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Polymer-Infiltrated Ceramic Network: A Comprehensive Review of Hybrid Ceramics in Dentistry

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Abstract

Polymer-infiltrated ceramic network (PICN) is a hybrid computer-aided design (CAD)/computer-aided manufacturing (CAM) restorative material consisting of an interconnected porous ceramic scaffold infiltrated with a polymer phase. The interpenetrating structure is intended to combine the stiffness of a ceramic framework with some of the strain accommodation of a polymer. The commercially established feldspathic PICN material contains approximately 86 wt.% (75 vol.%) ceramic and 14 wt.% (25 vol.%) polymer, principally based on urethane dimethacrylate (UDMA) and triethylene glycol dimethacrylate (TEGDMA). PICN materials have been investigated for inlays, onlays, veneers and single-unit crowns. Their properties differ from those of conventional glass ceramics, polycrystalline ceramics and resin-matrix composites. This narrative review discusses PICN structure, manufacturing, physical and mechanical properties, bonding characteristics, biocompatibility and clinical applications. Laboratory evidence indicates material-specific damage tolerance and wear behaviour, while flexural strength is generally lower than that of lithium disilicate and zirconia. Clinical evidence includes limited prospective data on wear, but does not establish overall clinical superiority or better patient outcomes. Material selection should therefore be based on restoration type, occlusal conditions, product-specific indications and appropriate adhesive protocols. Further comparative clinical studies with adequate follow-up are required to clarify clinical performance.

Categories: Dentistry
Keywords: clinical performance, computer-aided design (cad)/computer-aided manufacturing (cam), dental porcelain, dental restoration, flexural strength, hybrid ceramics, polymer

Introduction And Background

The importance of material selection for indirect restorations cannot be overstated, as it directly affects the longevity and function of dental work. Various options are available, including all-ceramic materials, porcelain-fused-to-metal, cast-gold alloys, zirconia-based ceramics, glass-based systems and resin-matrix composites; each offers unique advantages for specific clinical scenarios and aesthetic requirements [1].

Polymer-infiltrated ceramic network (PICN) is a computer-aided design (CAD)/computer-aided manufacturing (CAM) material that combines a porous ceramic network with an infiltrated polymer phase. The established feldspathic PICN system comprises approximately 86 wt.% (75 vol.%) ceramic and 14 wt.% (25 vol.%) polymer, principally urethane dimethacrylate (UDMA) and triethylene glycol dimethacrylate (TEGDMA) [2]. The ceramic and polymer phases form interpenetrating networks, distinguishing PICN from resin-matrix materials in which ceramic fillers are dispersed within a continuous resin matrix [2].

The concept of interpenetrating networks has historical links with glass-infiltrated ceramic systems such as In-Ceram. However, glass-infiltrated alumina ceramics and PICNs are compositionally distinct and should not be treated as identical materials. The development of PICN sought to combine a continuous ceramic framework with a polymer network to modify stress distribution and damage tolerance [2].

Previous reviews have discussed the composition and properties of PICN [3]. A systematic review of resin-ceramic CAD/CAM material wear also included PICN, but its evidence base comprised several material classes and only one clinical study [4]. Subsequent PICN investigations have examined wear, hardness and flexural modulus, optical properties and clinical use [5-9]. Surface-conditioning and bonding protocols have also been discussed [10]. Findings from resin nanoceramics and other resin-matrix materials should not be treated as direct evidence for PICN because their microstructures differ. Laboratory results also vary according to specimen design, test method, surface treatment and aging conditions.

The objective of this narrative review is to provide a clinically oriented overview of PICN materials,

including their structure, manufacturing procedure, physical and mechanical properties, bonding characteristics and restorative applications. Particular attention is given to distinguishing PICN from other hybrid CAD/CAM material classes and to discussing the limitations of the available evidence.

Relevant literature was identified through focused searches of the dental and biomedical literature using combinations of the terms "polymer-infiltrated ceramic network", "PICN", "VITA Enamic", "hybrid ceramics", "CAD/CAM", "mechanical properties", "wear", "fatigue", "bond strength", "biocompatibility" and "clinical performance". Foundational papers, relevant narrative reviews, laboratory studies and available clinical investigations were considered. Reference lists of pertinent articles were checked to identify additional relevant publications. Studies of other resin-matrix or hybrid CAD/CAM materials were used only for clearly labelled comparisons and were not treated as direct PICN evidence. The literature was organized thematically around composition, manufacture, mechanical and physical properties, bonding, biocompatibility and clinical use. This was a narrative review; selection was based on relevance to the review objectives and did not involve a predefined systematic screening process, formal risk-of-bias assessment or quantitative synthesis. Accordingly, the article should be interpreted as a thematic narrative synthesis rather than an exhaustive inventory of all available evidence.

Review

Structure of PICN

Ceramic Network

The ceramic component of a PICN material begins as a porous ceramic scaffold. In the established commercial feldspathic PICN system, this scaffold forms an interconnected three-dimensional framework that provides much of the material's stiffness and hardness. Experimental PICN formulations may use other ceramic compositions; therefore, descriptions of alumina- or zirconia-containing networks should not automatically be generalized to all commercial PICN materials.

Polymer Infiltration

The polymer phase generally comprises dental methacrylate-based resins, including UDMA and TEGDMA, in the established feldspathic system. The resin precursor penetrates the interconnected pores of the ceramic scaffold and is subsequently polymerized. The polymer phase contributes to the interpenetrating architecture and may influence energy dissipation and crack propagation.

Interfacial Bonding and Microstructure

The interface between the ceramic and polymer phases is important for load transfer and material integrity. The final material consists of two continuous, interpenetrating phases rather than ceramic particles dispersed in a resin matrix. The ceramic phase contributes rigidity and hardness, while the polymer phase may contribute compliance and damage tolerance [2].

Manufacturing procedure of PICN

The fabrication of PICN materials involves several critical steps to achieve the desired mechanical and physical properties (Figure *1*). The porosity and connectivity of the scaffold influence the extent of resin infiltration and the final material properties.

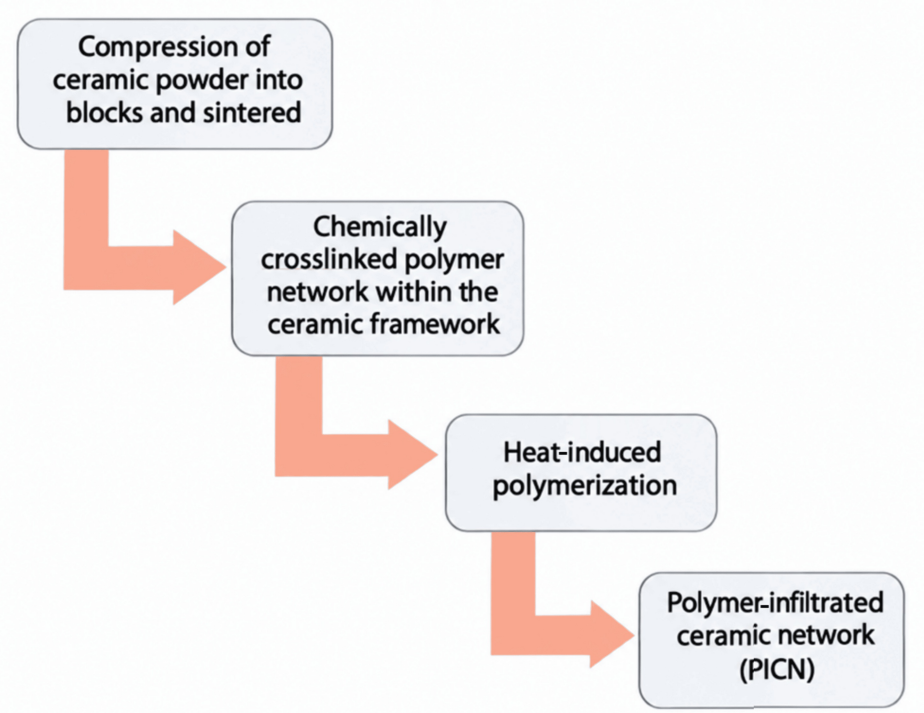


FIGURE 1: Manufacturing procedure of polymer-infiltrated ceramic network materials

The figure was created by the authors using Microsoft Word (Microsoft Corporation, Redmond, Washington, United States).

Step 1: Production of Porous Pre-sintered Feldspathic Ceramic

Initially, a porous pre-sintered feldspathic ceramic with adjustable density is produced. Ceramic powder is compressed into blocks and then sintered to form a porous ceramic network. The porosity of the ceramic can be controlled by adjusting the particle size of the ceramic powder and the firing temperature. This control of porosity is essential because it influences the final mechanical properties and the degree of resin infiltration.

Step 2: Resin Infiltration

Before resin infiltration, the porous ceramic network is conditioned with a coupling agent to facilitate chemical bonding between the ceramic and polymer networks.

Following conditioning, the porous ceramic structure is infiltrated with a cross-linking polymer mixture through capillary action. The polymer mixture typically consists of UDMA, TEGDMA and dibenzoyl peroxide. These components form a chemically cross-linked polymer network within the ceramic framework.

Step 3: Heat-Induced Polymerization

After resin infiltration, heat-induced polymerization is performed to initiate polymer curing. This process forms a solid polymer network that interpenetrates the ceramic framework, resulting in the final PICN material. The interpenetrating structure combines the advantageous properties of both ceramic and polymer phases, providing improved mechanical strength, stress distribution and aesthetic characteristics.

Physical properties of PICN

PICN materials combine a ceramic framework with a polymer phase, resulting in a combination of stiffness, hardness, compliance and optical characteristics that differs from conventional ceramics (Figure *2*). Their properties should be interpreted in relation to the specific product and test conditions. PICN-specific investigations have evaluated properties such as hardness and flexural modulus, which are influenced by material structure and composition [6].

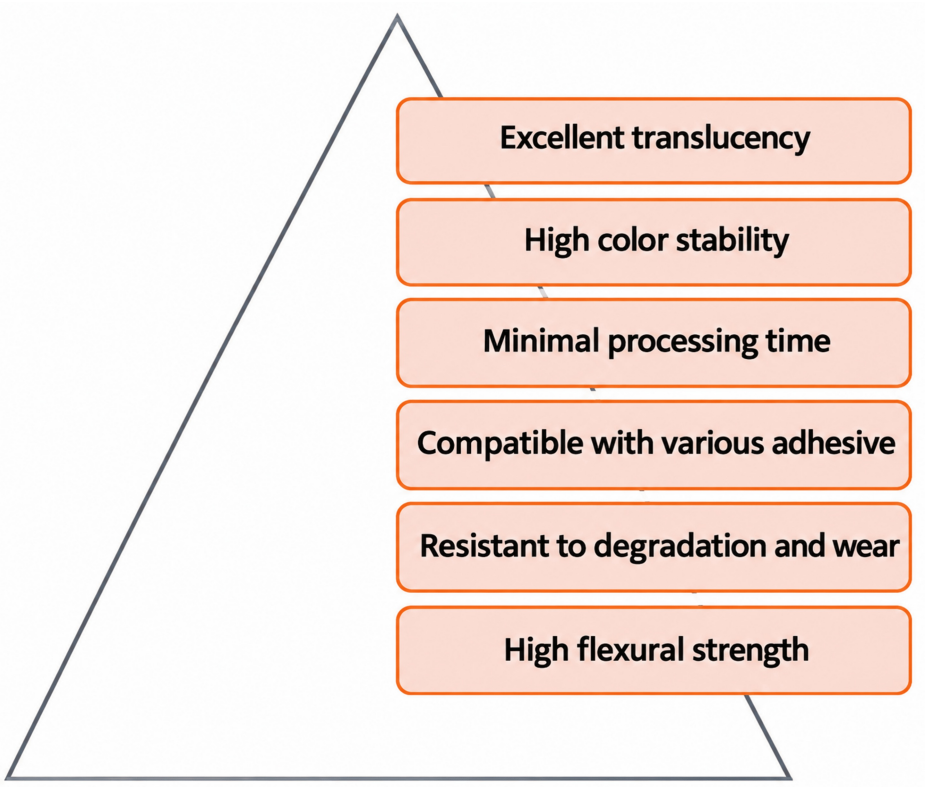


FIGURE 2: Physical properties of polymer-infiltrated ceramic network materials

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Flexural Strength

Flexural strength is an important mechanical property because it describes the stress at failure under a specified bending test. Available laboratory studies indicate that PICN has lower flexural strength than high-strength ceramics such as lithium disilicate and zirconia, although values vary with composition, specimen dimensions, surface preparation and testing method [2,11]. Findings from experimental PICN formulations and commercial materials should not be assumed to be interchangeable. The elastic behavior of PICN is distinct from that of more rigid ceramics and may influence stress distribution.

Fatigue Resistance

The interpenetrating structure may contribute to damage tolerance under cyclic loading. Nevertheless, fatigue performance depends on loading conditions, specimen geometry, surface flaws, environment and cementation. Resin-matrix CAD/CAM materials have been investigated as a separate material class; their findings should not be treated as direct evidence for PICN. Lava Ultimate, for example, is a resin-matrix nanoceramic rather than a PICN material [12]. Numerical fatigue values from different studies should not be directly compared unless test protocols are equivalent.

Wear Resistance

Wear behavior is influenced by the antagonist material, surface roughness, polishing protocol, loading pattern and test environment. In a laboratory comparison with enamel, PICN showed a wear-damage mode similar to enamel, but its wear resistance was lower than that of enamel [5]. A five-year prospective clinical study has also reported intraoral wear outcomes for PICN CAD/CAM restorations used in the treatment of severe tooth wear [7]. Numerical wear values reported across different investigations should be interpreted cautiously because measurement methods and units may differ. Controlled polishing has been shown to affect the flexural strength of dental ceramics; this is relevant to finishing after adjustment but is not a PICN-specific finding [13].

PICN is not completely resistant to chemical aging. Laboratory work has examined the effect of acidic agents

on wear behavior [14]. Such findings support consideration of the oral environment but do not establish a specific dietary intervention as a proven means of prolonging restoration survival.

Biocompatibility

In vitro investigations using human gingival fibroblasts have evaluated the cellular response to PICN materials [15]. These findings provide preliminary evidence under the specific experimental conditions studied; they do not establish complete biological inertness or predict all clinical tissue responses. Biocompatibility may also be influenced by surface condition, residual monomer, luting materials, marginal integrity and clinical handling. General principles of dental biomaterial biocompatibility have also been reviewed, although that review is not PICN-specific [16].

Fracture Toughness

Fracture toughness describes resistance to crack propagation in the presence of a flaw [17]. PICN has been investigated for damage tolerance after simulated bur adjustment and for strength degradation following indentation [2,11]. These studies provide evidence about damage response under specific laboratory conditions; they do not establish that PICN has greater fracture toughness than conventional ceramics as a class. The magnitude of any material advantage depends on composition, surface damage and test conditions.

Bond Strength and Surface Conditioning

Adhesive cementation is important for PICN restorations. For silica-based PICN materials such as VITA Enamic, hydrofluoric acid etching followed by silanization is commonly used; the etching concentration and duration must follow the current instructions for the specific product [10,18]. In vitro studies have shown that surface treatment affects bond strength to PICN, but the results depend on the substrate, repair or luting material, surface treatment and test method [18]. These laboratory findings should not be interpreted as proof of long-term clinical bond durability. Surface-conditioning protocols are material-dependent and should not be generalized across all hybrid CAD/CAM blocks. Zirconia is not etched with hydrofluoric acid and generally requires an appropriate air abrasion and 10-methacryloyloxydecyl dihydrogen phosphate (MDP)-based bonding approach, whereas lithium disilicate follows a glass ceramic-specific etching and silanization protocol.

Aesthetic Properties

Aesthetic performance is a critical factor in restorative dentistry because it directly affects patient satisfaction. Aesthetic performance is influenced by translucency, shade, restoration thickness, substrate color, cement shade and aging. PICN materials offer useful translucency and shade integration for selected restorations. Additionally, PICN materials can be polished to a smooth surface finish, reducing plaque accumulation and maintaining long-term aesthetic appearance. In vitro studies have evaluated their translucency and color stability after accelerated aging [8]. These properties may be advantageous in selected cases, but PICN should not be described as universally more aesthetic or more color-stable than all conventional ceramics.

Table *1* provides a qualitative comparison of broad material characteristics of PICN, lithium disilicate and zirconia. It is not intended as a quantitative ranking, because properties vary by formulation, product generation, test method and clinical indication. Wear studies on zirconia also demonstrate that composition and material formulation influence wear behavior, so a single generalized ranking should be avoided [19].

Property	PICN (e.g., VITA Enamic)	Lithium disilicate	Zirconia
Microstructure	Interpenetrating ceramic and polymer networks	Glass-ceramic matrix with crystalline phase	Predominantly polycrystalline ceramic
Strength and stiffness	Generally lower flexural strength than high-strength ceramics; modulus is material- and test-dependent	Generally higher flexural strength than PICN	High strength and stiffness; formulation-dependent
Damage behavior	May show damage tolerance after selected adjustment procedures; not proof of clinical fracture resistance	Brittle fracture behavior; sensitive to flaws	Transformation toughening in suitable formulations
Wear	Wear findings vary with antagonist, finish and test conditions; selected studies report favorable results	Depends on surface finish and antagonist	Polished surface is important, especially after adjustment
Optical properties	Translucent; affected by thickness and substrate	Good translucency and established aesthetic options	Translucency varies with formulation
Bonding	Silica-based PICN: HF etching and silane per manufacturer	HF etching and silane	Air abrasion and MDP-based primer/cement; no HF etching
Typical indications	Selected inlays, onlays, veneers and single-unit crowns, subject to manufacturer indications	Inlays, onlays, veneers and crowns	Crowns and fixed prostheses according to formulation
Evidence base	Limited comparative clinical evidence; long-term comparative outcomes remain uncertain	More extensive clinical evidence than PICN	More extensive clinical evidence than PICN; formulation-specific considerations

TABLE 1: Qualitative comparison of PICN, lithium disilicate and zirconia

The comparison summarizes broad material-class characteristics and should not be interpreted as direct head-to-head quantitative evidence.

PICN: polymer-infiltrated ceramic network; HF: hydrofluoric acid; MDP: 10-methacryloyloxydecyl dihydrogen phosphate

Factors affecting the properties of PICN

Composition of the Ceramic Phase

The ceramic skeleton provides structural strength and stability. Higher ceramic content improves hardness and flexural strength.

Composition of the Polymer Phase

Variations in polymer composition and additives can improve flexibility, strength and durability.

Polymerization Techniques

Optimizing polymerization pressure and temperature may improve polymer conversion and mechanical performance.

Density of the Ceramic Network

Higher ceramic density (59-72%) may significantly enhance flexural strength and fracture toughness.

Additives and Fillers

Incorporation of fillers can improve material strength, hardness and durability.

The relationship between these variables is not necessarily linear; therefore, fixed density ranges should not be used to predict a uniform improvement in every mechanical property. Experimental PICN-related investigations have also examined hardness and flexural modulus as tooth-relevant properties [6], while broader reviews and thesis work provide additional context for the development of this material class [3].

Environmental Factors

Environmental conditions such as temperature and humidity can influence degradation processes and moisture absorption in the polymer matrix.

Clinical Factors

Restoration design, thickness, occlusal loading, surface finishing and adhesive cementation also affect clinical performance.

Effect of chewing dynamics on PICN material properties

PICN restorations are exposed to repeated and variable masticatory loads. Their performance depends not only on intrinsic flexural strength but also on restoration geometry, support from the remaining tooth, occlusal contacts, surface flaws and bonding. The interpenetrating structure may provide useful damage tolerance under selected loading conditions; however, available evidence does not justify claims of minimal degradation or consistently superior longevity under all clinical conditions.

Clinical applications and limitations

PICN blocks have been used for CAD/CAM inlays, onlays, veneers and single-unit crowns, subject to product-specific indications and adequate restorative thickness. Their machinability, optical properties and relatively compliant behavior may be advantageous in selected clinical situations. Clinical reports describe the use of PICN CAD/CAM prostheses in the management of worn dentitions [7,20]. The five-year prospective wear study included seven patients and 192 restorations; its findings are relevant to wear in that specific treatment context but should not be generalized as proof of superior overall clinical outcomes or long-term superiority over other restorative materials [7].

Important limitations include heterogeneity among laboratory methods, limited long-term comparative clinical evidence, product-specific differences and the influence of surface treatment and cementation. Future studies should use standardized testing and prospective clinical designs with adequate follow-up.

Conclusions

PICN materials represent a distinct class of hybrid CAD/CAM restorative materials characterized by interconnected ceramic and polymer networks. Their potential advantages include useful machinability, a relatively compliant mechanical response compared with many conventional ceramics and favorable damage tolerance and wear characteristics under selected conditions. PICN materials may be considered for carefully selected inlays, onlays, veneers and single-unit crowns when product-specific indications and adhesive protocols are followed. PICN should not be regarded as universally superior to conventional ceramics or as a direct substitute for lithium disilicate or zirconia in every clinical situation. Its lower flexural strength relative to these materials, the importance of surface conditioning and cementation and the limited duration of much of the available clinical evidence should be considered during material selection. Current clinical evidence, including a five-year prospective wear study in a small patient cohort, is not sufficient to establish overall clinical superiority, improved patient outcomes or greater long-term survival compared with established ceramic systems. Further standardized laboratory investigations and well-designed prospective clinical studies with longer follow-up are needed to confirm their durability and clinical reliability.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Critical review of the manuscript for important intellectual content: Aarti S. Bedia, Sumit V. Bedia, Mahesh Ghadage, Amit Patil

Supervision: Aarti S. Bedia, Sumit V. Bedia, Mahesh Ghadage

Acquisition, analysis, or interpretation of data: Dipooja Patil, Priyanka Gupta, Amit Patil

Drafting of the manuscript: Dipooja Patil, Priyanka Gupta

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