controlling stem cell fate. Review. Interface Focus 2011;1:792–803.

17. Oshima M, Mizuno M, Imamura A, Ogawa M, Yasukawa M, Yamazaki H et al. Functional tooth regeneration using a bioengineered tooth unit as a mature organ replacement regenerative therapy. PLOS One 2011; 6:e21531.

18. Perdigao J. Dentin bonding-variables related to the clinical situation and the substrate treatment. Dent Mater 2010;26: e24–37.

19. Edwards PC, Mason JM. Head & Face Medicine 2006; 2:16

20. Kumar M, Haldia A, Acharya J, Meena D. Stem cells: an emerging and regenerative future in Dentistry -Review article .Journal of science and technology. 2015;1(4): 90-4.

21. Desgrandchamps F. Biomaterials in functional reconstruction. Curr Opin Urol 2000;10:201-6.

22. Busch S, Schwarz U, Kniep R. Chemical and structural investigations of biomimetically grown fluorapatite-gelatin composite aggregates. Adv Funct Mater 2003;13:189-98.

23. Guentsch A, Busch S, Seidler K, Kraft U, Nietzsche S, Preshaw P, et al. Biomimetic mineralization: effects on human enamel in vivo. Adv Eng Mater 2010:571-6.

24. Van Dijken JWV. A 6-year evaluation of a direct composite resin inlay/onlay system and glass ionomers cement-composite resin sandwich restorations. Acta Odontol Scand 1994; 52(6):368-76.

25. Gandolfi MPT, Siboni F, Modena E, De Stefano E, Prati C. Biomimetic remineralization of human dentin. Dent Mater 2011;27(11):1055-69.

26. Ning T, Xu X, Zhu L, Zhu X, Ch C, Liu L, et al. Biomimetic mineralization of dentin induced by agarose gel loaded with calcium phosphate. J Biomed Mater Res 2011.

27. Brunton PA, Davis RPW, Burke JL, Smith A, Aggeli A, Brookes SJ et al. Treatment of early caries lesions using biomimetic self-assembling peptides – a clinical safety trial. British Dental Journal 2013; 215.

28. Singh A, Tuli A, Jindal V. Biomimetics - A Review. Indian Journal of Dental Sciences.

How to cite this article: Srinivasan K, Chitra S. Emerging Trends in Oral Health Profession: The Biomimetic - A Review. Arch of Dent and Med Res 2015;1(3):40-47.