"Another term used to categorize these materials is 'resin-matrix ceramics,' which are designed to combine the advantages of polymers, such as minimal antagonist wear, improved flexural properties, and ease of finishing and polishing, with those of ceramics, such as color stability and structural durability."

CLINICAL REVIEW OF RESIN-BASED CAD/CAM RESILIENT CERAMIC MATERIALS

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Abstract

Resilient ceramics are a category of chairside CAD/CAM materials designed to improve the brittle nature of glass-ceramics to prevent chipping and fracture while maintaining the efficient finishing process of resin-based polymers. Resilient ceramics are not subject to polymerization shrinkage and have a low modulus of elasticity, meaning they also have good load capacity. They also have a decreased risk of chipping and wear favorably against opposing dentition. They are clinically indicated for inlays, onlays, crowns, and veneers. Resilient ceramics have demonstrated comparable clinical outcomes to ceramic materials for partial-coverage restorations over a 5-year period; however, longer-term data are lacking.

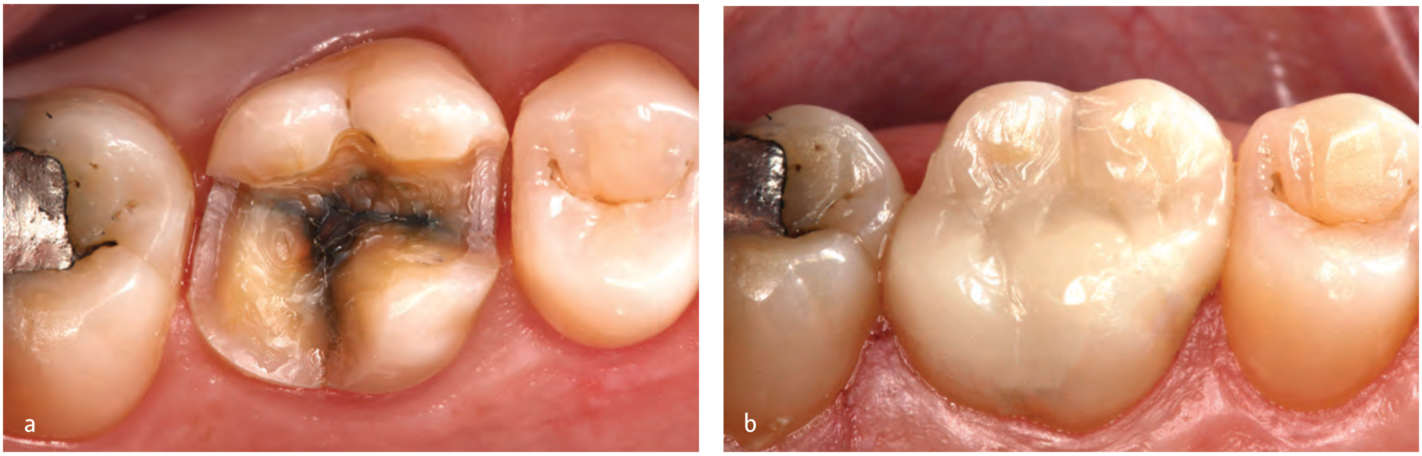
Key Words: CAD/CAM, resilient ceramics, resin-matrix ceramics, milled composite, digital chairside dentistry

TABLE 1

Categories of Chairside CAD/CAM Materials

Category	CAD/CAM Material	Brand (Manufacturer)
Adhesive Ceramic	leucite-reinforced	IPS Empress CAD (Ivoclar) Initial LRF (GC America)
	feldspathic	VITABLOCKS Mark II (VITA) CEREC Blocs C (Dentsply Sirona)
High-Strength Ceramic	lithium disilicate	IPS e.max CAD (Ivoclar) CEREC Tessera (Dentsply Sirona)
	zirconia lithium silicate	Celtra Duo (Dentsply Sirona) Suprinity (VITA)
Resilient Ceramic	nanoceramic	Lava Ultimate (3M) Tetric CAD (Ivoclar) Cerasmart (GC America)
	hybrid ceramic (PICN)	Enamic (VITA)
Composite	composite	Paradigm MZ100 (3M) Brilliant Crios (Coltene)
Zirconia	zirconia 3mol%	IPS e.max ZirCAD LT (Ivoclar) CEREC Zirconia (Dentsply Sirona)
	zirconia 4mol%	CEREC Zirconia+ (Dentsply Sirona) CEREC MTL Zirconia (Dentsply Sirona) CEREC Cercon 4D (Dentsply Sirona) IPS e.max ZirCAD Prime (Ivoclar) KATANA Zirconia One (Kuraray Noritake) 3M Chairside Zirconia (3M)
	zirconia 5mol%	KATANA Zirconia (Kuraray Noritake)
Provisional	reinforced resin	VITA CAD-Temp (VITA) Telio CAD (Ivoclar)

"Another way to distinguish between brands of resilient ceramics is to consider them as resin nanoceramic (RNC) or PICN materials. RNC materials are described as having a polymer matrix with randomly dispersed nanometer-sized ceramic fillers (silica or zirconia). PICN material is described as having a ceramic network with an interpenetrating polymer phase."



Figures 1a & **1b**: Views of (a) preparation and (b) cemented hybrid ceramic onlay (Tetric CAD) for the maxillary right first molar, demonstrating a very good chameleon effect as the monolithic restoration blends well with the adjacent tooth shade. Case from Fasbinder et al., 2022.[31]

Introduction

The advent of chairside CAD/CAM technology ushered in a new era in restorative dentistry. This technology enables dentists and their dental teams to fabricate and deliver indirect restorations in-office during a single dental appointment. This prevents the need to manage provisional restorations and avoids a second dental appointment.

The variety of materials available for chairside CAD/CAM application has expanded as the technology has evolved **(Table 1)**.[1] Adhesive glass-ceramic materials were initially introduced with the chairside CAD/CAM process, providing esthetic restorations with an efficient workflow. However, due to the brittle nature of ceramics, these materials had a risk of surface chipping or fracture. The development of high-strength ceramic and full-contour zirconia materials has led to their supplanting adhesive glass-ceramic materials for most restorative applications. However, these higher-strength materials require lengthier in-office fabrication processes, as oven firing or a sintering cycle is required after milling the restoration to achieve the desired strength. This longer post-milling process may require up to 35 to 40 minutes to complete.

Manufacturers have developed alternative materials that combine the properties of polymers and ceramics to improve the brittle nature of adhesive glass-ceramics so as to prevent chipping and fracture while maintaining an efficient finishing process. These materials have been referred to as "resilient ceramics" to distinguish them from conventional composite resins in CAD/CAM resin-based materials.[2] They have a modulus of elasticity similar to dentin that can withstand greater functional loads without succumbing to brittle fracture. Another term used to categorize these materials is "resin-matrix ceramics,"[3] which are designed to combine the advantages of polymers, such as minimal antagonist wear, improved flexural properties, and ease of finishing and polishing, with those of ceramics, such as color stability and structural durability. Additional terms are sometimes used to distinguish between brands of resilient ceramics, including nanoceramic, hybrid ceramic, and polymer-infiltrated ceramic network (PICN).

Clinicians may not be as familiar with this category of CAD/CAM materials as they are with high-strength and zirconia materials. The focus of this article is to explore the material properties, clinical indications, and clinical evidence of resilient ceramics for chairside CAD/CAM restorations.

Figures 2a-2c: Hybrid ceramic crown (Tetric CAD) on the mandibular left second molar with progressive functional occlusal wear compared to a leucite-reinforced ceramic crown (IPS Empress CAD) on the first molar at (a) baseline, (b) 6-month recall, and (c) 3-year recall. Case from Fasbinder et al., 2022.[31]

Resilient Ceramics

Since 2011, several manufacturers have introduced resilient ceramic materials for chairside CAD/CAM restorations. The demand for this category of materials in the North American marketplace is considerably lower than that for high-strength ceramics and zirconia; however, resin-based materials are very popular in international markets.

Lava Ultimate (3M; St. Paul, MN) was the first resilient ceramic chairside CAD/CAM material, introduced to the marketplace in 2011. It is described as a resin nanoceramic material containing a combination of 80% by weight aggregated 20 nm silica and 4- to 11-nm zirconia clusters in a highly cross-linked resin matrix.[2] It cannot be etched because it has no glass particles available for etching and requires air abrasion for adhesive cementation.[2] These CAD/CAM blocks are heavily particle-filled resins cured by the manufacturer at a high temperature and pressure.[4] The material exhibits a flexural strength of 200 MPa and a dentin-like modulus of elasticity of 12 GPa.[5]

VITA Enamic (VITA Zahnfabrik; Bad Säckingen, Germany) was introduced in 2013 and is described as a polymer-interpenetrating network (PICN) containing feldspathic porcelain at 86% by weight and an interpenetrating polymer network at 14% by weight.[6] This material differs from Lava Ultimate in that it contains pre-sintered ceramic, which facilitates a higher volume of filler (~70%). This increased filler load results in improved mechanical properties, as reported.[7,8] It also contains urethane dimethacrylate (UDMA) and triethylene glycol dimethacrylate (TEGDMA) cross-linked polymers and a fine, open, porous feldspathic ceramic structure network.[7]

Cerasmart (GC America; Alsip, IL) is referred to by the manufacturer as a "flexible" nanoceramic with a homogenous and evenly distributed nanoceramic network. The manufacturer has reported a flexural strength of 240 MPa. It is described as containing 29% polymer matrix (UDMA, dimethacrylate, ethoxylated bisphenol A dimethacrylate [bis-MEPP]) and 71% silica nanoparticles (20 nm) and barium glass (300 nm).[9]

Tetric CAD (Ivoclar; Amherst, NY) is a millable hybrid ceramic block. The manufacturer reports a flexural strength of 273.8 MPa and an elastic modulus of 10.2 GPa.[10] It is described as a nanohybrid composed of 28% polymer matrix (bisphenol A glycidyl methacrylate [bis-GMA], ethoxylated bisphenol A dimethacrylate [bis-EMA], TEGDMA, UDMA) and 71% inorganic fillers: barium aluminum silicate glass (< 1 mm) and silicon dioxide (< 20 nm).[9]

Another way to distinguish between brands of resilient ceramics is to consider them as resin nanoceramic (RNC) or PICN materials.[9] RNC materials are described as having a polymer matrix with randomly dispersed nanometer-sized ceramic fillers (silica or zirconia). PICN material is described as having a ceramic network with an interpenetrating polymer phase.

Material Properties

Composite resin is widely used as a restorative material for direct restorations; however, one of its most significant limitations is that it undergoes polymerization shrinkage when light-cured.[11] Polymerization shrinkage occurs as the composite resin cures because the resin monomers convert to polymers, resulting in a decrease in material volume.[12] Polymerization shrinkage stress may lead to cusp deflection, marginal and internal gaps, crack propagation, and decreased bond strength. Polymerization shrinkage can be minimized through incremental placement; however, it can be problematic when cavity margins extend laterally to the line angles or have subgingival cervical margins, resulting in less-than-optimal proximal contours or contacts. Resilient ceramics overcome this material limitation since they are premanufactured as mill blocks. The controlled manufacturing process, conducted under high temperatures and high pressures, creates higher volume filler loads and higher conversion rates (85%) compared to direct composite materials, which maximizes physical properties.[13,14] The filler type and particle size are manufacturer-specific. They also have the advantage of being milled as a monolithic restoration utilizing chairside CAD/CAM technology, which makes for more predictable proximal contours, contacts, and occlusal relationships compared to the incremental placement of direct composites.

High-strength restorative materials have become desirable because they resist fracture of the restoration. The flexural strength of resilient ceramics falls within the moderate range of 150 to 225 MPa; however, they also exhibit a modulus of elasticity approaching that of dentin.[14] This results in a material with a good load capacity for absorbing functional forces and a lower risk of brittle fracture than adhesive glass-ceramic materials.

Resilient ceramics are highly compatible with CAD/CAM manufacturing, as they exhibit higher damage tolerance and a lower risk of marginal chipping, resulting in smoother margins when milled.[15,16] Glass-ceramics, on the other hand, are brittle materials that are susceptible to chipping, particularly when the milled material approaches minimal thickness. Resin-based CAD/CAM materials have improved marginal accuracy following milling compared to glass-ceramics.[15]

One in vitro study reported that resilient ceramics demonstrate excellent accuracy of fit and marginal adaptation.[14] This study utilized a replica technique to compare the internal fit of CAD/CAM inlays made from two nanoceramics (Cerasmart and Lava Ultimate), a PICN material (VITA Enamic), and a machinable lithium disilicate glass-ceramic (IPS e.max CAD [Ivoclar]). All values were well within clinically acceptable guidelines, with no significant differences in the fit along the axial wall. There was no significant difference in the mean internal fit for IPS e.max and Cerasmart inlays, which were both significantly smaller than those for Lava Ultimate and VITA Enamic.

Resilient ceramics must be adhesively bonded to the tooth, as they lack sufficient strength properties for conventional cementation. Increasing the surface roughness of the restoration has been shown to be more important than chemical conditioning with silane to maximize the bonding properties of resilient ceramics.[17,18] Most resilient ceramics do not contain a significant glass phase volume that can be etched with hydrofluoric acid.[19] Most studies agree that air particle abrasion (using 50-µm alumina particles) is recommended to roughen the material surface to increase surface energy and maximize micromechanical interlocking.[18] The use of hydrofluoric acid to etch the material surface results in lower bond strength values, while treating the surface with silane after sandblasting is generally recommended to increase bond strength further.[18] PICN materials do contain a sufficient glass phase volume that can be etched with hydrofluoric acid for adhesive bonding.[20] It is important to review the specific manufacturer's instructions to ensure the correct means of preparing the material for adhesive bonding.

"Resilient ceramics are highly compatible with CAD/CAM manufacturing, as they exhibit higher damage tolerance and a lower risk of marginal chipping, resulting in smoother margins when milled."

Figures 3a-3d: The nanoceramic onlay (Lava Ultimate) for the mandibular left first molar in a patient with (a & b) an anterior open bite and heavy functional posterior wear, demonstrating compatible occlusal wear at the (c & d) 1-year recall.

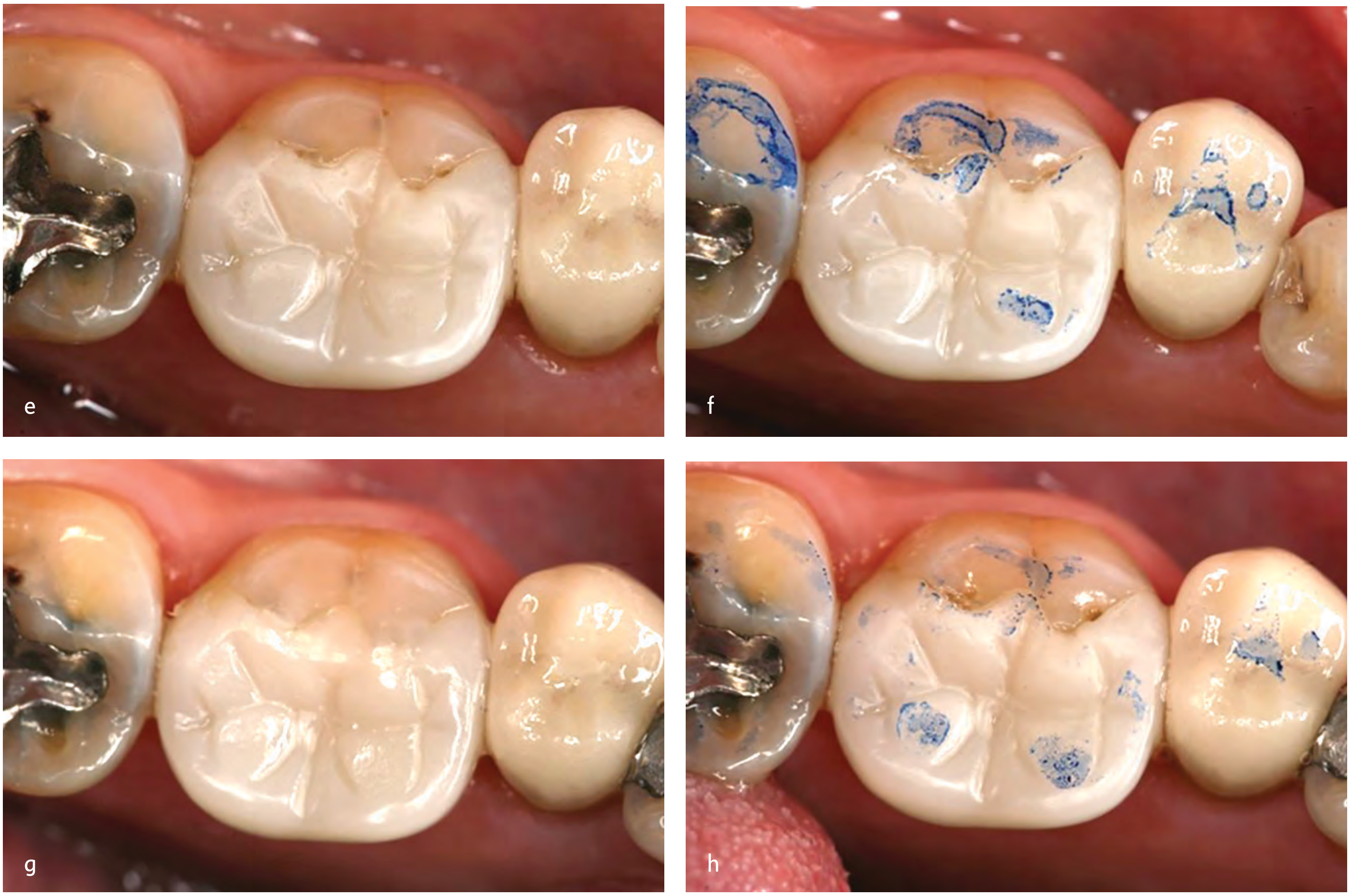
Clinical Indications

Resilient ceramics are clinically indicated for inlays, onlays, and veneers. They are also indicated for crowns, apart from Lava Ultimate, as 3M removed the crown indication in June 2015. These materials have an excellent chameleon effect, described as the ability to blend well with the adjacent tooth structure **(Figs 1a & 1b)**. This makes them a particularly suitable choice for inlays and onlays, as custom shading is generally not needed. Resilient ceramics can be shade-modified with surface resin tints that are applied and light-polymerized. However, the tints lack the color intensity found with ceramic stains and glaze.

Glass-ceramics tend to be more resistant to occlusal wear than resilient ceramics. However, ceramics also tend to be more abrasive to the opposing dentition. Resilient ceramics show greater wear in function compared to ceramics but cause low wear of the opposing dentition **(Figs 2a-2c)**. This characteristic suggests that resilient ceramics may be the most wear-compatible material for bruxers, as they have minimal effect on the opposing dentition.[9,21] A clinical application is illustrated in **Figures 3a-3h** of a patient with an anterior open bite and heavy posterior lateral function resulting from a lack of anterior guidance. The nanoceramic onlay demonstrated good adhesive retention, maintaining the surface despite heavy functional stress.

One study evaluated the wear resistance and abrasiveness of CAD/CAM materials.[22] A nanoceramic (Lava Ultimate), a PICN (VITA Enamic), a zirconia (Lava Plus), and two lithium disilicate ceramics (IPS e.max CAD and VITA Suprinity) were subjected to a 2-body wear test against the other materials in the study and enamel. The nanoceramic and PICN were more antagonist-friendly compared to other CAD/CAM materials such as the glass-ceramics and zirconia. They also caused the least enamel wear. One systematic review of material wear for CAD/CAM ceramic resin materials screened 310 articles and selected 26 for inclusion.[9] Of these, only one was a clinical study.[9] The PICN showed less abrasive wear than the RNCs. Of the RNCs, Cerasmart had less attrition wear and less wear of the opposing teeth.

Resilient ceramic materials do not require an oven firing or sintering process following milling. They are hand-polished



Figures 3e-3h: (e & f) 3-year recall and (g & h) 5-year recall. Case from Fasbinder et al., 2020.[27]

following milling, which results in the shortest post-milling processing for the final restoration to be ready for delivery.[7,18,23] Diamond-impregnated polishers used to contour and polish glass-ceramics are too aggressive to create the high-gloss surface desired on resilient ceramics. These materials require a less aggressive approach and tend to polish more like direct composite materials. The use of rubber polishers, bristle brushes, and diamond polishing paste can create a predictable high-gloss surface finish **(Fig 4)**.[24] When polished, resilient ceramics like Lava Ultimate and VITA Enamic have demonstrated a surface as smooth as the leucite-reinforced ceramic IPS Empress CAD (Ivoclar).[2]

Glazed ceramic surfaces have been considered the preferred standard in smoothness for ceramic materials. This has been an appreciated property of ceramic materials, as the surface is maintained over time. However, more recent literature has demonstrated that manually polished CAD/CAM ceramics provide a significantly smoother surface.[25] A reasonable concern with CAD/CAM resin-based restorations is their ability to retain an esthetic, glossy surface after years of clinical service. One recent in vitro study evaluated the effects of aging on color, surface gloss, and surface roughness of resilient ceramics.[26] Six different CAD/CAM resin-based materials were tested, including Cerasmart, Lava Ultimate, and Tetric CAD. Although there were significant differences in the roughness of the polished surfaces initially, no significant changes in surface gloss were found among materials after thermocycling and aging.

One early prospective clinical trial evaluated the use of adhesively bonded nanoceramic (Lava Ultimate) partial-coverage crowns over a 24-month period.[19] The restorations had a 95% success rate after 12 months and an 85.7% success rate at 24 months. Surface chipping did not occur for any of the restorations. The surface gloss was stable with minimal abrasion after 12 months. However, after 24 months, the surface gloss deteriorated even though the occlusal wear remained similar to that of enamel. Only by desiccating the surface of the nanoceramic restoration was it differentiated from enamel, as the nanoceramic had a matte surface appearance when desiccated.

Figure 4: Hybrid ceramic crowns (Tetric CAD) for the maxillary left first and second premolars demonstrating a high-gloss surface finish by hand-polishing. Case from Fasbinder et al., 2022.[31]

Another longer-term study reported there was no appreciable difference in the surface gloss between nanoceramic (Lava Ultimate) and leucite-reinforced ceramic (IPS Empress CAD) onlays after 5 years **(Figs 5a-5d)**.[27] The surface of the nanoceramic was comparable in smoothness and gloss to the leucite-reinforced ceramic restorations. Another clinical trial, however, reported that surface roughness was adversely impacted over time.[3]

A systematic review investigated the clinical performance of resin-matrix ceramic partial-coverage restorations.[28] Seven clinical studies met the inclusion criteria for the review, with six of them being randomized clinical trials. The results indicated that CAD/CAM resin-based composite restorations exhibited acceptable deterioration with no significant difference in esthetic properties, including surface luster and color matching. However, it was also pointed out that there is a lack of long-term clinical studies.

Fractures and debonding are the primary causes of adhesive ceramic restoration failures. Another common question about CAD/CAM resin-based restorations is their risk of fracture or chipping, given their moderate flexural strength. A 2021 clinical trial evaluated the survival of nanoceramic inlays and onlays over a mean period of 45 months.[29] A total of 57 nanoceramic (Lava Ultimate) inlay and onlay restorations were placed in 44 patients. Restorations were cemented using an adhesive resin cement (Duo-Link, Bisco Dental; Schaumburg, IL). Thirty-eight of the restorations were available for recall and evaluated using U.S. Public Health Service guidelines.[30] The survival rate of Lava Ultimate restorations was 86.8% after a mean time of 45 months. A total of 5 (13.2%) failures were identified. Two onlays debonded and were considered failures. Two of the three fractured onlays were endodontically treated teeth without cuspal coverage.

One longitudinal clinical trial investigated the performance of a monolithic, resilient ceramic material (Tetric CAD) for chairside CAD/CAM crowns, adhesively luted with a total-etch process and dual-curing resin cement.[31] Two clinicians placed 50 chairside CAD/CAM crowns in 36 molars and 14 premolars. The smooth surface finish of the crowns was maintained at the 3-year recall, as evidenced by no significant change in the FDI criteria for esthetic properties.[32] Anecdotally, a few of the crowns in patients with a flatter occlusal contour secondary to occlusal grinding/wear had a matte finish if the crown was dried thoroughly with air **(Figs 6a & 6b)**. Only one crown debonded at 18 months and was lost, requiring a new crown.

A 3-year clinical trial evaluated the survival rate of 103 resilient ceramic (VITA Enamic) restorations (45 inlays and 58 partial-coverage restorations).[3] The teeth were prepared with a defect-oriented preparation and adhesively bonded. The survival rates were 97.4% for inlays and 95.6% for partial-coverage restorations. There were three failed restorations identified: two onlays and one inlay that failed due to bulk fracture. Although secondary caries and debonding were not observed, a significant decrease in marginal adaptation was noted, similar to that reported in other clinical studies for partial-coverage ceramic restorations. The surface roughness increased significantly, particularly in functionally stressed areas of the restorations, which

Figures 5a-5d: Nanoceramic onlay (Lava Ultimate) for the maxillary right first premolar demonstrating maintenance of surface finish at (a) baseline, (b) 1-year recall, (c) 3-year recall, and (d) 5-year recall. Case from Fasbinder et al., 2020.[27]

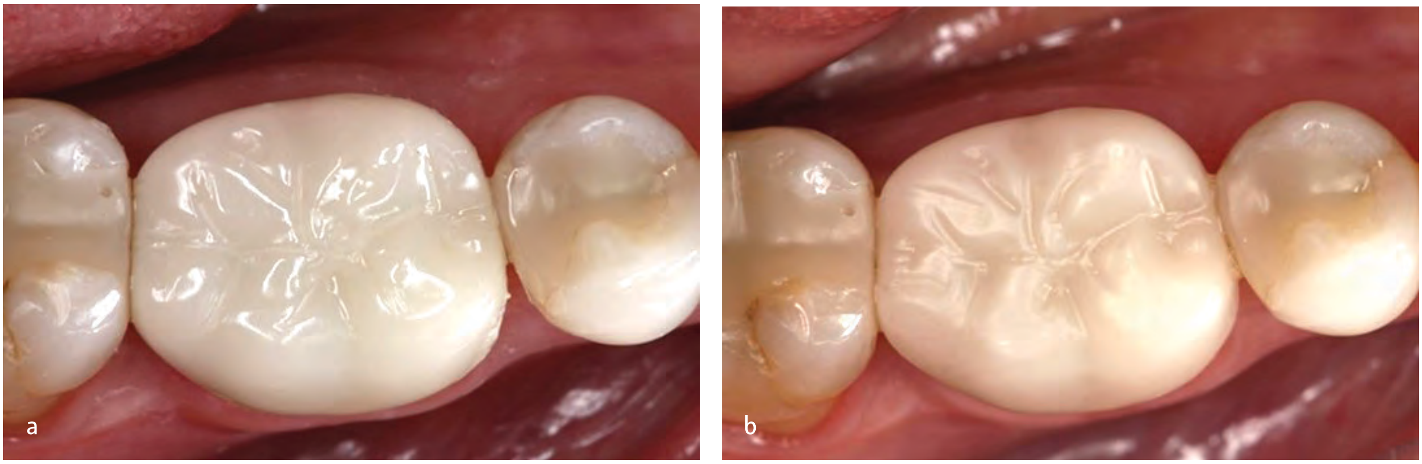
the authors noted was different from other clinical studies reporting much less change in surface roughness.

A 5-year clinical trial of 120 chairside CAD/CAM onlays included 60 nanoceramic (Lava Ultimate) onlays and 60 leucite-reinforced ceramic (IPS Empress CAD) onlays.[27] Equal-size groups of each type of onlay were cemented using total-etch and self-etch adhesive resin cements. The investigators reported that clinical outcomes between groups were similar, regardless of whether a self-etch or total-etch approach was used **(Figs 7a-7d)**. There was no statistically significant difference in fracture between the materials, with one fractured nanoceramic onlay and four fractured leucite-reinforced onlays. The nanoceramic onlays performed as well as the leucite-reinforced onlays after 5 years of clinical service.

Fracture and debonding are two primary failure mechanisms for adhesive ceramic restorations. The results of a recent systematic review revealed better outcomes for CAD/CAM resin-based composite partial-coverage restorations compared to adhesive ceramic restorations, and no clinically significant difference when compared to high-strength ceramics.[28]

Future Areas of Development

Studies are reporting on definitive restorations fabricated by additive manufacturing (3D printing).[33,34] These initial studies primarily involve resin-based materials. Additively manufactured restorations offer the possibility of custom color characterization during the printing process that cannot be obtained when a monolithic resilient ceramic is subtractively milled. Another advantage of additive manufacturing is that it is a more conservative process regarding material use than subtractive milling, where considerable excess material must be removed from the mill block to produce the final restoration. It will be interesting to discover if the additive manufacturing process has any significant impact on the clinical performance of resin-based materials.



Figures 6a & **6b**: Hybrid ceramic crown (Tetric CAD) on the mandibular right first molar with matte finish revealed after desiccating with a stream of air, shown at (a) baseline and (b) 1-year recall. Case from Fasbinder et al., 2022.[31]

Figures 7a-7d: Nanoceramic onlay (Lava Ultimate) for the mandibular right first molar. (a) Onlay preparation and (b) same-appointment delivery, demonstrating very good long-term retention using adhesive cementation, as shown at the (c) 3-year recall and (d) 5-year recall. Case from Fasbinder et al., 2020.[27]

Summary

Resilient ceramic materials were introduced for chairside CAD/CAM applications as an alternative material designed to reduce restoration chipping and fracture due to functional stress compared to more brittle glass-ceramic materials. They also exhibit a chameleon effect, enabling them to blend seamlessly with the surrounding tooth structure, while facilitating an efficient workflow and ease of surface finishing for the restoration. Laboratory studies document moderate strength properties and the least occlusal wear to opposing dentition compared to ceramic restorations. For partial-coverage restorations, resilient ceramics have demonstrated clinical outcomes comparable to ceramic materials in the moderate term (up to 5 years) but lack sufficient long-term data (up to 10 years or more).

"Resilient ceramic materials were introduced for chairside CAD/CAM applications as an alternative material designed to reduce restoration chipping and fracture due to functional stress compared to more brittle glass-ceramic materials."

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Disclosures: *The authors declare no conflicts of interest.*