Historical narrative review of Biomimetic concept and clinical rationale in restorative dentistry (1990-2022)

Abdulaziz Alrebdi,
Department of Conservative Dental Sciences, College of Dentistry,
Qassim University, Qassim, Saudi Arabia

Corresponding Author: Abdulaziz Alrebdi

AB.ALREBDI@qu.edu.sa

Abstract:

This narrative review covers biomimetic dentistry from 1990 to 2022. Biomimetics, also called bionics or biomimicry, mimics biological processes and structures to create new products, processes, and policies. Biomimetic dentistry restores dental tissues while preserving function and appearance. The review covers biomimetic principles, caries removal end points, and restorative treatment. The study emphasizes preserving natural tooth structures and using functional stress-resistant materials. Biomimetic restorative materials mimic natural tooth biomechanics and aesthetics. The review emphasizes the importance of maximum bond strength, long-term marginal seal, pulp vitality, and reduced residual stress in biomimetic restorative techniques. Biomimetic caries removal endpoints preserve tooth structure, eliminate infection, and maintain pulp vitality. Caries removal endpoints are determined using dyes and laser fluorescence. Establish a peripheral seal zone and avoid pulpal exposure while creating a highly bonded restoration. Biomimetic restorative methods use materials that look and function like natural tooth structure. Restorative dentistry uses biomimetics thanks to dental composite resins, clinical adhesives, and ceramics. Stress-reduction and bond-strength-boosting protocols are used. Glass ionomer cement (GIC), which mimics tooth colour, thermal expansion, and fluoride release, is also discussed in the review. GICs bond to enamel and dentin, kill bacteria, and promote sclerotic dentin, making them biomimetic. Biomimetic restorative dentistry restores dental tissues while maintaining function and aesthetics. Biomimetic principles, techniques, and materials improve long-term restoration success and patient satisfaction.

Keywords: Biomimetic material, Biomimetism, Biomimicry, Biomimicking, innovation in dentistry

DOI: 10.48047/ecb/2023.12.8.533

Introduction:

Otto Schmitt, a biophysicist and biomedical engineer, is credited with being the first person to use the term "biomimetic" in the 1950s [1].The term “bio” means life and “mimesis” in Greek means imitation or mimicking biochemical process with inspiration from nature. It is a simulation of the process of consulting life's genius in the form of nature in order to develop new products, processes, and policies for the purpose of developing new ways of life that are well adapted to earth. The discipline of biomimetics is also referred to as bionics, bioinspiration, biogenesis, biomimicry, biomimicking, and biomimetism. All of these terms refer to the same subject matter.

Definition:

Biomimetics can be defined as the study of the structure, formation, and function of biologically produced materials and also biological mechanisms and processes especially for the purpose ofsynthesizing similar products by artificial mechanisms which mimic natural ones [2]. A material thus formed by biomimetic technique based on the natural process is called a biomimetic material [3].

BIOMIMETIC PRINCIPLES IN RESTORATIVE DENTISTRY:

The study of biological structures and their functions, along with physics, mathematics, chemistry, and engineering, are all components of the emerging inter-disciplinary field of biomimetics. By mimicking the structure and operation of biological systems, this field seeks to develop the fundamental ideas required for the production of innovative synthetic materials and organs. A lot of focus has been placed on the use of biomimetic techniques in a number of fields, such as dentistry.Traditional dental restorative techniques involve removing extra tooth structures and replacing unhealthy tooth structures with rigid materials. These techniques and materials have significantly reduced the longevity of restorations and made tooth structures more brittle. Therefore, the main objective of biomimetic dentistry is to replace any lost dental tissues with substances that can withstand all functional stresses in attempt to re-establish full function while maintaining aesthetic outcomes. This is accomplished while adhering to the principles of biomimicry. The production of restorative materials with the capability of restoring the biomechanics of the natural tooth is the secondary objective. The utility of biomimetics has received considerable attention at the molecular level, particularly in relation to the promotion of wound healing as well as the regeneration of soft and hard tissues.[4]. Several different biomimetic restorative materials are capable of achieving the desired level of biomimetic preservation of the biomechanical, functional, and aesthetic integrity of the teeth at the macro structural level [5]. During the process of developing dental restorative materials, it is best for materials scientists to use tooth structure as a reference when doing so. In addition, a great deal of momentum has been added to the manufacturing of biomimetic materials through the use of nanotechnology as a result of multiple innovations of materials at the nanoscale[2].

Emerging biomimetic techniques have been applied in dentistry for a number of purposes, including the remineralization of teeth with the aid of bioinspired analogs, the creation of bioactive and biomimetic biomaterials, and tissue engineering for the purpose of regeneration. The purpose of this article is to conduct a comprehensive review of the many different biomimetic approaches that are used to restore dental tissues that have been lost or damaged through the application of tissue engineering and biomaterials. In addition, the structure of the tooth as well as the various biomimetic properties possessed by dental restorative materials are talked about.

Biomimetics in caries removal end points:

Adherence is the ideal complement to this strategy, which prioritizes the preservation of a greater portion of the natural tooth structure. A tooth that has been restored with adhesive is, in many ways, functionally equivalent to a natural tooth that has not been altered and has not been restored. Consequently, the biomimetically restored tooth does away with cracks in restoration or in dentin that occur because of lt of stress concentrations. This results in a reduction or elimination of postoperative pain and sensitivity, as well as the preservation of vitality, as bacteria are unable to invade and kill the pulp of the tooth [6,7].When a tooth is hydrated by its vital pulp, not only does it have greater natural flexibility, but its resistance to breaking is also increased [6,8].

Caries that are small and moderate are confined superficial enamel or dentin can typically be completely removed using the time-honoured visual and tactile technique. This method has a high rate of success. Dental treatments such as air abrasion, sonic diamond tips, and bonded composite resin and glass ionomer cement are examples of minimally invasive procedures that have lowered a need for traditional preparations, which involve removing important anatomical structures. These procedures are used to treat smaller lesions.[9-11].

In order to determine the ideal end point for the removal of caries from vital teeth with lesions of large depth, more complex techniques are required. When dealing with larger lesions, using traditional visual and tactile techniques is a less reliable for determining optimal caries removal end points that reliably preserve tooth structure and eliminate infection without exposing the pulp. This is because these techniques rely on the patient's sense of sight and touch. These ideal caries removal end points would maintain the vitality of the pulp without compromising the adhesive reconstruction's strength or long-term viability.

The foundation for today's biomimetic protocols was laid during the "silent revolution" of adhesive dentistry, which emerged in the 1980s and 1990s[12]. This was taken a step further by Japanese researchers, who distinguished between two distinct layers of carious dentin, each of which exhibited a unique set of dentin adhesion characteristics. These researchers were able to bond to dentin in a predictable manner by utilizing a cutting-edge technology known as a caries detecting dye. This innovation enabled a perfect caries removal end-point to be imaged in the critically important "peripheral seal zone"[8]. A bond to dentin could be formed using recently developed polymerizable monomers that were both hydrophilic and hydrophobic, provided that the dentin surface in question was free of denatured collagen. Caries detecting dye is combined with anatomic and histologic knowledge in this methodical approach in order to reach appropriate caries removal end point which is required for adhesive restoration. In order to better guide the clinician through the process of deep caries diagnosis and removal, laser fluorescence technologies may also be utilized. Using just the tactile and visual methods alone has a number of drawbacks, which can be avoided by employing this combination of multiple techniques that overlap one another [13].

The overarching goals of this methodical approach to determining the end point of caries removal are as follows: (a) the preservation of pulp vitality after restoration with adhesive methods; (b) the eradication of oral infection and (c) the preservation of intact tooth structure for long-term biomimetic function. These goals are listed in order from most important to least important. The establishment of a peripheral seal zone and the complete and utter avoidance of pulpal exposure are the specific goals of caries removal end point determination. These goals, along with the generation of a highly bonded restoration with a positive long-term prognosis, round out the list. It is possible to generate a bond strength of approximately 45–55 MPa by first generating a peripheral seal zone that is between 1 and 3 millimeters wide and consists of normal superficial dentin, the dentino-enamel junction, and enamel [14,15].A complete lack of caries-detecting dye staining will indicate that the peripheral seal zone has been established [16]. This caries free zone can also be confirmed by a DIAGNOdent (KaVo) reading of approximately [12].In addition, a bondability of approximately 30 MPa will be achieved in the deeper areas of the preparation by retaining the slightly infected or affected inner carious dentin that is located within the peripheral seal zone. [17]. This will be proven true when the caries-detecting dye leaves a stain that is light pink in color. Readings of approximately 20–24 for intermediate dentin and approximately 36 for deep dentin on the DIAGNOdent can also assist in determining the end point of caries removal. [18].

Case 1:

Fig1: Caries-free peripheral zone of 2mm to 3mm & Cavity preparation & pulp capping by CaoH

Fig 2: Chemical diagnosis using caries detection dyes

Fig 3: Fender wedge to elevate proximal margin

Fig 4: Immediate Dentin Sealing (IDS)

Fig 5a,b: Coating the immediate dentin sealing with a flowable resin(RC)&Deep margin elevation (DME) = "bio-base"

Fig 6: Onlay preparation

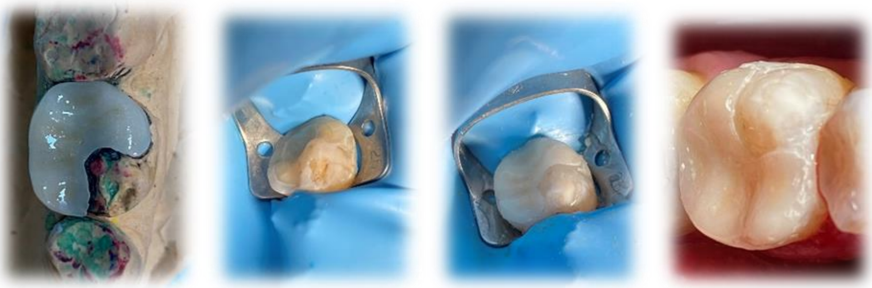

Fig 7a,b,c,d: Cusp Capping:Try in – Isolation – Cementation of indirect onlay

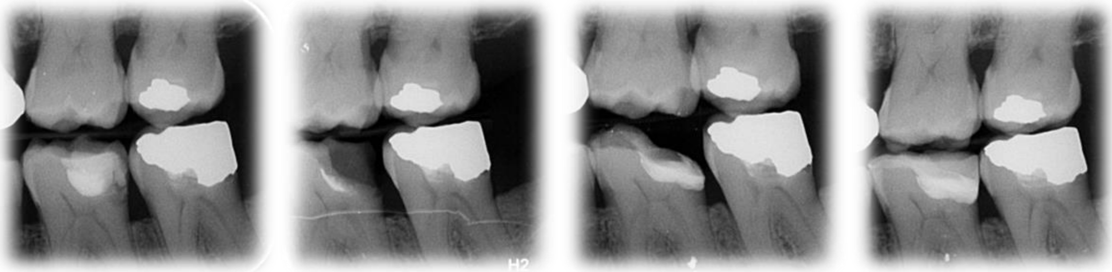

Fig 8,a/ Recurrent caries and Gap.

Fig 8 ,b/ Composite and caries removal +pulp capping

Fig 8, c/ Bio-base

Fig 8, d/Post onlay cementation

Case 2:

Fig 9 Preoperative photo

Fig 10: Caries-free peripheral zone of 2mm to 3mm &DME using wedging technique upper 6

Fig 11: Bio-baseand Cavity optimization for upper 6 and 4

Fig 12: Cast ready for scanning

Fig 13: Rubber dam isolation using active wingless clamps for more gingival retraction

Fig 14: Lithium disilicate indirect restoration

Fig 15: Air abrasion using aluminium oxide (50 m)for refreshing the surface to enhance bonding protocol

Fig 16: Surface after cleaning ready to the bonding protocol

Fig 17: After finishing and polishing

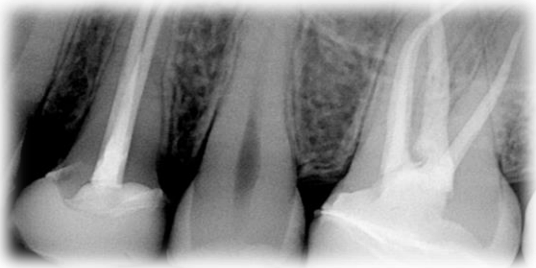

Fig 18: Radiograph

Biomimetics in restorative treatment:

The physiological performance of teeth that are whole and unaltered is the result of close and harmonious relationships between the mechanical, biological, functional, and aesthetic parameters. Therefore, a biomimetic approach to restorative dentistry would mean using restorative materials that are equal to natural tooth. This would apply to both the aesthetics and the functionality of the materials. In restorative dentistry, the purpose of biomimetics is to return all of the prepared dental tissues to full function. This is accomplished by creating a hard surface to allow stress transformation, thereby transforming the entire crown into the final functional biologic and esthetic unit [19].

Back in the 19th century, the teeth were restored with amalgam. But with time the entire paradigm shifted towards aesthetics [20]. Unfortunately, there is no biomaterial that can be used in dentistry that has the properties similar to teeth (i.e., enamel, dentin, and cementum). In contrast, the biomimetic approach to restorative dentistry seeks to find materials that has functional and aesthetic properties that are more similar to those of tooth structure. The application of biomimetics in restorative dentistry was aided and made possible by the development of dental composite resins, clinical adhesives, and dental ceramics [12,21].At this time, the restorations that utilize tooth-colored restorative materials are on par with those that utilize conventional restorative materials. This is due to the fact that minimal cavity preparation and proper bonding can reduce the trauma to the tooth, which in turn preserves the tooth's vitality and functionality[22]. If you choose composites and their modifications over amalgam, you can prevent the fracture of unsupported cusps in primary as well as permanent teeth. This applies to both types of teeth.

The four fundamental paradigms that form the basis of biomimetic restorative dentistry are as follows: (i) Maximum bond strength: Because of the strong bond, the biomimetically restored teeth are able to function and withstand stress in the same way that natural teeth do. (ii) Long-term marginal seal: A strong and secure bond enables the establishment and maintenance of a long-term marginal seal during functional stresses, thereby preventing further microbial invasion. This can be accomplished by preventing further microbial invasion [23,24], (iii) Increased pulp vitality: a biomimetic restoration with a highly bonded seal that is three times fracture resistant of restored teeth [25] and (iv) Decreased residual stress: Decreased residual stress is the end objective of any biomimetic restorative technique. This goal is to reduce stress while preserving the maximum possible bond strength [26].

The protocols that have been advocated to follow these paradigms can be classified in to (i) stress reducing protocols and (ii) bond maximising protocols. Stress reducing protocols include; 1-Usage of indirect restorations (to reduce the development of compressive stress), 2- Replacing the lost dentine with horizontal layers of composite that are 1mm or less of similar elastic modulus so as to help absorb and dissipate the stress evenly, 3- Use of fibres on the pulpal floor and axial wall to cause hindrance to crack propagation, 4- Capping of the cusp thinner than 2mm, 5- Converting the tensile forces in to vertical compressive forces (compression dome concept) [24,27,28].According to the compression dome concept, a natural tooth is intended to be more resilient to the effects of compressive stress as opposed to tensile stress. Vertical stress is produced by forces acting on the top of the dome, whereas tensile stress is produced by forces acting away from top of the dome. A tooth is comparable to a cathedral's dome. According to this theory, lateral stresses are produced when tooth margins are placed much more occlusally, as they would be in the case of onlays, overlays, and table top preparations, as opposed to forces produced by margins placed much more cervically, as they would be in a conventional crown preparation. These forces are more destructive in nature. This is because the conventional crown preparation places the tooth margins closer to the gum line. Tensile stresses are changed into more vertical tangents in margins that are placed more occlusally. These tangents are easier for the tooth to tolerate [29].

However, the other protocols is the bond maximization procedures included ;1-Establishing a caries-free peripheral zone of 2mm to 3mm . This is done without exposing the pulp, and it is followed by 2-Air abrading the underpinning composite surfaces for bonding/cementation, which also will increase bond strength both to normal and carious dentin.[30], 3-Deactivating matrix metalloproteinases by using 2% chlorhexidine for 30 seconds or a dentin bonding system with the MDPB monomer [8] (by doing so, it prevents between 25 and 30 percent of the bond strength from deteriorating) [31], 4-Using of a good standard bonding agent [32],
5-Immediate dentin sealing (increases the microtensile bond strength), 6-Coating the immediate dentin sealing with a flowable resin that stops the air inhibition and transduction

to create a secure bond, 7-Deep margin elevation whenever required (to achieve a biomimetic bond strength in microtensile testing that is greater than 30 MPaImmediately following immediate dentin sealing, resin coating, and composite "dentin replacement," a deep margin elevation known as "bio-base" takes place.

When all of the protocols are combined, along with the appropriate amount of care and caution, it is possible to achieve a restoration that will last for an anticipated amount of time.

Biomimetic restorative materials:

In restorative dentistry, the application of biomimetic principles can lead to the development of novel approaches to the conservation and preservation of teeth. It is crucial to consider elements like hues, shades, intra-coronal anatomy, mechanics, and the placement of teeth in the arch when restoring the damaged portion of the teeth to ensure that the principles of biomimicry are upheld. Dental ceramics, glass–ionomer cements (GICs), and resin dental composites (RDCs) are the materials that are most frequently used to restore such features. The material that is used is determined by the level of damage as well as the aesthetic requirement.

Glass Ionomer Cement:

GIC is a restorative cement that closely resembles tooth color. GICs are regarded as biomimetic materials because they adhere firmly to enamel and dentin, release fluoride over an extended period of time, and have a coefficient of thermal expansion that is the same as that of tooth structure [33].GICs have the potential to promote sclerotic dentin and are bactericidal due to the fluorides they release. Additionally, these cements meet the requirements of the biomimetic concept because they have qualities similar to dentin [34]. GICs are used as restorative materials in class I or II deep cavities in pedodontics. Additionally, class V cavities can have their damage repaired using GICs. Because of their low tensile strength, GICs are generally not recommended for use in the load-bearing posterior dentition. In the future, biodentine, a newly developed material, might be used instead of GIC as a liner in deep fillings. However, there is still a need for additional research in this area. The use of GIC as the Additional stresses could be applied to the teeth as a result, which could damage the teeth or cause the restoration to fail.material in minimally invasive dentistry is becoming increasingly common. Dentin and enamel both have much higher EM values than the elastic modulus of GICs, which is significantly lower. As a result, additional stresses may be transferred to the teeth, which may result in either damage to the tooth itself or the failure of the restoration [34,35].

The performance of the glass ionomer material has been improved through the application of a number of different modifications to both the powder and the liquid forms of the material. In order to produce GIC-HA hybrids, nanoparticles of hydroxyapatite (HA) have been added to GIC. These hybrids have showed enhanced release of fluoride ions as well as better mechanical and antimicrobial properties [35]. Furthermore, Garoushi et al. found that adding 10 weight percent of hollow discontinuous glass fiber to GICs led to a significant improvement in fracture toughness from 280 to 220% and flexural range from 176 to 140% [36].

Resin dental composites:

RDC is a restorative material that is activated by light and filled with nanoparticles. RDC is an important subgroup of hybrid biomaterials, which are characterized by having ainorganic fillers and resin matrix as their constituent parts. In these composites, amorphous calcium phosphate is used as the filler phase. When the pH falls below 5.5, the calcium, fluoride, and hydroxyl ions that are contained in the filler are released. These ions are deposited as crystals of apatite, which is comparable to the hydroxyapatite that is found in teeth and bone [37]. Since the 1960s, the field of dentistry has made extensive use of RDC due to the material's superior esthetic qualities, high biocompatibility, and ease of application [38]. This is done in order to restore teeth that have been damaged by disease or have defects. The majority of hybrid RDCs have the potential to imitate enamel and dentin in some way. In addition, there is evidence in the published scientific literature to suggest that certain RDCs have elastic modulus values that are comparable to dentin. It has been hypothesized that RDCs could be used to repair teeth that have suffered only moderate damage [19]. Minimal preparation of the teeth is required for RDC restorations, which, in turn, can reduce the likelihood of tooth fracture and pulpal exposure. In addition, RDCs, when placed in tooth defects with a low configuration factor, have the potential to strengthen the remaining tooth structure [28]. However, the surface hardness of RDCs is significantly lower in comparison to the surface hardness of tooth enamel, and as a result, they are more prone to surface wear and failure. It is also important to point out that in accordance with Griffith's Law, the presence of porosities on the surface of RDC restorations is likely to act as flaws. This is something that should be mentioned. These surface porosities can be thought of as nuclei, and they can contribute to the spread of cracks, which can lead to the failure of restorations [39].

Ceramics:

Ceramics can mimic a tooth's natural appearance when used in dentistry. Two ceramic materials that are frequently used in dentistry are alumina and hydroxyapatite. Along with having a high strength and resistance to wear, alumina also exhibits exceptional corrosion resistance. The ceramic substance hydroxyapatite is composed of calcium phosphate .It is the primary component of bone as well as teeth. The study of bioceramics is a relatively new development in this field. These materials are extremely biocompatible and are able to maintain their chemical stability in oral environments. In the year 2000, Holland and colleagues [40] were successful in developing apatiteleucite glass ceramics. These ceramics are composed of apatite building blocks that resemble needles and are similar to those found in living dental tissues. The aesthetic and mechanical qualities of the material were both enhanced as a result of the needle-like apatite crystals. Dental ceramics made using biomimicry should be able to adhere to the restored dental material without gaps and encourage the regeneration of the tissues around it. In order to achieve certain physical properties, hybrid ceramics combines the benefits of ceramics and composites (such as Young's modulus and hardness) comparable to those of enamel and dentin [41]. Dental ceramics are among the most modern indirect restorative materials, and they have properties that are comparable with enamel. These properties include elastic modulus, hardness, and thermal expansion. Because of this, ceramic veneers are the material of choice in modern restorative dentistry for repairing the anterior dentition when it has been damaged. This is because the stresses are more likely to be distributed uniformly across the tooth-restoration interface.

Inlays and onlays:

There is ongoing discussion regarding the best techniques to use when placing bonded inlays and onlays, and clinical concepts are only loosely standardized. The variety of options first pertain to the indication (direct or indirect), then to the fabrication technique (chairside or in-lab, using conventional or CAD/CAM processing), to the selection of material (composite resin or different types of ceramics), and finally to the intricate clinical guidelines with regard to gingival recession, temporization, and cementation. The concepts of biomimetics and bioemulation are also frequently associated with restorations of this kind. Due to our continued reliance on monolithic restorations for the majority of bonded posterior indirect restorations, the empirically sound concept of following the natural model has only been partially realized (using either composite or ceramics) [42].

Clinical protocol:

The following are some of the fundamental ideas that underpin the suggested approach to treatment: (A) the placement of an adhesive base/liner (also known as Dual Bonding and Cavity Design Optimization), and, if necessary. Dual bonding was initially presented in 1997 by Paul and Scharer for crown preparations [42], and it was later renamed as immediate dentin sealing by Magne and colleagues [43]. [42] Paul and Scharer were the pioneers of dual bonding. In order to circumvent the needless removal of tissue during the process of adapting inner-cavity design to an indirect technique [44], the concept of CDO was developed in tandem with dual bonding and immediate dentin sealing. To fill in all undercuts and give the cavity an ideal geometry in full compliance with dual bond formation dentin sealing concept, a composite resin liner is applied; (B) a simultaneous relocation of deep cervical margins is performed (cervical margin relocation [CMR]), followed by (C) the taking of an impression in order to ensure conservative steps. In the case of deep proximal preparations, a first layer of flowable composite is applied to reposition the margin after the correct positioning of a matrix in the cervical region. This is done after the matrix has been positioned correctly. If more material is required, it is recommended to use a combination of restorative and flowable composites. The use of flowable composites is only recommended for thicknesses of up to one and a half millimeters. For this procedure, it is best to use either a highly filled flowable composite or a bulk fill flowable base [45]; (D) the utilization of a highly filled, light-curing restorative material for the cementation (controlled adhesive cementation [CAC]), in conjunction with restoration insertion facilitation, the application of sonic/ultrasonic energy, and/or material heating. The CAC ensures that the most efficient amount of work time and control is used. CAC, when used in conjunction with the CMR technique, makes it possible to see the margins of the tooth, which makes it easier to remove excess cement in an accurate and uncomplicated manner. The practitioner will be able to eliminate the most common challenges that are encountered when preparing tooth-colored inlays and onlays by following the clinical protocol that has been suggested. These challenges include isolating the affected tooth, taking an impression, and cementing the restoration.

Here is pic of cementation with rubber dam

Restorative material for inlays and onlays:

Ceramics, whether pressed or fired, have historically been favored as the restorative material of choice for inlays and onlays because it was believed that they were more robust and dependable than their composite equivalent. Despite this, the cited research never definitively proves that ceramics are superior to other restorative materials, which is especially surprising when one considers the different testing environments that each type of material was subjected to [46,47]. In point of fact, the patient selection and clinical environment were clearly more favorable to ceramic restorations. Indirect ceramic restorations were not placed in social clinics, nor were they placed in patients with severe bruxism. On the other hand, such restrictions did not normally apply (or did not apply as strictly) to composite studies. Despite this, composite resins have found widespread use in the fabrication of inlays and onlays due to their superior esthetics, easier repairability, and more straightforward manufacturing process. Composite resins also have a simpler manufacturing process, which results in a lower cost. The CAD/CAM restoration method, which can produce restorations in ceramic or composite resin blocks, is a more modern alternative that is gaining popularity. Because there is still a lack of medium- to long-term clinical evidence, CAD/CAM composite resins or pressed CAD/CAM lithium disilicate glass ceramics are often recommended in cases of severe bruxism or tooth fragilization. Despite the fact that this choice relies primarily on limited in vitro research, it is common practice to make this recommendation.

Conclusion

In conclusion, there have been significant developments in the field of biomimetics in restorative dentistry between 1990 and 2022. Based on mimicking natural processes and structures, biomimetics seeks to create restorative materials and methods that closely resemble the function and appearance of healthy teeth. The use of biomimetic techniques in dentistry has produced materials and procedures that prioritize maintaining tooth structure, encourage long-term restoration success, and preserve the pulp's health. To produce results that are both functional and aesthetically pleasing, a variety of biomimetic restorative materials have been used, including dental ceramics, glass-ionomer cements, and resin dental composites. Clinicians can restore dental tissues while ensuring long-term biomechanical integrity by adhering to biomimetic principles and using stress-reducing and bond-maximizing protocols. Overall, biomimetics in restorative dentistry offers promising methods for maintaining and restoring teeth, giving patients long-lasting, realistic-looking results.

ACKNOWLEDGMENT

The researcher would like to thank the Deanship of Scientific Research, Qassim University, for funding the publication of this project.

References:

1. Harkness, J.M. An idea man (the life of Otto Herbert Schmitt). IEEE Eng. Med. Biol. Mag. 2004, 23, 20–41.
2. Kottor J. Biomimetic endodontics. Barriers and strategies. Health Sci 2013;2:JS007.
3. Srinivasan K, Chitra S. Emerging trends in oral health profession: The biomimetic – A review. Arch Dent Med Res 2015;1:40-7.
4. Slavkin HC. Biomimetics: replacing body parts is no longer science fiction. J Am Dent Assoc. 1996;127(8):1254–7.
5. Zafar MS, Amin F, Fareed MA, Ghabbani H, Riaz S, Khurshid Z, Kumar N. Biomimetic aspects of restorative dentistry biomaterials. Biomimetics (Basel). 2020;5(3):34.
6. Brannstrom M. Dentin and Pulp in Restorative Dentistry. London, UK: Wolfe Medical Publications; 1982.
7. Brannstrom M. The hydrodynamic theory of dentinal pain: sensation in preparations, caries and the dentinal crack syndrome. Journal of Endodontics. 1986;12(10):453-457.
8. Alleman D, Magne P. A systematic approach to deep caries removal end-points: The peripheral seal concept in adhesive dentistry. Quint Int. 2012;43(3):197-208.
9. Magne P, Oganesyan T. CT scan–based finite elemental analysis of premolar cuspal deflection following operative procedures. Int J Periodontics Restorative Dent 2009;29:361–369.
10. Splieth CH, Ekstrand KR, Alkilzy M, et al. Sealants in dentistry: Outcomes of the ORCA Saturday Afternoon Symposium 2007. Caries Res 2010;44:3–13.
11. Neuhas KW, Ciucchi P, Donnet M, Lussi A. Removal of enamel caries with an air abrasion powder. Oper Dent 2010;35:538–546.

12. Roulet J-F, Degrange M. Adhesion: The Silent Revolution in Dentistry. Chicago, IL: Quintessence Publishing; 2000.
13. Yazici AR, Baseren M, Gokalp S. The in vitro performance of laser fluorescence and caries-detector dye for detecting residual carious dentin during tooth preparation. Quintessence Int 2005;36:417–422.
14. Shirai K, De Munck J, Yoshida Y, et al. Effect of cavity configuration and aging on the bonding effectiveness of six adhesives to dentin. Dent Mater 2005;21:110–124.
15. Yoshiyama M, Urayama A, Kimochi T, Matsuo T, Pashley D. Comparison of conventional vs self etching adhesive bonds to caries-affected dentin. Oper Dent 2000;25:163–169.
16. Boston DW, Sauble JE. Evaluation of laser fluorescence for differentiating caries dye-stainable versus caries dye-unstainable dentin in carious lesions. Am J Dent 2005;18:351–354.
17. Nakajima M, Ogata M, Okuda M, Tagami J, Snao H, Pashley DH. Bonding to caries-affected dentin using self-etching primers. Am J Dent 1999;12:309–314.
18. Yonemoto K, Eguro T, Maeda T, Tanaka H. Application of DIAGNOdent as a guide for removing carious dentin with Er:YAG laser. J Dent 2006;34:269–276.
19. Magne P. Composite Resins and Bonded Porcelain: The Post amalgam Era? CDA. JOURNAL, 34(2), 2006.
20. Shenoy A. Is it the end of the road for dental amalgam? A critical review. J Conserv Dent 2008;11:99–107.
21. Magne P, Douglas WH. Rationalization of esthetic restorative dentistry based on biomimetics. Journal of Esthetic and Restorative Dentistry. 1999 Jan;11(1):5-15.
22. Chesterman J, Jowett A, Gallacher A, Nixon P. Bulk-fill resin-based composite restorative materials: a review. Br Dent J 2017;222:337–44.

23. Nikaido T, Kunzelmann K-H, Chen H, et al. Evaluation of thermal cycling and mechanical loading on bond strength of a self-etching primer system to dentin. Dent Mater. 2002;18(3):269-275.
24. Bottacchiari S. Composite Inlays and Onlays: Structural, Periodontal and Endodontic Aspects. Milan, Italy: QuintessenzaEdizioni; 2016.
25. Kishen A, Vedantam. Hydrodynamics in dentine: Role of dentinal tubules and hydrostatic pressure on mechanical stress-strain distribution. Dental Mater.2007;23(10):1296-1306.
26. Versluis A, Tantbirojn D, Pintado M, De Long R, Douglas WH. Residual shrinkage stress distributions in molars after composite restoration. Dental Mater.2004;20(6):554-564.
27. Trindade, F.Z.; Valandro, L.F.; de Jager, N.; Bottino, M.A.; Kleverlaan, C.J. Elastic properties of lithium disilicate versus feldspathic inlays: Effect on the bonding by 3D finite element analysis. J. Prosthodont. 2018,27, 741–747.
28. Morin, D.; DeLong, R.; Douglas, W. Clinical science cusp reinforcement by the acid etch technique. J. Dent.Res. 1984, 63,1075–1078.
29. Milicich G. The compression dome concept: the restorative implications. General dentistry. 2017 Sep 1;65(5):55-60.
30. Sattabanasuk V, Burrow MF, Shimada Y, Tagami J. Resin adhesion to caries-affected dentine after different removal methods. Aust Dent J. 2006;51(2):162-169.
31. Pashley D, Tay F, Yui C, Hashimoto M, Breschi L, Carvalho R, Ito S. Collagen degradation by host-derived enzymes during aging. J Dent Res. 2004;83(3):216-221.
32. De Munck J, Mine A, Poitevin A, Van Ende A, Cardoso MV, Van Landuyt KL, Peumans M, Van Meerbeek B. Meta-analytical review of parameters involved in dentin bonding. J Dent Res. 2012;91(4):351-357.

33. Malhotra S, Hegde M. Analysis of marginal seal of ProRoot MTA, MTA Angelus biodentine, and glass ionomer cement as root-end filling materials: An in vitro study. J Oral Res Rev. 2015;7(2):44–9.
34. Ngo, H. Biological Properties of Glass-Ionomers. In An Atlas of Glass-Ionomer Cements a Clinician's Guide, 3rd ed.; Martin Dunitz: London, UK, 2002; pp. 43–55.
35. Alatawi RAS, Elsayed NH, Mohamed WS. Influence of hydroxyapatite nanoparticles on the properties of glass ionomer cement. J Mater Res Technol. 2019;8(1):344–9.
36. Garoushi S, Vallittu P, Lassila L. Hollow glass fibers in reinforcing glass ionomer cements. Dent Mater. 2017;33(2):e86–93.
37. Shanthi M, Sekhar ES, Ankireddy S. Smart materials in dentistry: Think smart!. Journal of Pediatric Dentistry. 2014 Jan 1;2(1):1-4.
38. Yeli M, Kidiyoor K, Nain B, Kumar P. Recent advances in composite resins-a review. J Oral Res Rev. 2010;2(3):134–6.
39. Baran, G.; Boberick, K.; McCool, J. Fatigue of restorative materials. Critical reviews in oral biology and medicine: An o_cial publication of the American association of oral biologists. Crit. Rev. Oral Biol. Med. 2001, 12, 350–360.
40. Holand W, Rheinberger V, Wegner S, Frank M. Needle-like apatite-leucite glass-ceramic as a base material for the veneering of metal restorations in dentistry. J Mater Sci Mater Med. 2000;11(1):11–7.
41. Dirxen C, Blunck U, Preissner S. Clinical performance of a new biomimetic double network material. Open Dent J. 2013;7(1):118–22.
42. Paul SJ, Schärer P. The dual bonding technique: a modified method to improve adhesive luting procedures. Int J Periodontics Restorative Dent 1997;17:536–545.
43. Magne P. Immediate dentin sealing: a fundamental procedure for indirect bonded restorations. J EsthetRestor Dent 2005;17:144–154.

44. Dietschi D, Spreafico R. Indirect techniques. In: Adhesive metal-free restorations – current concepts for the esthetic treatment of posterior teeth. Berlin: Quintessence Publishing, 1997.
45. Dietschi D, Olsburgh S, Krejci I, Davidson C. In vitro evaluation of marginal and internal adaptation after occlusal stressing of indirect class II composite restorations with different resinous bases. Eur J Oral Sci 2003;111:73–80.
46. Huth KC, Chen HY, Mehl A, Hickel R, Manhart J. Clinical study of indirect composite resin inlays in posterior stress-bearing cavities placed by dental students: results after 4 years. J Dent 2011;39:478–488.
47. Manhart J. Direct composite restorations in posterior region: a case history using a nanohybrid composite. Dent Today 2004;23:66,68–70.