

Biomimetics in Pediatric Dentistry

Somen Roychowdhury¹, Debabrata Biswas¹, Gautam Naskar², Debarati Bhowmick³, Moumita Nayek³, Vineet Nair^{2*}

¹Department of Pedodontia, Dr. R. Ahmed Dental College and Hospital, Kolkata, West Bengal, India.

²Department of Prosthodontia, Dr. R. Ahmed Dental College and Hospital, Kolkata, West Bengal, India.

³Department of Periodontia, Dr. R. Ahmed Dental College and Hospital, Kolkata, West Bengal, India.

Abstract

Restoration of carious teeth by filling the cavity with amalgam needs to sacrifice the tooth structure to impart the property of retention of the filling. Moreover, the restoration-tooth interface does not have proper bondage, leading to microleakage and shortening the lifespan of the filling. Hence, to minimize the tooth structure loss and improve the interface property came the era of biomimetic materials like composites and glass ionomer cement. The arrest of an incipient carious lesion by mineralization of enamel with an optimum concentration of fluoride and the formation of nanocrystals imitates physiological mineralization. Similarly, the mineralization of dentin with amorphous calcium phosphate uses non-collagenous protein analogs for intra- and interfibrillar apatite crystal growth.

Keywords: Composite, Demineralization, Glass ionomer cement, Mineralization, Nanocrystals, Osteoconduction, Osteoinduction.

INTRODUCTION

Various laws of engineering, biology, and chemistry are used to produce materials, synthetic systems, or appliances that work in a way that imitates methods in living tissues. Reproduction of plants through seeds, as in Velcro, occurs by the placement of hook-through coats on animals. A bullet train in Japan imitates the beaks of birds. By definition, biomimetics involves the study of the formation, structure, and the function of biologically produced substances and materials (such as silk and conch shells) and biological mechanisms and processes (such as protein synthesis) for the purpose of synthesizing similar products by artificial mechanisms that mimic natural ones.^[1] The credit goes to Otto Schmitt who introduced the term “Biomimetics” in 1950.^[2,3]

Many bioactive materials are under research that will produce biomimetic “presence” in life to affect repair much better in quality than many dental materials nowadays. Bioactivity is defined in ISO 23317 as a property that elicits a specific biological response at the interface of the material, which results in the formation of a bond between tissue and material.^[1] Bioactivity imparts antibacterial, recalcifying, and osteoinductive materials. Biomimetic calcium phosphate linings for implants are undergoing experiments to accelerate osteoconductive characteristics and healing surrounding the vicinity of implants.

Biodentine, first used in 2011, contains calcium carbonate, tricalcium silicate, zirconium oxide, and a water-based liquid

containing calcium chloride. Biodentine forms mechanical adhesion with dentin. CPP-Amorphous calcium phosphate (ACP) is a mineralizing agent for subsurface carious lesions. CPP holds calcium and phosphate in solution and acts as a mineral store. Smart materials are defined as synthetic materials that interact with external stimuli, such as light, temperature, stress, moisture, pH, and the electric/magnetic field, in such a way as to alter their specific properties in a controlled fashion and return to the original state after the stimulus has been removed.^[1] Smart sutures, smart pressure bandages, hydrogel, and cercon smart ceramics are examples of smart materials.^[4]

BIOMIMETICS IN DENTISTRY

Principles of biomimetics in dentistry rely on non-invading processes and the preservation of normal tooth structure with its biophysical functions and positive appearance.^[1] This is contrary to the age-old amalgam restorations requiring Sir G. V. Black’s extension for prevention, line angles, and

Address for correspondence: Dr. Vineet Nair,

Department of Periodontia, Dr. R. Ahmed Dental College and Hospital,
Kolkata, West Bengal, India.

Email: drvineet_nair@yahoo.co.in

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point angles at the cost of tooth structure. The changeover to adhesive restorations with composite resin and glass ionomers have two advantages: (1) conservative cavity preparation and (2) fluoride release, and thus making the remaining tooth structure more mineralized and stronger. This philosophy of restorative dentistry has been termed as biomimetic process because of the use of “tooth-like” ingredients (composite resin and ceramics) that also adhere to tooth enamel and dentine.^[5] Materials used in biomimetic dentistry are more retentive and thus reduce tooth cutting, which in turn helps in saving the pulp’s vitality.^[1] The benefits of biomimetic dentistry are manifold: (a) conservative cavity design; (b) reduced danger to pulp vitality; (c) enhanced binding capacity; (d) reduced root canal treatment; (e) removed postoperative complications; (f) restored grossly affected teeth otherwise nonrestorable.^[1] One important aspect is the use of components to precisely substitute the form and function of the oral tissues. The real help to dentistry comes from nanotechnology in the restoration of teeth with nanocomposites. The superiority of nanocomposites due to the filler particle size of <100 nm is their strength and positive appearance as opposed to traditional microfilled and hybrid resin-based composites (RBC). In addition to the flexural strength and microhardness of posterior RBCs, the nanocomposites possess precise shade differences, polishability, and evenness.^[6]

BIOMIMETIC MATERIALS USED IN PEDIATRIC DENTISTRY

Glass ionomer cements (GIC) and resin-modified GIC (RMGIC)

In pediatric dentistry, GIC and RMGIC are used as aesthetic and adhesive restorative materials. These are used in primary molars^[7,8] with conservative tooth preparation and in public dental health in place of amalgam. GIC and RMGIC have thus established themselves as materials of choice in pediatric dentistry. This new approach to tooth restoration in dentistry is termed the “biomimetic era,” which is supported by evidence-based records in favor of composite resin and porcelain.

Biomimetic concepts used in composite resins and ceramics

In medicine, biomimetics means manufacturing substitutes for biological “composites” with improved structure and physiology. In dentistry, biomimetics is used primarily following the processes similar to those in the oral cavity, e.g., mineralization of unmineralized matrix. Biomimetics also means preparing a restoration that restores the tooth structure almost to its original strength. Preserving the composition, biophysics, and positive appearance of dental structures is the forerunner of biomimetics. The biological action of the dental arch is obtained by optimizing the biophysical, functional, and positive appearance aspects.^[5] Operative dentistry causes changes in the structural framework of natural teeth. The physiological and anatomical balances of the normal teeth are changed. Another aspect is the age changes in enamel and dentin. The deformity of teeth can

be compensated by replenishing enamel with a resilient material. The biophysical properties of composite resin and ceramics are mimicking that of dentin and enamel, respectively.

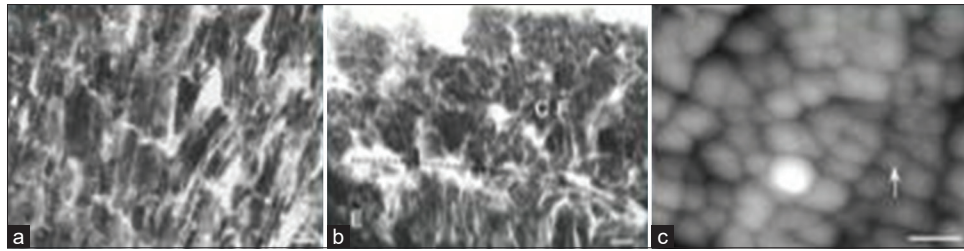
Biomimetic mineralization of enamel caries mimicking natural mineralization

Dental caries is a dynamic process of demineralization and remineralization^[9] and the idea of biomimetic mineralization mimicking natural mineralization is thought to be a substitute for restorative processes and a chance to reverse an incipient lesion. The enamel lesion can be treated by planning to rebuild fabricated hydroxyapatite nanorods using an overloaded calcium phosphate solution. Octacalcium phosphate (OCP) is broken down by 0.1–2 mg/l fluoride in mineralizing solution to apatite.^[10,11] Needle-like apatite crystals are formed at 2 mg/l of fluoride from thread-like OCP at 0.1–1 ppm F.^[12] Studies show that fluoride can be added to fluoridated hydroxyapatite in a controlled environment on decalcified enamel instead of calcium fluoride intermediate. With this method, without using a higher concentration, fluoridated hydroxyapatite can be mineralized for lesion or erosion prevention. It has been found that fluoride can hasten apatite crystal growth in parent OCP.^[10,13] Also, fluoride reduces OCP formation and initiates, needle-like apatite.^[12] From these results of different studies, a biomimetic process of enamel calcification using the action of fluoride on the calcium phosphate mineral phase can be beneficial. 20–50 nm needle-like nanocrystals on enamel could be produced using 1 mg/l fluoride. Nano crystals are similar with native enamel and in mechanical properties.

Coherent biomimetic repair of early carious lesion without cutting, in a very short time

Submicroscopic (50 µm) incipient carious lesions traditionally restored by amalgam or resin^[14–17] do not adhere to the original tooth structure due to chemical and structural differences and thus are not ideal.^[18,19] These early or incipient carious lesions can be restored with a slurry of altered hydroxyapatite in a very short time. Transmission electron microscopic (TEM) examination shows crystalline growth of 100–400 nm long and 20–80 nm broad growing end to end in the gap and aligned in the normal fashion of enamel structure. Thus, the slurry ideally repaired the early carious lesion (Figure 1a-c).

The atomic resolution TEM study of newly grown crystals shows a and c interaxis distances similar to those of apatite crystals and also unidirectional (0001 face) with tooth surface revealed by photoelectron spectroscopy scanning. Such an incipient lesion when repaired with acidulated phosphate fluoride, the TEM study shows calcium fluoride with a heterogeneous layer^[20,21] which is thinner and has a distinct discontinuity (Figure 1c). Hence, the altered hydroxyapatite slurry can repair an incipient carious lesion by producing nanometric, homogeneous crystal growth without sacrificing enamel or tooth structure (Figure 2).



AQ6 **Figure 1:** Restoration of the carious lesion by slurry of altered hydroxyapatite

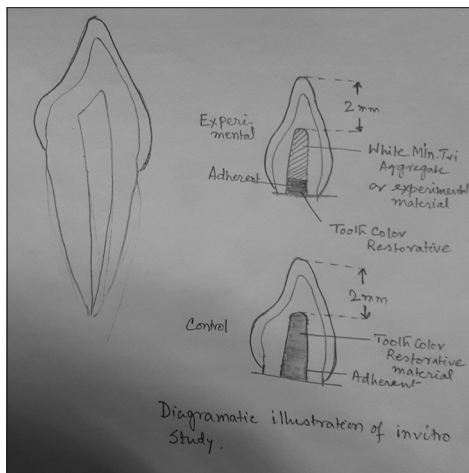


Figure 2: Diagrammatic illustration of *in vitro* study

Pulp capping, apexification, and apical sealing with biodentine show no color change

Mineral trioxide aggregate (MTA) is used in pulp capping, apexification, and apical sealing.^[22-24] In many clinical situations, white MTA (WMTA) placed coronally shows that teeth on application of WMTA sustain discoloration.^[25-28] Also, WMTA shows discoloration under polymerization light in anaerobic conditions.^[29] Biodentine, a calcium silicate-based material used in similar situations as MTA^[30-35] shows color stability. Biodentine liberates calcium hydroxide on hydration^[36,37] and forms hydroxyapatite in presence of tissue fluid.^[38-40] Biodentine has tricalcium silicate, calcium carbonate, zirconium oxide as a radiopacifier, and liquid containing calcium chloride and water.^[41] The calcium silicate-based materials having bismuth oxide (Bi_2O_3) blacken in light and anaerobic conditions, but biodentine, being devoid of bismuth, is color stable.^[42] Discoloration following WMTA restoration is evident in 1 week, increases with time, and is aggravated by blood.^[27,28] Bi_2O_3 in WMTA breaks into bismuth and oxygen, and reduced bismuth crystals impart a black color.^[43,44] This color change is also caused by contact with root canal irrigant and sodium hypochlorite (NaOCl).^[45]

Biodentine has zirconia as a radiopacifier instead of Bi_2O_3 and does not show discoloration.^[46] Marciano *et al.* reported from a study of biodentine in the tooth cavity that zirconium oxide and calcium tungstate used as radiopacifiers did not show color change.^[46] Also, biodentine's color stability is resistant to collagen.

Dentin remineralization with an ACP analogue

As the filling in a tooth with amalgam or resin done in the past undergoes discoloration and fracture, it requires replacement. Therefore, calcification of carious dentin is a major problem in pediatric and preventive dentistry. Biomimetic calcification of carious dentin with the parent material ACP imitates physiological mineralization. Other than collagenous proteins, mucoproteins play an important role in controlling mineralization.^[47] The non-collagenous proteins (NCP) have a craving for ionic calcium and collagen fibrils and influence mineralization. These are dentin matrix protein 1, DMP-2, DPP (phosphoryn), serine, and threonine remnants.^[48] Polyacrylic acid (PAA) and polyvinylphosphonic acid (PVPA) are NCP analogues in the biomimetic mineralization of dentin^[49] PAA, PVPA, or sodium tri metaphosphate (STMP) are used as ACP fixing analogues and templates, respectively, to imitate NCP and cause well-controlled intrafibrillar nanoapatite crystallization.^[50-54] PVPA or STMP phosphorylates dentin collagen, reacts with parent ACP, and precipitates apatite, which results in intrafibrillar and interfibrillar remineralization of dentin.

In this biomimetic remineralization of dentin, intrafibrillar mineralization occurs instead of interfibrillar mineralization of collagen.^[55] The calcium and phosphate ions independently assemble and form ACP following a reaction with NCP analogues. These parent ACP enter the intrafibrillar region of collagen and create apatite in the intrafibrillar region. This intrafibrillar remineralization spreads to the interfibrillar zone of collagen, and thus dentin remineralization takes place. In this type of remineralization, called the bottom-up process, parent ACP plays a critical role in the biomimetic remineralization of carious dentin.

CONCLUSION

Biomimetic materials have a wider use in pedodontics. Bioactive nanotechnology for nanorestoration can produce hydroxyapatites that cause remineralization of early caries or restoration interface. If repair and regeneration are compared, while repair is done by metal, ceramics, or resin, regeneration is the fruit of regenerative medicine. Biological materials and biomaterials are needed for the regeneration of dental structures. Whole-tooth regeneration may be an extension or broader field of research with these biomimetic materials. But dentistry may find some day that repair and

replacement of tooth parts will be replaced by regeneration of the whole tooth.

REFERENCES

- Shen C, Rawls HR, Esquivel-Upshaw JF. Phillips' Science of Dental Materials. Emerging Technologies. 13th ed. United States: Saunders; 2021. p. 517-31.
- Vincent JFV, Bogatyreva AV, Bogatyreva NR, Bowyer A, Pahl AK. Biomimetics: Its practice and theory. J R Soc Interface 2006;3:471-482.
- Torgal FP, Labrincha JA, Diamanti MV, Yu CP, H.K. Lee (eds.). Biotechnologies and Biomimetics for Civil Engineering. 2014;3:57-79.
- Owens BM. Bioactivity, biocompatibility and biomimetic properties for dental materials: Clarifying the confusion? Mod App Dent Oral Health Care 2018;2:136-8.
- Magne P, Belser U. Understanding the intact tooth and the biomimetic principle. In: Bonded Porcelain Restorations in the Anterior Dentition - A Biomimetic Approach. Chicago: Quintessence Publishing Co.; 2002. p. 23-55.
- Saunders SA. Current practicality of nanotechnology in dentistry. Part 1: Focus on nanocomposite restoratives and biomimetics. Clin Cosmet Investig Dent 2009;1:47-61.
- Garcia-Godoy F. Resin-based composites and compomers in primary molars. Dent Clin North Am 2000;44:541-70.
- Garcia-Godoy F, Donly KJ. Dentin-enamel adhesives in pediatric dentistry. Pediatr Dent 2002;24:462-4.
- Featherstone JD. Dental caries: A dynamic disease process. Aust Dent J 2008;53:286-91.
- Moriwaki Y, Doi Y, Kani T, Aoba T, Takahashi J, Okazaki M. Synthesis of enamel-like apatite at physiological temperature and pH using ion-selective membranes. In: Suga S, editor. Mechanisms of Tooth Enamel Formation. Tokyo: Quintessence Publishing; 1983. p. 239-56.
- Iijima M, Moradian-Oldak J. Control of apatite crystal growth in a fluoride containing amelogenin-rich matrix. Biomaterials 2005;26:1595-603.
- Iijima M. Formation of octacalcium phosphate *in vitro*. Octacalcium phosphate. In: Chow LC, Eanes ED, editors. Monogr Oral Sci. Vol. 18. Basel: Karger; 2001. p. 17-49.
- Iijima M, Tohda H, Suzuki H, Yanagisawa T, Moriwaki Y. Effect of F- on apatite-octacalcium phosphate intergrowth and crystal morphology in a model system of tooth enamel formation. Calcif Tissue Int 1992;50:357-61.
- Raskin A, Michotte-Theall B, Vreven J, Wilson NH. Clinical evaluation of a posterior composite 10-year report. J Dent 1999;27:13-9.
- Wilson NH, Mjor IA. The teaching of Class I and Class II direct composite restorations in European dental schools. J Dent 2000;28:15-21.
- Carvalho RM, Pereira JC, Yoshiyama M, Pashley DH. A review of polymerization contraction: The influence of stress development versus stress relief. Oper Dent 1996;21:17-24.
- Hilton TJ. Can modern restorative procedures and materials reliably seal cavities? *In vitro* investigations. Part 1. Am J Dent 2002;15:198-210.
- Frank RM, Brendel A. Ultrastructure of the approximal dental plaque and the underlying normal and carious enamel. Archs Oral Biol 1966;11:883-912.
- Johnson NW. Transmission electron microscopy of early carious enamel. Caries Res 1967;1:356-69.
- Gerould CJ. Electron microscope study of the mechanism of fluorine deposition in teeth. Dent Res 1945;24:223-33.
- Duschner H, Gotz H, Ogaard B. Fluoride-induced precipitates on enamel surface and subsurface areas visualised by electron microscopy and confocal laser scanning microscopy. Eur J Oral Sci 1997;105:466-72.
- Bidar M, Moradi S, Jafarzadeh H, Bidad S. Comparative SEM study of the marginal adaptation of white and grey MTA and Portland cement. Aust Endod J 2007;33:2-6.
- Parirokh M, Torabinejad M. Mineral trioxide aggregate: A comprehensive literature review--part III: Clinical applications, drawbacks, and mechanism of action. J Endod 2010;36:400-13.
- Gomes-Filho JE, Rodrigues G, Watanabe S, Bernabé PF, Lodi CS, Gomes AC, *et al.* Evaluation of the tissue reaction to fast endodontic cement (CER) and Angelus MTA. J Endod 2009;35:1377-80.
- Belobrov I, Parashos P. Treatment of tooth discoloration after the use of white mineral trioxide aggregate. J Endod 2011;37:1017-20.
- Akbari M, Rouhani A, Samiee S, Jafarzadeh H. Effect of dentin bonding agent on the prevention of tooth discoloration produced by mineral trioxide aggregate. Int J Dent 2012;2012:563203.
- Lenherr P, Allgayer N, Weiger R, Filippi A, Attin T, Krastl G. Tooth discoloration induced by endodontic materials: A laboratory study. Int Endod J 2012;45:942-9.
- Felman D, Parashos P. Coronal tooth discoloration and white mineral trioxide aggregate. J Endod 2013;39:484-7.
- Valles M, Mercade M, Duran-Sindreu F, Bourdelande JL, Roig M. Color stability of white mineral trioxide aggregate. Clin Oral Investig 2013;17:1155-9.
- Zanini M, Sautier JM, Berdal A, Simon S. Biodentine induces immortalized murine pulp cell differentiation into odontoblast-like cells and stimulates biomineralization. J Endod 2012;38:1220-6.
- Tran XV, Gorin C, Willig C, Baroukh B, Pellat B, Decup F, *et al.* Effect of a calcium-silicate-based restorative cement on pulp repair. J Dent Res 2012;91:1166-71.
- Nowicka A, Lipski M, Parafiniuk M, Sporniak-Tutak K, Lichota D, Kosierkiewicz A, *et al.* Response of human dental pulp capped with biodentine and mineral trioxide aggregate. J Endod 2013;39:743-7.
- Kim JR, Nosrat A, Fouad AF. Interfacial characteristics of Biodentine and MTA with dentine in simulated body fluid. J Dent 2015;43:241-7.
- Naik M, de Ataide Ide N, Fernandes M, Lambor R. Treatment of combined endodontic: Periodontic lesion by sealing of palato-radicular groove using biodentine. J Conserv Dent 2014;17:594-7.
- Rajasekharan S, Martens LC, Cauwels RG, Verbeeck RM. Biodentine material characteristics and clinical applications: A review of the literature. Eur Arch Paediatr Dent 2014;15:147-58.
- Camilleri J. The chemical composition of mineral trioxide aggregate. J Conserv Dent 2008;11:141-3.
- Camilleri J. Characterization and hydration kinetics of tricalcium silicate cement for use as a dental biomaterial. Dent Mater 2011;27:836-44.
- Tay FR, Pashley DH, Rueggeberg FA, Loushine RJ, Weller RN. Calcium phosphate phase transformation produced by the interaction of the Portland cement component of white mineral trioxide aggregate with a phosphate-containing fluid. J Endod 2007;33:1347-51.
- Gandolfi MG, Ciapetti G, Perut F, Taddei P, Modena E, Rossi PL, *et al.* Biomimetic calcium-silicate cements aged in simulated body solutions. Osteoblast response and analyses of apatite coating. J Appl Biomater Biomech 2009;7:160-70.
- Han L, Okiji T, Okawa S. Morphological and chemical analysis of different precipitates on mineral trioxide aggregate immersed in different fluids. Dent Mater J 2010;29:512-7.
- Laurent P, Camps J, De Meo M, Déjou J, About I. Induction of specific cell responses to a Ca(3)SiO(5)-based posterior restorative material. Dent Mater 2008;24:1486-94.
- Valles M, Mercade M, Duran-Sindreu F, Bourdelande JL, Roig M. Influence of light and oxygen on the color stability of five calcium silicate-based materials. J Endod 2013;39:525-8.
- Sanz O, Haro-Poniatowski E, Gonzalo J, Navarro JF. Influence of the melting conditions of heavy metal oxide glasses containing bismuth oxide on their optical absorption. J Non Cryst Solids 2006;352:761-8.
- Zhang Y, Yang Y, Zheng J, Hua W, Chen G. Effects of oxidizing additives on optical properties of Bi2O3-B2O3-SiO2 glasses. J Am Ceram Soc 2008;91:3410-2.
- Camilleri J. Color stability of white mineral trioxide aggregate in contact with hypochlorite solution. J Endod 2014;40:436-40.
- Marciano MA, Costa RM, Camilleri J, Mondelli RF, Guimarães BM, Duarte MA. Assessment of color stability of white mineral trioxide aggregate angelus and bismuth oxide in contact with tooth structure. J Endod 2014;40:1235-40.
- George A, Veis A. Phosphorylated proteins and control over apatite nucleation, crystal growth, and inhibition. Chem Rev 2008;108:4670-93.
- He G, George A. Dentin matrix protein 1 immobilized on Type I

- collagen fibrils facilitates apatite deposition *in vitro*. J Biol Chem 2004;279:11649-56.
49. Tay FR, Pashley DH. Guided tissue remineralisation of partially demineralised human dentine. Biomaterials 2008;29:1127-37.
50. Liu Y, Li N, Qi YP, Niu LN, Elshafiy S, Mao J, *et al.* The use of sodium trimetaphosphate as a biomimetic analog of matrix phosphoproteins for remineralization of artificial caries-like dentin. Dent Mater 2011;27: 465-77.
51. Qi YP, Li N, Niu LN, Primus CM, Ling JQ, Pashley DH, *et al.* Remineralization of artificial dentinal caries lesions by biomimetically modified mineral trioxide aggregate. Acta Biomater 2012;8:836-42.
52. Gu L, Kim YK, Liu Y, Ryou H, Wimmer CE, Dai L, *et al.* Biomimetic analogs for collagen biomineralization. J Dent Res 2011;90: 82-7.
53. Sun J, Chen CQ, Pan HH, Chen Y, Mao CY, Wang W, *et al.* Biomimetic promotion of dentin remineralization using l-glutamic acid: Inspiration from biomineralization proteins. J Mater Chem B 2014;2:4544-53.
54. Gajjaraman S, Narayanan K, Hao J, Qin C, George A. Matrix macromolecules in hard tissues control the nucleation and hierarchical assembly of hydroxyapatite. J Biol Chem 2007;282:1193-204.
55. Colfen H, Antonietti M. Mesocrystals: Inorganic superstructures made by highly parallel crystallization and controlled alignment. Angew Chem Int Ed Engl 2005;44:5576-91.