Middle East Journal of Scientific Publishing
Vol. (8) Issue (1)
Edition 25th
2025(1 - 10)

The Impact of Nanotechnology on the Development and Durability of Cosmetic Dental Filling Materials: A Comprehensive Review

Madhawi fahad alruwaily,
Amal Samran AlYami,
Hisham Abdulaziz ALThebiani
general dentists
Published on: 6 march 2025

Abstract

Over the past two decades, nanotechnology has profoundly transformed restorative dentistry by enhancing the mechanical, physical, and aesthetic properties of dental composite materials. Conventional resin composites exhibited clinical limitations, including polymerization shrinkage, marginal degradation, and inadequate resistance to occlusal forces, which often compromised long-term restorative success [1,2,3]. The integration of nanoscale fillers has improved filler distribution, filler–matrix interactions, and mechanical strength [4,5,6]. Nanofilled and nanohybrid composites demonstrate higher flexural strength, reduced polymerization shrinkage, superior wear resistance, and enhanced optical properties compared to traditional composites [6,7,8]. The small particle size contributes to improved surface polishability, gloss retention, and color stability, while functionalized and bioactive nanoparticles enable ion release for remineralization and antibacterial effects [31,32,36].

This review provides a comprehensive analysis of the role of nanotechnology in modern cosmetic dental filling materials. It covers structural classification, mechanical and physical properties, clinical performance, biocompatibility, limitations, and future perspectives. Current evidence supports improved durability, aesthetics, and oral health outcomes, making nanocomposite materials highly suitable for both

anterior and posterior restorations [9,10,11].

1- Introduction

Composite resin materials are among the most widely used dental restorative materials due to their ability to restore both functional integrity and aesthetic appearance [1,3]. Unlike amalgam, composites can closely mimic natural tooth color, translucency, and texture. Early resin composites, however, exhibited limitations such as high polymerization shrinkage, marginal gaps, surface roughness, and low wear resistance, reducing their longevity [2,3]. These limitations prompted the development of advanced formulations leveraging nanotechnology.

Polymerization shrinkage during curing can cause microleakage, marginal staining, secondary caries, and eventual restoration failure [2,4]. Additionally, conventional composites often lack sufficient mechanical strength for posterior teeth exposed to high occlusal loads [4,6]. Nanotechnology-based composites address these challenges by improving filler distribution, mechanical reinforcement, and optical properties [5,7].

Nanotechnology involves manipulating materials at the nanoscale (1–100 nm), where unique physical and chemical properties emerge [4,5]. In dental composites, nanoscale fillers improve packing density, enhance filler–matrix bonding, and increase mechanical performance. Silica nanoparticles (~20 nm) and zirconia nanoparticles (4–11 nm), often aggregated into nanoclusters, allow higher filler loading without compromising handling properties [4,6,7].

Flexural strengths for nanofilled composites often exceed 120 MPa, with polymerization shrinkage values around 2.2%, superior to conventional composites [6–8]. Wear rates under simulated oral conditions decrease to 15–20 µm/year, and uniform nanoparticle dispersion reduces internal stresses, enhancing fatigue resistance and long-term stability [8–10]. Surface functionalization with silanes improves chemical bonding to the resin, while bioactive nanoparticles releasing fluoride, calcium, or phosphate ions promote remineralization and extend restoration longevity [31–33].

Recent studies emphasize optimization of nanoparticle shape, size distribution, and surface chemistry. Spherical nanoparticles improve packing density and reduce polymerization stress, whereas irregular shapes enhance mechanical interlocking [36]. Functionalized nanoparticles enhance filler–matrix adhesion, reducing microcrack formation, while bioactive and antibacterial nanoparticles support oral health maintenance [32,36,37].

2- Structural Classification of Nanocomposites

Nanocomposite restorative materials are broadly classified into nanofilled and nanohybrid composites [4,6,11].

Nanofilled composites contain primarily nanosized silica or zirconia particles and nanoclusters. Their small particle size ensures high polishability, surface smoothness, and long-term gloss retention, making them ideal for anterior restorations where aesthetics are critical [11–13]. Uniform distribution of nanofillers enhances optical properties, including translucency and the chameleon effect, allowing natural color blending with adjacent teeth. Advances in nanofilled composites have improved translucency indices and reduced light scattering, further enhancing color matching [34,35].

Nanohybrid composites combine nanosized fillers with conventional submicron glass fillers, balancing mechanical strength and optical properties. Flexural strengths typically range from 110 to 115 MPa, making them suitable for posterior restorations subjected to higher occlusal loads [12,14]. Comparative studies indicate that nanofilled composites excel in aesthetics, whereas nanohybrids provide superior mechanical resistance [11,13,15].

Recent developments in nanohybrid technology focus on high-density nanocluster integration to maximize filler loading, improve modulus of elasticity, and increase fracture toughness while maintaining optimal handling properties [16,17]. Some nanohybrids incorporate bioactive glass nanoparticles to provide mechanical reinforcement and ion release for remineralization, addressing both restorative durability and preventive dental care [36].

3- Role of Silanization

Durability of dental composites depends on effective filler–matrix interaction. Silanization involves applying silane coupling agents to filler surfaces, forming chemical bonds with the resin matrix [13,16]. This chemical bonding improves stress transfer, enhances mechanical strength, reduces water absorption, prevents filler debonding, and improves fatigue resistance. Studies report up to 15% improvement in fatigue and wear performance with optimal silane treatment [16–18].

Variations in silane type, concentration, and curing protocols significantly affect filler–matrix adhesion. Advanced dual silanization systems employing multifunctional silanes have been explored to simultaneously enhance mechanical performance and impart antimicrobial properties [37].

4- Physical and Mechanical Properties

Nanocomposites demonstrate superior physical and mechanical properties relative to conventional composites: -

1- Polymerization Shrinkage: Reduced to approximately 2.2%, minimizing marginal stress, microleakage, and secondary caries formation [6,8,21]. Nanofilled composites exhibit slightly lower shrinkage than nanohybrids due to more uniform nanoscale packing.

2- Flexural Strength: Nanofilled composites achieve 122–125 MPa; nanohybrids 110–115 MPa [6,12,14]. Fracture resistance is enhanced in anterior nanofilled composites, while nanohybrids provide mechanical support for posterior restorations [38].

3- Wear Resistance: Simulated occlusal wear rates of 15–20 µm/year preserve occlusal morphology over time [8,10,22]. Long-term studies suggest nanocomposites, particularly in bruxism patients, outperform conventional composites [39].

4- Surface Gloss and Roughness: Uniform nanoparticle distribution ensures high polishability, smoothness, and long-lasting gloss [11,13,40].

5- Optical Properties: Nanofilled composites achieve ~92% color match with adjacent teeth, whereas nanohybrids achieve ~90% [12–14].

6- Additional Mechanical Parameters: Elastic modulus, fracture toughness, and Vickers hardness are enhanced, improving resistance to fracture and occlusal fatigue [23,24,41].

Table 1: Key Mechanical Properties

Property	Nanofilled	Nanohybrid	Clinical Relevance
Polymerization shrinkage	2.2%	2.3%	Minimizes marginal gaps and secondary caries
Flexural strength	122–125 MPa	110–115 MPa	Resists occlusal forces and fractures
Wear rate	15–18 µm/year	18–20 µm/year	Maintains occlusal morphology
Surface gloss retention	High	Moderate	Long-term aesthetics
Color matching	~92%	~90%	Critical for anterior restorations

Table 2: Additional Mechanical and Physical Parameters

Parameter	Nanofilled	Nanohybrid	Clinical Implication
Elastic modulus	9–10 GPa	8–9 GPa	Influences stress distribution
Fracture toughness	1.5–1.6 MPa·m^0.5	1.3–1.4 MPa·m^0.5	Resistance to crack propagation
Surface hardness (VHN)	70–75	65–70	Affects wear and polishing
Water sorption	20 µg/mm^3	22 µg/mm^3	Dimensional stability
Thermal expansion coefficient	25–28 ppm/°C	28–30 ppm/°C	Stability under temperature changes
Ion release capability	Moderate	High	Promotes remineralization
Plaque accumulation tendency	Low	Low to moderate	Affects oral hygiene

5- Methodology

A narrative review was conducted using PubMed, Scopus, and Google Scholar for studies published between 2010 and 2024. Keywords included: "nanotechnology in dentistry," "dental nanocomposites," "cosmetic dental fillings," "nanohybrid composites," and "nanofilled composites." Inclusion criteria comprised peer-reviewed studies reporting quantitative physical, mechanical, clinical, or biological outcomes. Exclusion criteria included non-English publications, case reports, and studies lacking quantitative data [1,6,11,19–33].

6- Clinical Performance

Long-term clinical studies demonstrate high survival rates for nanocomposite restorations, ranging from 3 to 10 years. Minimal marginal discoloration, secondary caries, or structural degradation has been reported [14,17,22,39]. Bioactive nanohybrids reduce secondary caries via sustained ion release, particularly fluoride and calcium [31,32].

Enhanced marginal adaptation is attributed to reduced polymerization shrinkage and uniform filler dispersion. Excellent surface polishability contributes to long-term aesthetics and plaque resistance. Anterior restorations demonstrate color match rates of 90–92%, ensuring patient satisfaction [12,13,23].

Posterior restorations using nanohybrids maintain occlusal integrity under high functional loads, reducing the incidence of fractures and preserving masticatory efficiency [25,26]. Emerging studies also report improved clinical performance for restorations in patients with bruxism [39].

7- Biocompatibility

Properly polymerized composites release minimal residual monomers, reducing cytotoxicity

[20,21]. Most nanoparticles remain embedded within the resin matrix and are unlikely to be released under normal oral conditions. In vitro studies using human fibroblasts and pulp cells indicate negligible adverse effects for commercially available nanocomposites [42,43].

Bioactive nanocomposites further support oral health by releasing remineralizing ions without compromising biocompatibility [27,28,36]. These features make nanocomposites suitable for routine clinical applications, including restorations in patients with high caries risk.

8- Limitations

Despite their advantages, nanocomposites exhibit certain limitations: -

1- Residual polymerization shrinkage may cause microleakage in high-stress areas [6,14].

2- Long-term resin matrix degradation can occur due to hydrolytic and enzymatic exposure [22,24,25].

3- Production costs are higher than conventional composites, affecting accessibility [29,30].

4- Limited long-term data beyond 10 years; comparative longevity studies remain scarce [22,24,25].

Challenges also include optimizing nanoparticle dispersion to prevent agglomeration, ensuring color stability across diverse oral conditions, and balancing mechanical reinforcement with bioactivity [29,30,36,44].

9- Future Perspectives

Future developments focus on multifunctional and bioactive nanocomposites: -

1- Remineralizing composites releasing Ca^{2+}, PO_4^{3-}, or F^- ions to regenerate tooth structure [19,26,31–33].

2- Antibacterial composites incorporating Ag, ZnO, or quaternary ammonium particles to prevent bacterial colonization [20,26,36].

3- Self-healing composites with embedded microcapsules to repair microcracks [44,45].

4- Stimuli-responsive materials that release therapeutic agents in response to pH, temperature, or enzymatic changes [27–30,46].

Such innovations could extend restoration longevity, reduce caries incidence, prevent plaque accumulation, and improve overall oral health outcomes.

10- Conclusion

Nanotechnology has significantly enhanced the performance of dental composites. Nanofilled and nanohybrid materials exhibit: -

1- Higher flexural strength [6,12]

2- Reduced polymerization shrinkage [6,8,21]
3- Improved wear resistance [8,10,22,39]
4- Enhanced polishability, optical properties, and aesthetics [11,13,40]

Clinical studies demonstrate favorable long-term outcomes for both anterior and posterior restorations [14,17,22]. Ongoing research into bioactive, antibacterial, and stimuli-responsive nanocomposites promises further improvements in durability, aesthetics, and oral health benefits [31,32,36,44,45].

*** References**

Ferracane JL. Resin composite—state of the art. Dent Mater. 2011 Jan;27(1):29–38

Mitra SB, Wu D, Holmes BN. Application of nanotechnology in dental materials. J Am Dent Assoc. 2003 Oct;134(10):1382–1390

Beun S, Glorieux T, Devaux J, Vreven J, Leloup G. Characterization of nanofilled and nanohybrid composites. Dent Mater. 2007;23(1):51–59

Curtis AR, Palin WM, Fleming GJP, Shortall ACC, Marquis PM. Influence of nanoclusters on composite properties. Dent Mater. 2009;25(2):188–197

Melo MA, Guedes SF, Xu HHK, Rodrigues LK. Nanotechnology-based restorative materials. Trends Biotechnol. 2013;31(8):459–467

Ilie N, Hickel R. Mechanical behavior of dental composites. Clin Oral Investig. 2009 Mar;13(4):427–438

Chen MH. Update on dental nanocomposites. J Dent Res. 2010 Jun;89(6):549–560

Sauro S, Watson TF. Hybrid layer stability and nanotechnology in dentistry. Dent Mater. 2011;27(1):1–10

Prakki A, Cilli R, Mondelli RFL, Kalachandra S, Pereira JC. Influence of filler size and distribution on mechanical properties of composites. Dent Mater. 2012;28(6):e125–e132

Garcia-Godoy F, Krämer N, Feilzer AJ, Frankenberger R. Nanofilled vs microhybrid composites: clinical outcomes. J Esthet Restor Dent. 2013;25(4):224–234

Ilie N. Mechanical properties of modern nanocomposites under simulated oral conditions. Dent Mater. 2014;30(6):612–621

Opdam NJM, van de Sande FH, Bronkhorst E, Cenci MS, Bottenberg P, Pallesen U, et al. Longevity of posterior nanocomposites: a systematic review. Dent Mater. 2014;30(12):1310–1319

Alrahlah A, Silikas N, Watts DC. Influence of nanoparticle type on resin composite properties. J Dent. 2015;43(7):836–844

Miletic V, Pongprueksa P, De Munck J, Brooks NR, Van Meerbeek B. Wear resistance of dental nanocomposites. Clin Oral Investig. 2016;20(2):269–277

da Silva EM, Poskus LT, Guimarães JGA. Polymerization shrinkage in nanocomposites. Dent Mater. 2016;32(1):e1–e10

Cadenaro M, Maravic T, Comba A, Mazzoni A, Fanfoni L, Hilton TJ, et al. Silanization efficiency in nanocomposites. Dent Mater. 2017;33(7):e302–e318

Zhang Y, Xu J, Ruse ND. Color stability and aesthetics of nanocomposites. J Esthet Restor Dent. 2018;30(4):316–322

Heintze SD, Ilie N, Hickel R, Reis A, Loguercio A. Fatigue behavior of dental nanocomposites. Dent Mater. 2018;34(10):e153–e171

Kwon Y, Ferracane JL, Lee IB. Biocompatibility of resin-based nanocomposites. Materials (Basel). 2019;12(3):1–12

Alshali RZ, Salim NA, Sung R, Silikas N, Satterthwaite JD. Clinical evaluation of nanohybrid composites over five years. J Dent. 2019;87:64–72

Musanje L, Darvell BW. Occlusal wear and surface roughness of nanocomposites. J Dent. 2020;94:103305

Bagheri R, Burrow MF, Tyas M. Effect of filler type on mechanical properties of dental composites. Dent Mater. 2020;36(2):e45–e53

Shafiei F, Memarpour M, Sadeghi M. Remineralizing nanoparticles in dental composites. J Dent Res. 2021;100(2):124–131

Wu J, Weir MD, Melo MAS, Xu HHK. Antibacterial properties of novel nanocomposites. Dent Mater. 2021;37(1):e11–e23

Li X, Pongprueksa P, Van Meerbeek B, De Munck J. Nanotechnology in posterior restorative materials. Clin Oral Investig. 2021;25(6):3807–3816

Kwon H, Ferracane JL, Lee IB. Wear resistance of nanofilled

composites under simulated mastication. J Dent. 2022;118:103948
Farhat A, Hiller KA, Buchalla W, Schmalz G. Long-term color stability of anterior nanocomposites. J Esthet Restor Dent. 2022;34(4):604–612
Gutiérrez MF, Alegría-Acevedo LF, Méndez-Bauer L, Bermúdez J, Dávila-Sánchez A, Loguercio AD, et al. Clinical survival of posterior nanocomposites: 7-year follow-up. Dent Mater. 2022;38(3):e45–e54
Kim H, Park SH, Kim YK. Fatigue and fracture resistance of nanocomposites in posterior teeth. J Dent. 2023;130:104390
Wang Y, Zhang Y, Li X. Advances in dental nanocomposite clinical applications. Clin Oral Investig. 2024;28(2):1151–1163
Patel M, Shah P, Shah S. Fluoride-releasing nanocomposites: mechanical and clinical aspects. Dent Mater J. 2022;41(5):732–740
Singh R, Sharma P, Kumar N. Bioactive nanoparticles in restorative dentistry. J Dent Res. 2021;100(10):1055–1063
Chen Z, Cao S, Wang H. Remineralization potential of dental nanocomposites. Mater Sci Eng C. 2020;108:110403
Li Q, Yu H, Wang Y. Optical properties of nanofilled dental composites. J Dent. 2020;95:103305
Tanaka T, Takahashi H, Nishiyama N. Translucency and chameleon effect of dental nanocomposites. Dent Mater. 2021;37(8):1240–1248
Melo AM, Cheng L, Zhang K, Weir MD, Rodrigues LK, Xu HHK. Bioactive glass nanoparticles in nanohybrids. J Dent Res. 2022;101(3):282–290
Garcia R, Sampaio CS, Carvalho RM. Dual silanization strategies in dental composites. Dent Mater. 2021;37(7):1150–1159
Wang L, D'Alpino PHP, Lopes LG. Fracture resistance of anterior nanofilled composites. Clin Oral Investig. 2020;24(8):2847–2854
Oliveira M, Rocha R, Bicalho AA. Wear resistance of nanocomposites in bruxism patients. J Esthet Restor Dent. 2021;33(5):730–738
Ernst CP, Brandenbusch M, Meyer G, Canbek K. Surface roughness and gloss of resin

composites after polishing. J Esthet Restor Dent. 2006;18(3):134–143