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BIOMIMETICS IN DENTISTRY: AN INNOVATIVE DIRECTION IN MODERN RESTORATIVE TREATMENT

Suyunova Aziza Xidir qizi
Termiz Iqtisodiyot va Servis Unversiteti Tibbiyot fakulteti Stomatologiya ta'lim yònalishi 4 kurs talabasi

Eshkarayev Sadriddin Choriyevich
Termiz iqtisodiyot va servis universiteti
Ilmiy ishlar va innovatsiyalar bo‘yicha prorektori
Sadridin_eshkarayev@tues.uz
0000-0003-1711-3303

Abstract: This article analyses the theoretical foundations, clinical workflow, materials, and evidence-based limitations of biomimetic restorative dentistry. Biomimetic care aims to reproduce not only tooth morphology but also the biomechanical behaviour of the enamel–dentin complex, stress distribution, pulpal vitality, and long-term function. Selective caries removal, adhesive bonding, immediate dentin sealing, partial-coverage restorations, layered composite placement, and bioactive materials are reviewed. Tissue preservation is biologically and mechanically sound; however, the claimed superiority of every branded or bundled biomimetic protocol is not consistently supported by high-quality clinical evidence.

Keywords: *biomimetics, restorative dentistry, adhesive restoration, enamel, dentin, minimally invasive dentistry*

INTRODUCTION

For many years, restorative dentistry was primarily directed towards replacing tissue lost through caries or fracture with a strong material. Under this approach, the restoration was often treated as an isolated structure, with insufficient attention to the fact that a tooth is a complex biological and mechanical system. Contemporary biomimetics instead takes the architecture, elastic modulus, fracture resistance, adhesive behaviour in a moist environment, and occlusal load-distribution mechanisms of the natural tooth as the starting point for clinical decisions [1–3]. Therefore, the central question in biomimetic treatment is not “Which material is the strongest?” but “Which solution will function most reliably together with the remaining tooth tissues?”

In a natural tooth, enamel provides high hardness and resistance to wear, whereas dentin has a lower elastic modulus and the capacity to absorb energy. The dentinoenamel junction redistributes stress and slows the deep propagation of cracks. The pulp–dentin complex is living biological tissue that responds to thermal, chemical, and bacterial insults. Consequently, extensive preparation, over-drying, polymerisation shrinkage, or inappropriate occlusal contacts may compromise not only the restoration but the entire biomechanical system [2,3].

In clinical practice, the term biomimetics is sometimes used as a marketing concept, implying that various materials and techniques are automatically “equivalent to a natural tooth”. An evidence-based critical review published in 2024 showed that several popular claims—such as the

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need for fibre reinforcement in every case, the possibility of creating an entirely stress-free restoration, or the universal superiority of a complex protocol over conventional adhesive treatment—lack adequate clinical support [1]. The value of the biomimetic philosophy therefore lies not in blindly reproducing a protocol, but in integrating tissue preservation, biological safety, and mechanical logic with the best available evidence.

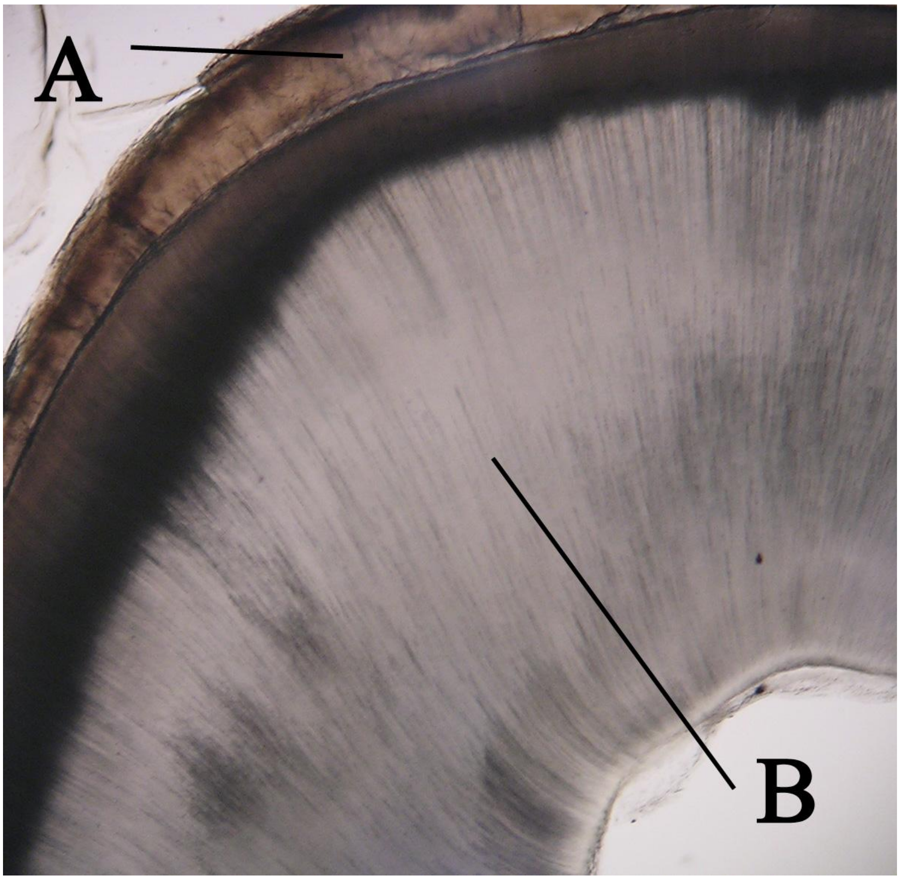

Figure 1. Enamel and dentin layers of a natural tooth: the biological model for biomimetic design

Source: Wikimedia Commons, "Crosssectiontooth11-24-05.jpg", author Dozenist, CC BY-SA/GFDL; https://commons.wikimedia.org/wiki/File:Crosssectiontooth11-24-05.jpg

MATERIALS AND METHODS

This study was conducted as a narrative scientific review. Reviews, clinical studies, and consensus documents published between 2014 and 2026 were analysed in PubMed, PMC, BMC Oral Health, the Journal of Applied Oral Science, and Biomimetics using the keywords "biomimetic restorative dentistry", "adhesive dentistry", "immediate dentin sealing", "partial coverage restoration", "selective caries removal", and "bioactive restorative material". The principal inclusion criteria were direct relevance to restorative clinical decision-making, methodological transparency, and the practical interpretability of the findings.

The evidence was organised into five analytical domains: natural-tooth biomechanics; the extent of preparation and carious-tissue removal; management of the adhesive interface; selection of restorative materials and designs; and clinical outcomes and limitations of the evidence. Laboratory tests were not regarded as complete substitutes for clinical durability. Accordingly, bond strength, fracture resistance, and microleakage were evaluated as mechanistic evidence, whereas long-term survival was assessed separately as clinical evidence.

RESULTS

1. Maximum tissue preservation and selective caries removal

The first principle of the biomimetic approach is to avoid sacrificing enamel and dentin that can be preserved. In deep caries, complete removal of soft dentin close to the pulp increases the risk of pulpal exposure; selective excavation, by contrast, protects the pulpal wall while leaving sufficient sound tissue at the periphery for a strong and hermetic bond. This decision should be based on caries activity, symptoms, radiographic depth, and the clinical status of the pulp. Biomimetic minimalism does not mean “leaving caries untreated”; it is a strategy of reliably isolating the bacterial substrate beneath the restoration while preserving pulpal vitality.

Partial-coverage designs such as onlays, overlays, and endocrowns often preserve sound axial walls that would otherwise be circumferentially reduced for a full crown. Conservatism, however, is not an absolute objective: retaining a very thin, cracked, or poorly prognostic cusp may later result in catastrophic fracture. Preparation extent must therefore be individualised according to residual wall thickness, crack direction, occlusal load, parafunction, and the feasibility of adhesive isolation [4].

Table 1. Components of the natural tooth and biomimetic restorative objectives

Natural component	Principal function	Biomimetic clinical objective	Appropriate solutions
Enamel	High hardness and resistance to wear and compression	Preserve enamel at the margins and create a smooth, stable occlusal surface	Bonded ceramic, nanohybrid composite, selective enamel etching
Dentin	Elasticity, energy absorption, and pulpal protection	Avoid excessive excavation and manage the moist adhesive substrate	Universal or multi-step adhesive, composite, and calcium-silicate material when indicated
Dentinoenamel junction	Stress distribution and limitation of crack propagation	Create a layered architecture that reduces abrupt changes in elastic modulus	Incremental composite placement and a base material with compatible elasticity
Pulp–dentin complex	Biological response and formation of reparative dentin	Reduce thermal, chemical, and bacterial trauma	Selective excavation, hermetic sealing, and a bioactive liner only when indicated

2. Management of the adhesive interface and polymerisation stress

The long-term success of an adhesive restoration depends on the stability of micromechanical and chemical bonding to enamel and dentin. Clinical isolation, contamination control, adherence to the adhesive manufacturer's instructions, adequate solvent evaporation, and complete light polymerisation are more important than the biomimetic label itself. If dentin is over-dried, the collagen network collapses; excessive moisture, conversely, can dilute the adhesive layer and contribute to nanoleakage. Rubber-dam isolation, optical magnification, and a standardised protocol are therefore key quality-control measures that determine the outcome.

Immediate dentin sealing involves applying an adhesive to freshly cut dentin after preparation for an indirect restoration and before the laboratory phase. Mechanistic and clinical evidence suggests that this technique may reduce postoperative sensitivity and improve bonding conditions. Its benefit, however, depends on the material system, provisional cement, scanning or impression technique, and final cementation protocol. It should be regarded not as a universal miracle solution, but as a controlled adhesive step [1,2].

Polymerisation shrinkage of composite generates stress along cavity walls. Placement in small increments, appropriate layering direction, sufficient light energy, and compliance with the material's depth-of-cure limits help control this stress. Bulk-fill materials may also be effective when correctly indicated; it is not scientifically justified to consider them incompatible with a biomimetic philosophy. Selection should depend on cavity geometry, access, curing depth, and clinical time. Short-fibre-reinforced composites may be useful as a dentin-replacing layer that slows crack propagation in large cavities, but they are not mandatory as a preventive measure in every tooth.

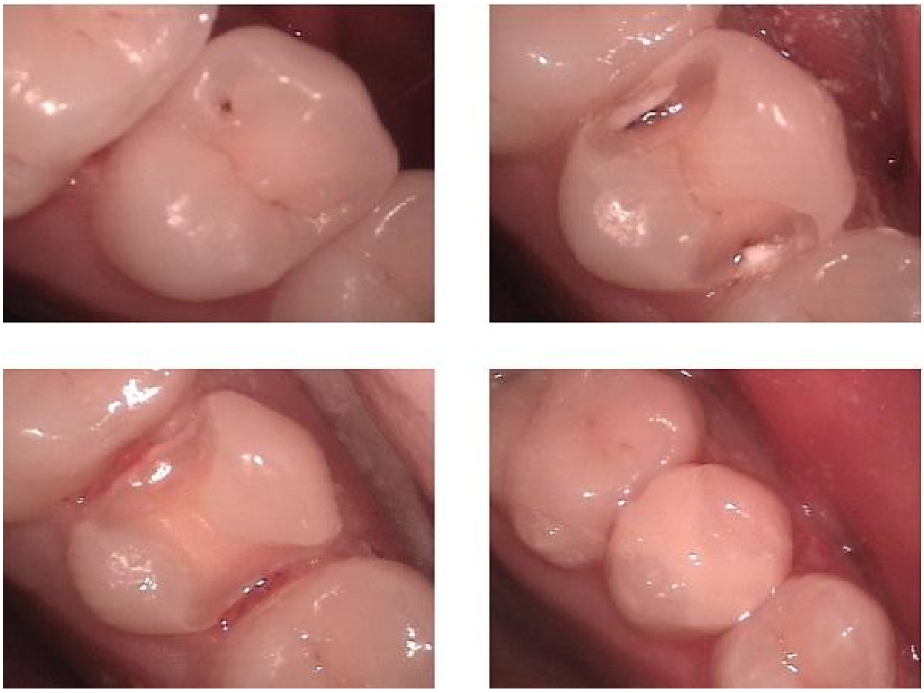

Figure 2. Clinical appearance of an adhesive composite restoration
Source: Wikimedia Commons, "Dental Restoration.jpg", author Jeffrey Dorfman, CC BY-SA 3.0; https://commons.wikimedia.org/wiki/File:Dental_Restoration.jpg

3. Material selection and functional integration

A biomimetic material is selected not because it is described as "natural", but because it fulfils a defined clinical task. Ceramics provide hardness and optical properties close to enamel, yet excessive thickness or inappropriate occlusion may cause antagonist wear and brittle fracture. Composite is advantageous because it is repairable and requires limited preparation, but it is sensitive to polymerisation variables, water sorption, and surface degradation. Glass ionomer and resin-modified glass ionomer are useful in cervical, temporary, or high-caries-risk situations because of fluoride release and chemical bonding, but they should not be regarded as universal solutions under heavy load.

The term "bioactive" must likewise be interpreted cautiously. Demonstration of ion release, pH buffering, or formation of an apatite-like layer under laboratory conditions does not mean that a material will completely prevent caries clinically. Calcium-silicate cements are important in vital pulp therapy and protection of deep dentin, but they require a hermetic and mechanically stable restoration above them. Biological activity cannot compensate for poor marginal adaptation or an incorrect diagnosis [2,3].

Table 2. Step-by-step clinical algorithm for biomimetic restorative treatment

Stage	Key decision	Quality control	Principal risk
1. Diagnosis	Assess pulpal status, cracks, residual walls, and caries risk	Clinical tests, radiographs, and occlusal analysis	Failure of conservative treatment because of an incorrect diagnosis

Stage	Key decision	Quality control	Principal risk
2. Isolation	Use a rubber dam and control contamination	A dry and clearly visible operative field	Salivary or blood contamination and reduced bond strength
3. Preparation	Selective excavation and management of unsound cusps or cracks	Integrity of the peripheral enamel–dentin ring	Excessive or insufficient tissue removal
4. Adhesive stage	Substrate-appropriate etching and primer/bond protocol	Solvent evaporation and complete light polymerisation	Nanoleakage, sensitivity, and early debonding
5. Reconstruction	Selection of material, layering, and coverage design	Contact, contour, and increment thickness	Shrinkage stress, voids, and cusp fracture
6. Final review	Occlusion, finishing, monitoring, and repair	Static/dynamic contacts, radiographs, and photographs	High contacts, marginal degradation, and secondary caries

PRACTICAL CLINICAL RECOMMENDATIONS

When biomimetic treatment is introduced into practice, a minimal but mandatory quality package should be defined. The first element is a documented diagnosis supported by preoperative photography, radiographs, and pulp tests. The second is rubber-dam isolation, or an equally reliable form of isolation, throughout the adhesive procedure. The third is a restoration design based on residual walls, cracks, and occlusal contacts. The fourth is documentation of the adhesive and restorative materials used, the output of the curing light, and the thickness of each increment. Unless these four requirements are met, a complex fibre layer or expensive ceramic cannot guarantee success.

For a large MOD cavity, the decision sequence may be as follows: assess symptoms and pulpal status; evaluate crack depth and cusp thickness; remove carious tissue to hard dentin at the periphery and selectively near the pulp; plan the matrix and proximal contact after isolation; choose a partial-coverage design when a weakened cusp requires coverage; perform the adhesive protocol according to the manufacturer's instructions; and verify occlusion in both static and dynamic movements. This algorithm is independent of the material brand and focuses control on the stages most likely to generate error.

During follow-up, a restoration should not be evaluated simply as "present or absent". Marginal staining, minor chipping, weakened proximal contact, or a localised surface defect can often be managed by polishing, resealing, or repair rather than complete replacement. Every full replacement removes an additional portion of sound tissue. The success of biomimetic care is therefore not the permanence of the first restoration, but long-term preservation of a vital and functional tooth, postponement of extensive re-preparation, and early detection of complications.

Patient factors are as important as design factors in clinical decision-making. Bruxism, high masticatory forces, an erosive diet, dry mouth, high caries activity, and failure to attend regular reviews can shorten the service life even of an excellent adhesive restoration. Redistribution of occlusal load and a night guard for parafunction, fluoride prevention and dietary modification for high caries risk, and control of acid exposure in erosive conditions are inseparable from the restoration itself. Biomimetics is not merely a local tooth technique; it is the combined management of the biological environment and functional load.

Absolute promises such as “we will return the tooth completely to its natural state” should be avoided in patient communication. The accurate explanation is that treatment preserves natural tissue as far as possible and restores the defect mechanically and aesthetically, but no artificial material exactly reproduces the living enamel–dentin complex and every restoration has a finite service life. Alternatives—direct composite, an indirect partial restoration, full coverage, or observation—should be discussed together with their cost, time requirements, repairability, and biological cost. Informed choice is an ethical component of biomimetic treatment.

DISCUSSION

The analysis indicates that the strongest aspect of biomimetic dentistry is its biological and conservative decision logic. Preservation of sound tissue, recognition of pulpal vitality as a primary outcome, use of bonded partial restorations, and retention of the option to repair restorations are consistent with contemporary minimally invasive dentistry. This approach helps manage the “remaining lifetime” of the tooth: the more tissue removed during the first intervention, the less reserve remains for subsequent retreatment.

The biomimetic concept may, however, increase clinical complexity and cost. Rubber dams, microscopes, multi-step adhesive systems, additional appointments, and laboratory restorations are not available in every setting. A complex protocol also increases the number of points at which operator error may occur. When a simpler, well-studied, and correctly executed method offers the same prognosis, choosing a more expensive option solely because it carries a “biomimetic” label is not ethically justified. Clinicians should therefore prioritise patient risk, isolation conditions, operator experience, and repairability over material marketing.

The hierarchy of evidence is equally important. Laboratory fracture-resistance tests, scanning electron microscopy images, and short-term bond tests provide useful mechanistic information but do not directly prove clinical longevity, biological complications, or outcomes that matter to patients. Future research should compare standardised clinical endpoints over the long term—including pulpal vitality, catastrophic fracture, need for repair, patient satisfaction, and cost-effectiveness—rather than focusing only on isolated techniques [1,4].

CONCLUSION

Biomimetics shifts restorative dentistry from a "filling the cavity" model to a model of managing the biological and biomechanical integrity of the tooth. Its practical foundations are accurate diagnosis, maximum preservation of sound tissue, selective caries excavation, reliable isolation, a substrate-appropriate adhesive protocol, rational stress management, and a repairable restoration design. No ceramic, composite, fibre-reinforced, or bioactive material produces a biomimetic outcome by itself; the result emerges from the integration of material, design, biological indication, and technical execution. Adoption of biomimetic principles in clinical practice is appropriate, but unsupported absolute claims, unnecessary complexity, and marketing terminology should be avoided.

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