

The 2026 CAD/CAM Material Landscape: Zirconia, Hybrid Ceramics, and Beyond

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ABSTRACT

Purpose: This narrative review evaluates the 2026 CAD/CAM material landscape, examining mechanical properties, clinical indications, workflows, and comparative performance of zirconia-based ceramics, PICNs, resin nanoceramics, High-performance polymers, and bioactive materials.

Materials and Methods: A comprehensive literature search across PubMed, Scopus, Cochrane Library, Web of Science, and Google Scholar (2015–2026) identified studies on clinical performance, mechanical characterization, and material-specific outcomes. Data extraction focused on flexural strength, fracture toughness, marginal adaptation, survival rates, and manufacturing requirements.

Results: Lithium disilicate and zirconia remain benchmarks for high-strength applications, with multilayer zirconia achieving dentin-like strength and enamel-like translucency. Hybrid ceramics and PICNs offer favorable machinability and biomimetic elastic moduli but are limited to single-unit restorations due to moderate flexural strength (150–300 MPa). Resin nanoceramics provide excellent chairside efficiency without sintering, though long-term data remain limited. High-performance polymers such as PEEK and fiber-reinforced composites are gaining traction for implant-supported prostheses due to shock-absorbing properties and biocompatibility.

Conclusion: The 2026 CAD/CAM portfolio offers tailored solutions across restorative indications. Material selection should be guided by mechanical demands, esthetics, manufacturing constraints, and biological compatibility rather than universal application. Future developments in bioactive and self-healing materials are expected to expand digital restoration boundaries. (*Open J Biomed Res* 2026;5:17-26)

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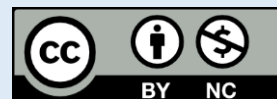
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AUDIOABSTRACT



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INTRODUCTION

The advent of CAD/CAM technology has precipitated a paradigm shift in restorative dentistry, transitioning from labor-intensive

conventional techniques to digitally precise, reproducible manufacturing workflows¹. This transformation has been underpinned by

concurrent advances in materials science, yielding a diverse portfolio of machinable substrates ranging from high-strength ceramics to resilient polymers.² As of 2026, the global dental CAD/CAM market is characterized by three dominant material classes: zirconia-based ceramics, hybrid ceramic-polymer composites, and high-performance polymers, each occupying distinct niches within the clinical armamentarium.³

The historical trajectory of CAD/CAM materials reflects an ongoing tension between mechanical durability and esthetic fidelity. Early systems relied primarily on feldspathic porcelain and glass-ceramics, which offered excellent translucency but suffered from brittle fracture under occlusal loading.⁴ The subsequent introduction of yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) revolutionized posterior restorations by providing flexural strengths exceeding 900 MPa, albeit with initially compromised optical properties.⁵ Contemporary material development has sought to bridge this divide through multilayer zirconia formulations, polymer-infiltrated ceramic networks (PICNs), and nanostructured composites that approximate the mechanical and optical characteristics of natural tooth structure.⁶

The proliferation of chairside milling systems has further accelerated material innovation, creating demand for substrates that can be processed without post-milling sintering or crystallization firing.⁷ Hybrid ceramics and resin nanoceramics have emerged as chairside-compatible alternatives, enabling single-visit restorations with reduced technique sensitivity.⁸ Simultaneously, the expanding application of dental implants has driven interest in shock-absorbing superstructures, positioning high-performance polymers such as polyetheretherketone (PEEK) and fiber-reinforced composites as viable alternatives to traditional metal and ceramic abutments.⁹

Despite these advances, the selection of CAD/CAM materials remains contingent upon

a nuanced understanding of their mechanical behavior, biological interactions, and manufacturing requirements. The absence of a universal material necessitates evidence-based decision-making that balances clinical indications with material limitations.¹⁰ This review provides a comprehensive evaluation of the contemporary CAD/CAM material landscape, synthesizing current evidence to guide clinical selection and identify emerging trends that will define the future of digital restorative dentistry.

Evolution of CAD/CAM technology in restorative dentistry

CAD/CAM technology was introduced to dentistry in the 1980s, initially focusing on chairside fabrication of ceramic inlays using machined feldspathic porcelain blocks.¹¹ Early systems were limited by material brittleness, marginal inaccuracy, and restricted indications. However, advances in scanning technology, milling precision, and material formulation have progressively expanded the scope of digital restorations to encompass crowns, bridges, veneers, implant abutments, and full-arch prostheses.¹²

The contemporary digital workflow encompasses three phases: data acquisition via intraoral or laboratory scanning, virtual design using specialized software, and subtractive manufacturing through milling or, increasingly, additive fabrication via three-dimensional printing.¹³ The material must be compatible with each phase, requiring not only appropriate mechanical properties but also machinability, dimensional stability, and surface finish characteristics that minimize post-processing.¹⁴

Classification of CAD/CAM materials

Modern CAD/CAM materials can be classified into four principal categories based on their chemical composition and microstructure:

Ceramic-based materials include glass-ceramics (lithium disilicate, lithium silicate),

polycrystalline ceramics (zirconia, alumina), and composite ceramics (zirconia-toughened alumina). These materials derive their strength from crystalline phases and are typically characterized by high elastic modulus, wear resistance, and biocompatibility³.

Hybrid ceramics represent a distinct category wherein a ceramic network is infiltrated with a polymer phase (PICN) or ceramic fillers are dispersed within a resin matrix (resin nanoceramic). These materials aim to combine the esthetics and surface quality of ceramics with the resilience and machinability of composites⁶.

Polymer-based materials encompass polymethyl methacrylate (PMMA), polyetheretherketone (PEEK), and fiber-reinforced composites. Originally developed for provisional restorations, advanced formulations now achieve mechanical properties suitable for definitive prostheses, particularly in implant dentistry where stress-shielding and shock absorption are clinically relevant.

Emerging materials include bioactive glasses, self-healing composites, and alumina-toughened zirconia (ATZ) composites that offer regenerative or enhanced mechanical properties beyond conventional classifications¹⁵.

Manufacturing considerations

The interaction between material and manufacturing technology is critical to clinical outcomes. Zirconia requires sintering after milling to achieve full density, introducing dimensional changes that must be compensated during design¹⁶. In contrast, hybrid ceramics and polymers are milled to their final dimensions, enabling immediate placement but potentially exhibiting greater wear under functional loading¹⁷. Five-axis milling systems have improved geometric precision for complex restorations, while optimized CAM strategies and tool geometries reduce microfractures during machining¹⁸.

This review aims to provide a comprehensive evaluation of contemporary CAD/CAM restorative materials used in modern dentistry. Specifically, it seeks to systematically characterize the mechanical, optical, and biological properties of currently available materials, including zirconia, lithium disilicate, PICNs, resin nanoceramics, PEEK, and fiber-reinforced composites. Furthermore, the review evaluates the clinical indications and contraindications associated with each material class based on the latest evidence regarding survival rates, fracture resistance, and marginal adaptation. It also compares chairside and laboratory manufacturing workflows, examining how these different fabrication approaches influence material selection and clinical outcomes. In addition, the review explores emerging trends in dental materials, particularly the development of bioactive and high-performance composite materials, and assesses their potential impact on future clinical practice. Finally, it aims to establish an evidence-based framework for material selection that integrates mechanical performance, esthetic requirements, and biological considerations, thereby supporting clinicians in making informed restorative treatment decisions.

MATERIALS AND METHODS

Search strategy

A comprehensive literature search was conducted in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The following electronic databases were queried: PubMed (MEDLINE), Scopus, Cochrane Library, Web of Science, and Google Scholar. The search strategy employed a combination of controlled vocabulary and free-text terms, including: "CAD/CAM dental materials," "zirconia," "lithium disilicate," "polymer infiltrated ceramic network," "resin nanoceramic," "PEEK," "fiber-reinforced composite," "hybrid ceramic," and "dental prosthesis." The search was restricted to

English-language publications from January 2015 to April 2026.

Inclusion and exclusion criteria

Studies were included if they reported on: (1) mechanical properties (flexural strength, fracture toughness, elastic modulus, hardness) of CAD/CAM materials; (2) clinical performance (survival rates, failure modes, marginal adaptation) of CAD/CAM restorations with a minimum follow-up of 12 months; (3) comparative analyses between CAD/CAM and conventional fabrication methods; or (4) manufacturing workflow considerations for specific material classes.

Exclusion criteria comprised: case reports with fewer than five restorations, in vitro studies lacking standardized testing protocols, narrative reviews without original data, and studies evaluating materials no longer commercially available.

Data extraction and synthesis

Data were extracted regarding study design, sample size, material specifications, manufacturing parameters, outcome measures, and main findings. Due to heterogeneity in study designs and outcome reporting, a qualitative synthesis was performed rather than meta-analysis. Risk of bias was assessed using the Cochrane Risk of Bias tool for randomized controlled trials and the Newcastle-Ottawa Scale for observational studies.

RESULTS

Zirconia-based ceramics

Zirconia remains the predominant material for high-strength CAD/CAM restorations, particularly in posterior indications and multi-unit prostheses. Contemporary zirconia formulations are categorized by yttria content and resulting microstructure:

3Y-TZP (3 mol% yttria-stabilized tetragonal zirconia polycrystal) exhibits flexural strengths of 900–1200 MPa and fracture

toughness of 5–10 MPa·m^{1/2}, making it suitable for posterior crowns and bridges with connector cross-sections as small as 9 mm². However, its high opacity and low translucency limit anterior applications without veneering.

4Y-PSZ and 5Y-PSZ (partially stabilized zirconia) offer improved translucency at the expense of strength, with flexural strengths ranging from 500–800 MPa. These materials are indicated for anterior crowns and veneers where esthetic demands predominate.¹⁹

Multilayer zirconia represents a significant innovation, incorporating gradient yttria content that transitions from a high-strength dentin-like core to a translucent enamel-like surface within a single blank. This architecture enables monolithic restorations with natural light transmission while maintaining sufficient strength for posterior loading. Clinical studies report survival rates exceeding 95% for multilayer zirconia crowns at five-year follow-up, with failures primarily attributable to secondary caries rather than material fracture.

Alumina-toughened zirconia (ATZ) and zirconia-toughened alumina (ZTA) composites are emerging as next-generation materials for implant applications. ATZ combines the fracture toughness of zirconia with the hardness and wear resistance of alumina, achieving bending strengths of approximately 993 MPa with enhanced reliability parameters (Weibull modulus) that reduce quality deviation in industrial production.²⁰ These composites are particularly relevant for endosseous implants and screw-retained prostheses where thread geometries require high mechanical integrity.²¹

Lithium disilicate glass-ceramics

Lithium disilicate (Li₂Si₂O₅) glass-ceramics, commercially available as IPS e.max CAD (Ivoclar Vivadent), represent the benchmark for esthetic CAD/CAM restorations. The material is supplied in a precrystallized blue state, milled to oversized dimensions, and subsequently subjected to a crystallization firing that increases flexural

strength from approximately 160 MPa to 360–400 MPa while generating a fine-grained microstructure with 70% crystalline content.²²

Clinical evidence supports the use of lithium disilicate for anterior crowns, veneers, and posterior partial-coverage restorations. A systematic review of CAD/CAM ceramic restorations reported survival rates of 95.5% for lithium disilicate crowns over a mean follow-up of 36 months, with chipping and fracture representing the primary failure modes.²³ The material's favorable optical properties, including translucency and fluorescence, enable highly esthetic outcomes that mimic natural enamel.

However, lithium disilicate is contraindicated for multi-unit bridges in high-stress posterior regions due to its lower fracture toughness compared with zirconia. The material also requires crystallization firing, precluding true chairside placement without an oven.

Polymer-infiltrated ceramic networks (PICNs)

PICN materials, exemplified by Vita Enamic (Vita Zahnfabrik), consist of a continuous ceramic network (feldspathic, zirconia-reinforced, or lithium silicate-based) infiltrated with a polymer phase (typically UDMA, Bis-GMA, or TEGDMA). This dual-network architecture yields mechanical properties intermediate between ceramics and composites, with elastic moduli (16–28 GPa) closely approximating human dentin (18 GPa) and enamel (80 GPa).⁶

The biomimetic stiffness of PICN materials reduces stress concentration at the restoration-tooth interface, potentially minimizing adhesive failure and tooth fracture. Additionally, the polymer phase confers excellent machinability, producing smooth margins with minimal chipping and reduced tool wear compared with fully crystalline ceramics. PICN restorations can be milled and polished without sintering, enabling efficient chairside workflows.

Limitations include moderate flexural strength (150–300 MPa depending on ceramic network composition), which restricts indications to single-unit inlays, onlays, veneers, and anterior or premolar crowns.²⁴ The material is not recommended for molar crowns or bridges where occlusal loads exceed its fatigue resistance. Recent innovations include polymer-infiltrated lithium disilicate networks that seek to enhance strength while retaining the crack-arresting benefits of the PICN architecture.

Resin nanoceramics

Resin nanoceramics, such as Lava Ultimate (3M ESPE) and Cerasmart (GC Corporation), consist of nanoceramic particles (zirconia, silica) dispersed within a highly cross-linked resin matrix.²⁵ These materials are milled from fully polymerized blocks, eliminating the need for post-milling sintering or crystallization and enabling immediate intraoral placement.

The nanoceramic filler content (approximately 80% by weight) provides improved wear resistance, color stability, and surface hardness compared with conventional resin composites, while the resin matrix confers shock absorption and reparability. Flexural strengths range from 150–200 MPa, with elastic moduli (12–15 GPa) lower than dentin, which may reduce stress transmission to the supporting tooth structure.

Clinical indications include inlays, onlays, veneers, and single crowns in low-stress situations. A retrospective study reported 98.5% survival for resin nanoceramic partial crowns over 36 months, though long-term data beyond five years remain sparse. The material's primary advantage lies in workflow efficiency, making it ideal for chairside same-day dentistry. However, its lower strength and potential for wear antagonist enamel limit application in patients with bruxism or heavy occlusal loads.

High-performance polymers

Polyetheretherketone (PEEK) is a semi-crystalline thermoplastic polymer with a flexural strength of 140–170 MPa and elastic modulus (3–4 GPa) closely matching human bone.²⁶ Its radiolucency, biocompatibility, and ability to be modified with fillers (such as barium sulfate for radiopacity or titanium dioxide for esthetics) have established PEEK as a versatile material for implant abutments, removable prosthesis frameworks, and fixed prosthetic superstructures.

PEEK's low elastic modulus provides shock absorption that may reduce peri-implant bone stress compared with rigid metal or ceramic abutments, potentially improving long-term implant stability. However, its low hardness and susceptibility to surface scratching necessitate veneering with composite resin or specialized coatings for esthetic applications.

Polyetherketoneketone (PEKK) offers higher mechanical properties than PEEK, with improved temperature resistance and chemical stability, though clinical adoption remains limited by higher cost and processing complexity.

Fiber-reinforced composites

Fiber-reinforced composites (FRCs) incorporate continuous glass, carbon, or polymer fibers within a resin matrix to enhance strength and fatigue resistance. CAD/CAM-processable FRC blocks, such as everX Posterior (GC Corporation), achieve flexural strengths of 300–400 MPa with fracture toughness superior to particulate-filled composites.²⁷

The fiber architecture arrests crack propagation and provides load-bearing capacity that approaches ceramic materials while retaining reparability and favorable wear characteristics. Indications include posterior crowns, temporary bridges, and implant-supported prostheses where resilience is prioritized over maximum strength.²⁸ FRCs are particularly relevant for patients with parafunctional habits or when replacing failed

ceramic restorations where tooth structure conservation is paramount.

Comparative clinical performance

A systematic review of CAD/CAM ceramic restorations synthesized data from 22 studies encompassing 1,300 restorations and reported overall survival rates of 96.3% at mean follow-up periods ranging from 12 to 120 months.²⁹ Zirconia and lithium disilicate demonstrated the highest survival rates (97.8% and 95.5%, respectively), while hybrid ceramics and resin nanoceramics showed satisfactory but slightly lower outcomes (94.1% and 93.8%, respectively) that may reflect their more restricted indications.

Marginal adaptation, assessed by micro-CT and silicone replica techniques, was consistently superior for CAD/CAM restorations compared with conventionally fabricated prostheses, with mean marginal gaps of 50–100 µm for milled zirconia versus 100–200 µm for pressed ceramics. This precision is attributed to the elimination of manual laboratory steps and the dimensional stability of machined materials.

Manufacturing workflow considerations

The selection of CAD/CAM materials is inextricably linked to manufacturing logistics:

Chairside workflows favor materials that require no post-milling processing. Hybrid ceramics, resin nanoceramics, and polymers can be milled, polished, and cemented within a single appointment, improving patient convenience and reducing laboratory costs.³⁰ However, these materials generally offer lower strength than sintered ceramics.

Laboratory workflows accommodate zirconia and lithium disilicate, which require sintering or crystallization firing. While this introduces additional time and equipment requirements, the resulting mechanical properties justify the investment for high-stress indications.

Milling center production leverages industrial five-axis systems for complex multi-

unit frameworks and implant bars. Optimized feed rates, tool geometries, and clamping systems are essential to prevent microfractures in zirconia and delamination in fiber-reinforced polymers.³¹

Emerging trends

Bioactive materials represent a frontier in CAD/CAM development. Bioactive glasses and ceramics with ion-releasing capabilities (calcium, phosphate, fluoride) can promote remineralization of adjacent tooth structure and provide antimicrobial effects.³² While currently a niche segment, integration of bioactive fillers into machinable blocks could transform restorations from passive replacements into therapeutic devices.

Self-healing composites embed microcapsules containing polymerizable agents that rupture upon crack formation, autonomously sealing microfractures and extending restoration longevity.³³ Though primarily experimental, this technology addresses the clinical challenge of secondary caries at restoration margins.

3D-printed ceramics are gaining traction as additive manufacturing complements subtractive milling. Direct ink writing of zirconia scaffolds followed by polymer infiltration enables customized PICN architectures with tunable mechanical properties.³⁴ Lithography-based ceramic manufacturing (LCM) now achieves wall thicknesses up to 17 mm with medical-grade ATZ, opening applications for patient-specific implants and complex geometries impractical to mill.³⁵

DISCUSSION

The 2026 CAD/CAM material landscape reflects a maturation of digital dentistry, wherein material selection has evolved from a binary choice between strength and esthetics to a nuanced decision matrix incorporating biological, mechanical, logistical, and economic variables. Zirconia, in its various formulations, maintains dominance in high-load applications due to exceptional strength

and improving translucency, while hybrid materials have carved essential niches in conservative, chairside, and biomimetic dentistry.

The convergence of material science and digital manufacturing is perhaps most evident in multilayer zirconia, which resolves the historical compromise between opacity and strength through gradient microstructural engineering. Similarly, PICN materials demonstrate that restorative materials need not replicate enamel's stiffness to function optimally; rather, matching dentin's elastic modulus may prove more protective of the residual tooth structure over the long term.⁶ This biomimetic approach is supported by finite element analyses showing that stress distribution at the restoration-tooth interface is more favorable when material stiffness approximates that of the supporting substrate, thereby reducing the risk of catastrophic tooth fracture.⁶

However, significant knowledge gaps persist. Long-term clinical data for hybrid ceramics and resin nanoceramics remain limited beyond five years, creating uncertainty regarding their performance in younger patients with longer life expectancies. A recent retrospective cohort study comparing zirconia and lithium disilicate restorations over five years found comparable cumulative survival rates (94.0% vs. 89.0%, respectively), though zirconia exhibited fewer technical complications, particularly in posterior and implant-supported situations.³⁶ This evidence suggests that while lithium disilicate remains the esthetic benchmark for anterior applications, zirconia's mechanical reliability may offer superior longevity under high occlusal loads.³⁶ The biological interaction of polymer phases with oral biofilms requires further investigation, particularly as concerns about microleakage and secondary caries persist across all material classes.

The emergence of high-performance polymers and fiber-reinforced composites challenges the assumption that restorations

must be rigid to be durable. In implant dentistry, where stress-shielding can precipitate bone loss, the deliberate selection of lower-modulus materials may improve biological outcomes despite conventional mechanical inferiority. Finite element studies have demonstrated that carbon fiber-reinforced PEEK (CFR-PEEK) implants reduce stress peaks at the implant-bone interface compared with titanium, thereby improving mechanical compatibility and load sharing along the implant length.³⁷ Similarly, investigations of PEEK hip prostheses have shown that the material's elastic modulus (3–4 GPa) closely matches human cortical bone, resulting in minimal stress shielding and significantly reduced bone resorption compared with titanium alloys (Ti6Al4V).³⁸ Specifically, PEEK implants demonstrated a 104% reduction in stress shielding increase and a 72% reduction in total bone loss compared with titanium counterparts.³⁸ This paradigm shift from maximum strength to optimal stress distribution will likely guide future material development, particularly as clinicians recognize that peri-implant bone preservation is as critical as prosthetic survival.

Manufacturing workflow integration remains a critical determinant of clinical success. The material-machine interface, encompassing tool selection, milling parameters, and post-processing protocols, directly influences marginal accuracy and surface integrity. As hybrid manufacturing chains combining 3D printing with subtractive finishing mature, material formulations must evolve to accommodate both additive and subtractive processing without compromising properties. Lithography-based ceramic manufacturing (LCM) now enables the production of alumina-toughened zirconia (ATZ) implants with wall thicknesses up to 17 mm, offering patient-specific geometries that are impractical to achieve through milling alone.²⁰ This additive capability is particularly relevant for ATZ composites, which combine the fracture toughness of zirconia with the hardness and wear resistance of alumina, achieving bending strengths of approximately

993 MPa with enhanced reliability parameters (Weibull modulus) that reduce quality deviation in industrial production.²⁰

Finally, sustainability considerations are increasingly influencing material selection. The energy-intensive sintering of zirconia, the waste generated during milling, and the non-recyclable nature of many polymer matrices present environmental challenges that the next generation of materials must address. Bioactive and biodegradable options, though currently nascent, may define the post-2026 landscape. A recent systematic review and meta-analysis of 40 randomized controlled trials (encompassing 5,506 restorations) provided conclusive evidence that bioactive restorative materials reduce the risk of secondary caries by 45% compared with conventional passive materials (risk ratio = 0.55; 95% CI: 0.46–0.65; $p < 0.001$).³⁹ Glass ionomer cements demonstrated the strongest protective effect (64% reduction), while newer bioactive resin composites showed promising trends.³⁹ This evidence supports the transition from passive restorations to therapeutic materials that actively modulate the oral environment, though future research must address the long-term mechanical longevity of these formulations to ensure they can withstand functional loading over extended periods.³⁹

CONCLUSION

The contemporary CAD/CAM material portfolio offers clinicians an unprecedented array of options tailored to specific clinical scenarios. Zirconia, particularly multilayer and alumina-toughened formulations, remains the material of choice for high-strength posterior and implant-supported restorations. Lithium disilicate continues to set the standard for esthetic anterior applications requiring a balance of strength and translucency. Hybrid ceramics and PICN materials provide biomimetic, conservative solutions for single-unit restorations, while resin nanoceramics optimize chairside efficiency. High-performance polymers and fiber-reinforced

composites expand indications into stress-distributing implant prostheses and resilient definitive restorations.

No universal CAD/CAM material exists; rather, optimal outcomes depend upon matching material properties to clinical demands, manufacturing capabilities, and biological contexts. As bioactive, self-healing, and sustainable materials transition from research to clinical application, the functional definition of dental restorations will expand beyond passive replacement toward active therapeutic interaction with the oral environment. Clinicians and researchers must maintain fluency in this evolving landscape to harness the full potential of digital restorative dentistry.

Conflicts of Interest: The authors declare no conflicts of interest.

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