Biomaterials in esthetic restorative dentistry

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Abstract

Esthetic restorative dentistry has seen a paradigm shift toward conservative approaches that prioritize tooth preservation, functional longevity, and patient-specific customization. Biomaterials play a pivotal role in this transformation. From traditional feldspathic ceramics and lithium-reinforced glass-ceramics to zirconia, CAD/CAM composites, PICN (hybrid ceramic), and 3D-printed materials, the spectrum of options continues to expand. However, an ideal material capable of meeting all requirements simultaneously does not exist. Clinical success therefore depends on judicious material selection and a thorough understanding of the advantages and limitations of each biomaterial class. This review synthesizes the available data across material families, evaluating their properties and clinical behavior, with particular emphasis on minimally invasive protocols and bruxism-prone patients.

Keywords

CAD/CAM, ceramics, glass-ceramics, zirconia, composites, polymer-infiltrated ceramic network (PICN), hybrid ceramic, 3D printed, minimally invasive dentistry

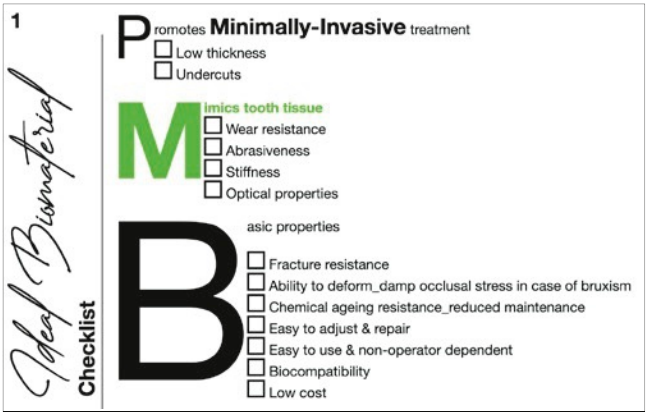

Fig 1 Key requirements for an ideal biomaterial.

Introduction

In recent years, social media has increasingly promoted invasive esthetic treatments, with some practitioners often applying the same "recipe" and the same materials to all clinical cases and situations. However, scientific evidence confirms that no universal or ideal biomaterial exists, and no single option has been proven superior in all contexts.[1,2]

What would the ideal biomaterial look like? It would support minimally invasive dentistry, be manufacturable in low thicknesses and adaptable to undercuts, and replicate natural tooth tissue in terms of wear resistance, abrasiveness, and stiffness for effective stress distribution. Additional desirable properties would include emulating optical characteristics, high mechanical and fracture resistance, controlled deformation to absorb occlusal forces in bruxism, chemical aging resistance with minimal maintenance, ease of adjustment and repair, minimal technique sensitivity, biocompatibility, and affordability (Fig 1). Since such a material does not exist, the selection of the suitable material must be based on the clinical indication and an understanding of the strengths and limitations of the available options.

Current restorative materials can be classified into four main families:

1. **Light-cured direct composites**
2. **Glass-ceramics**, including lithium-reinforced glass-ceramics (approximately four times stronger than feldspathic ceramics)
3. **Zirconia**, the strongest ceramic currently available (≈ 1200 MPa for 3Y-TZP)
4. **CAD/CAM composites**, including polymer-infiltrated ceramic network (PICN) material (hybrid ceramic), introduced around 2010

The past decade has seen the emergence of new indirect materials such as translucent and high-translucent zirconia, PICN (hybrid ceramic), and second-generation lithium-reinforced glass-ceramics (Fig 2). Current trends emphasize faster workflows, reduced costs, stronger materials, and monolithic restorations. Whether this shift represents a true revolution in patient treatment or merely an evolution in material selection remains an open question.

1. Direct composites

The composition of direct composite restorative materials has remained largely unchanged since their introduction in the 1960s and 1970s. Their formulation typically consists of a bisphenol A-glycidyl methacrylate (Bis-GMA), urethane dimethacrylate (UDMA), or triethylene glycol dimethacrylate (TEGDMA) resin matrix reinforced with glass fillers, including clusters, fibers, or pre-polymerized resin particles (Fig 3). Most systems are light cured, a characteristic that represents a major limitation. The polymerization reaction does not achieve complete conversion (40% to 75% in vitro), and exhibits spatial inhomogeneity,[3,4] adversely affecting all material properties. Structural defects such as bubbles introduced during the build-up process may act as crack initiators, promoting fracture.

A wide range of commercial variations exists, which can be classified according to:

- **Microstructure**, influencing polishability, mechanical performance, and wear resistance:
  - Micro/nanohybrid composites: containing 0.4- to 1-µm filler particles and/or nanoparticles (1 to 100 nm).
  - Nanofill composites: containing exclusively nanoparticles.
- **Intended use**, including:
  - Viscosity-based categories: eg, flowable composites, commonly applied in injection techniques.

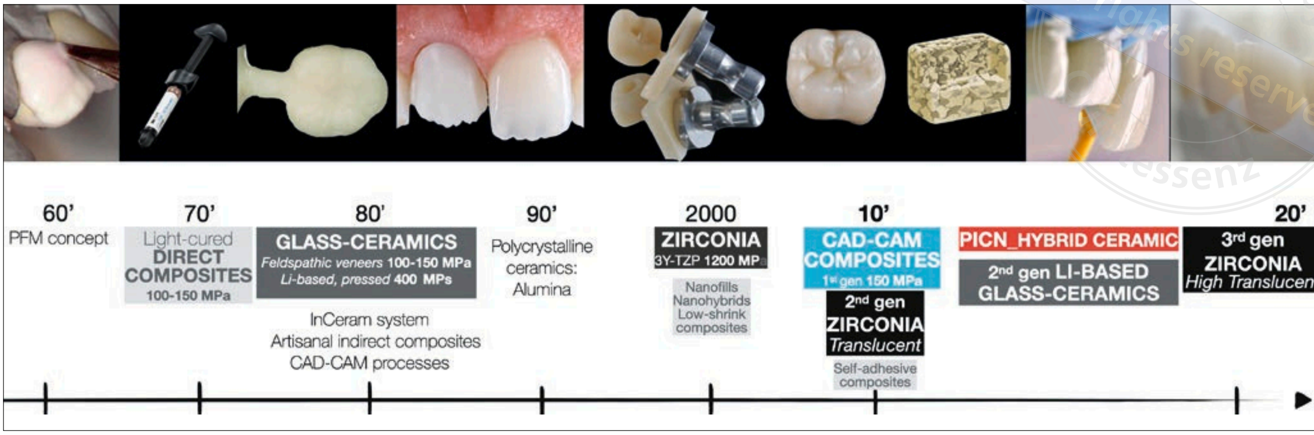

Fig 2 Timeline of the introduction of the different biomaterials in esthetic restorative dentistry, with currently used materials highlighted in boxes.

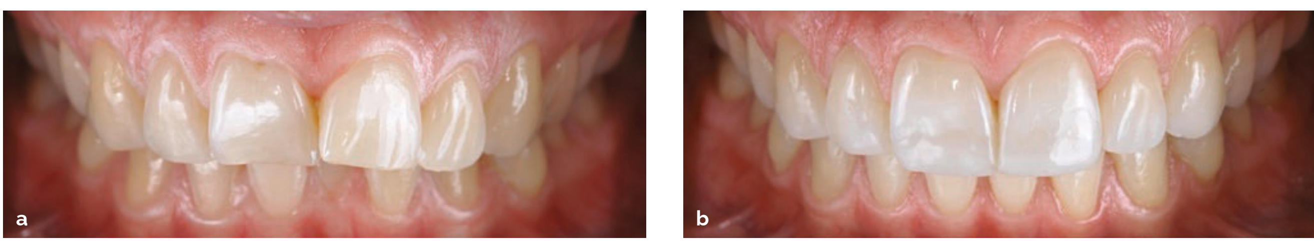

Fig 3a and b Clinical case of a young female patient treated with orthodontic aligners for tooth alignment, followed by bleaching and noninvasive restoration of the two central incisors using a palatal silicone index and a natural layering technique with direct composites (Inspiro Direct; Edelweiss, Zug, Switzerland; a). Follow-up at 1.5 years (b). Orthodontics: Dr Annick Bruwier (Liège, Belgium).

- Bulk-fill composites, which allow placement in thicker increments without incremental photopolymerization; however, clinical evidence remains insufficient, with systematic reviews highlighting the need for longer-term, well-designed clinical trials.[5,6]
- Self-adhesive composites, which are flowable systems designed for Class I and II restorations or undercut fillings; they generally exhibit lower bond strength than conventional adhesive systems, and clinical data are lacking.[7,8]

Meta-analyses indicate no clear superiority of direct or indirect techniques. For non-vital posterior teeth in the short term, low-quality evidence suggests equivalent performance.[7] Long-term data—defined as at least 3 years of follow-up in anterior and posterior regions—are scarce, with no consensus recommendations available.[8] The reported annual failure rate for both techniques is approximately 1%.

Several methodologic limitations are recurrent in systematic reviews:

- **Failure definition standardization:** There is no consistent approach regarding replacement, repair, or maintenance. Some studies omit surface degradation or marginal staining from failure definitions, although direct composites are prone to these phenomena.[9]
- **Tissue loss quantification:** Often this is not reported, despite evidence linking greater tissue loss to higher failure rates.[10]
- **Inclusion of high-risk patients:** Many studies exclude patients with bruxism or significant tooth wear, although these conditions markedly reduce success rates and increase maintenance needs.[11,12]

Fig 4a to d Clinical case of a young female patient treated with crown lengthening of teeth 21 and 22, bleaching, and replacement of 15-year-old direct composite restorations on teeth 12 and 11 using a palatal silicone index and a natural layering technique (Miris; Coltene, Altstätten, Switzerland). Pretreatment (a) and post-treatment (b). Follow-up at 5.5 years (c and d) showing material wear (the patient is a bruxer). Surgery (teeth 21 and 22 crown lengthening): Prof France Lambert (Liège, Belgium).

- **Material-specific data omission:** Details regarding composition, microstructure, polymerization process, and manufacturing protocol are often lacking, despite their influence on clinical performance.
- **Restoration thickness data omission:** As an important determinant of fracture risk, particularly in minimally invasive treatments.
- **Long-term performance reporting:** Insufficient follow-up cannot capture the effects of mechanical and chemical aging in the oral environment.
- **Reporting on effects on antagonist teeth:** The effects of restorations on antagonist teeth are rarely assessed, despite the potential of certain materials to cause wear or damage to the opposing dentition.

Direct composites present several advantages relative to the ideal biomaterial checklist. They possess favorable optical properties and are suitable for minimally invasive approaches. In addition, they are adaptable to low-thickness restorations and undercuts, cost-effective, and capable of damping occlusal stress due to their polymer content. They are compatible with the antagonist teeth and are easy to adjust and repair. Limitations include low wear resistance (Fig 4), insufficient fracture resistance, a modulus of elasticity lower than that of dental tissue, susceptibility to discoloration and water absorption, and operator-dependent performance.[3,13] Potential monomer toxicity also remains a concern.

2. Glass-ceramics

The second class of restorative materials comprises ceramics containing glass. Within this group, feldspathic ceramics (≈ 100 MPa flexural strength) represent the weakest category, followed by leucite-reinforced ceramics (≈ 100 MPa), while lithium (di)silicate-reinforced glass-ceramics achieve the highest values (≈ 350 to 400 MPa). These materials can be handcrafted, pressed, or CAD/CAM milled, with the manufacturing technique influencing the presence of flaws and mechanical properties such as fracture resistance (Figs 5 to 7). Handcrafted processes, in particular, tend to increase flaws and material inhomogeneity.

Clinical indications include veneers, posterior partial-coverage restorations, single crowns, and, for

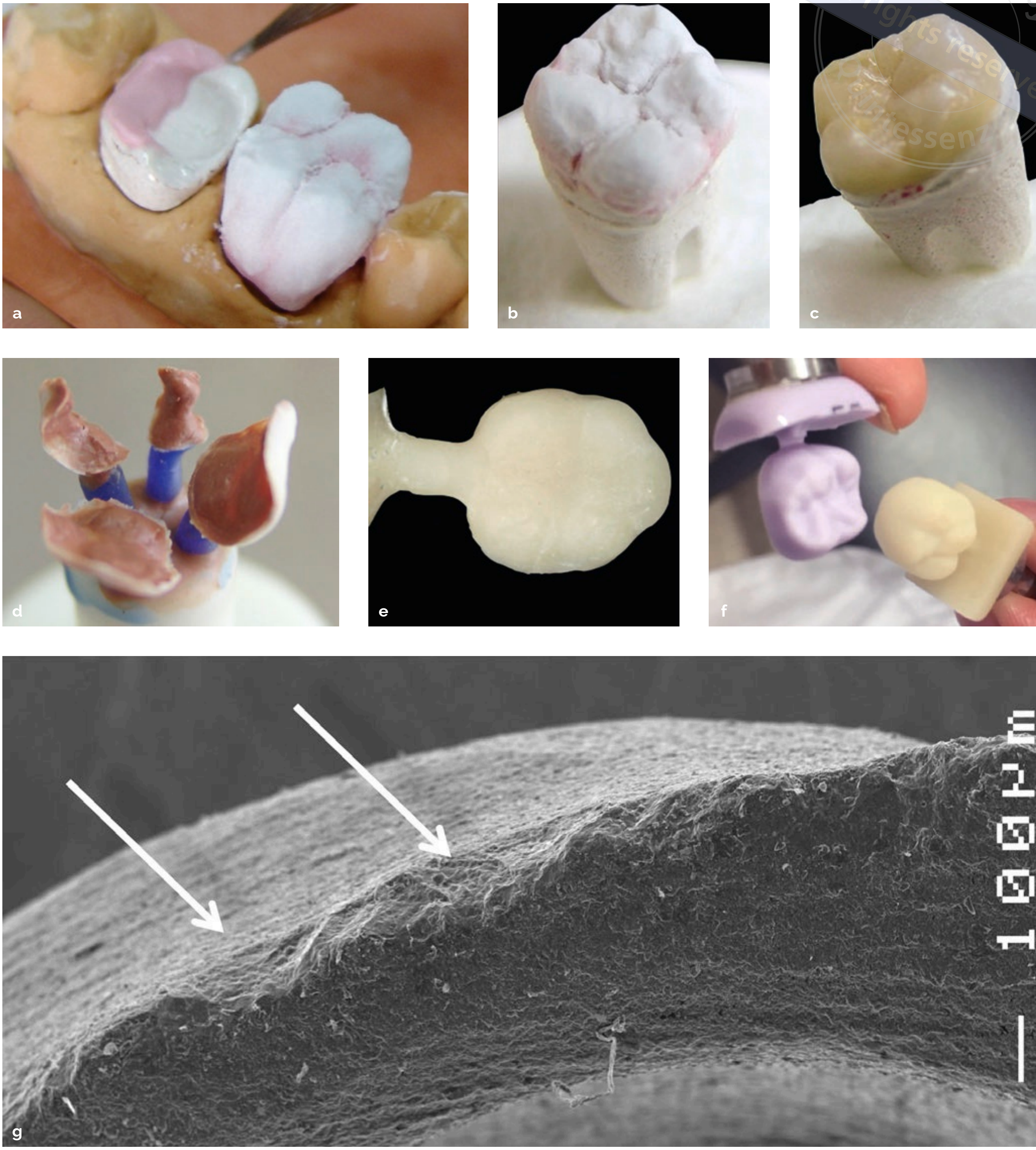

Fig 5a to g Manual fabrication process of a feldspathic ceramic overlay with ceramic built up by brush on a refractory stone die (a to c). Fabrication of a lithium disilicate glass-ceramic veneer using the lost-wax technique: wax patterns are created and then an industrially manufactured ingot is heated and pressed into the mold (d). Final restoration after investment removal (e). CAD/CAM fabrication of a lithium disilicate glass-ceramic overlay: Block immediately after milling and then after crystallization firing, which provides the final shade (f). Scanning electron microscopy image of the margin of a lithium disilicate glass-ceramic restoration immediately after CAD/CAM milling, showing edge chipping (g). Ceramics are brittle materials and therefore not ideally suited to milling, which generates this type of chipping.

Fig 6a to d Clinical case of a young female patient whose central incisors were restored with no-prep feldspathic ceramic chips (window veneers), while teeth 12 and 13 were restored with direct composites (Inspiro Direct). Dental technicians: Luc and Patrick Rutten (Dental Team, Tessenderlo, Belgium).

lithium-reinforced glass-ceramics specifically, resin-bonded fixed partial dentures (FPDs). Clinical evidence supports the use of these materials. Veneers demonstrate excellent long-term survival.[14,15] Similarly, data for partial coverage restorations are reassuring, as confirmed by a recent meta-analysis.[16] Lithium-reinforced endocrowns also show excellent long-term outcomes.[17]

Second-generation lithium-reinforced glass-ceramics were introduced to circumvent existing patents (Ivoclar, Schaan, Liechtenstein) by modifying the glass composition. Such changes alter the microstructure, including crystal size and volume fraction, with direct consequences on mechanical resistance. Pressable ceramics have been shown to be significantly stronger than their CAD/CAM-milled counterparts, with the exception of IPS e.max CAD (Ivoclar).[18] Moreover, CAD/CAM milling can induce edge chipping, highlighting the limitations of this process for inherently brittle ceramic materials (see Fig 5).

To improve efficiency, manufacturers have also developed one-step CAD/CAM blocks that eliminate the need for a separate crystallization firing, such as Celtra Duo (Dentsply, Bensheim, Germany) and LiSi Block (GC, Tokyo, Japan). While this approach saves time, it substantially reduces mechanical resistance—sometimes by half—and lacks robust clinical validation.[19] Material selection is therefore critical, as significant differences exist between products, and compromises in properties are unavoidable.

In relation to the ideal biomaterial checklist, glass-ceramics present several advantages: well-documented long-term clinical performance, superior wear and fracture resistance compared with direct composites, reliable bonding properties, gloss retention, color stability, absence of water absorption, favorable optical properties, operator independence, and satisfactory biocompatibility. Disadvantages include the need for at least 1-mm thickness in occlusal contact areas, wear inferior to enamel leading to po-

Fig 7a to e Clinical case of a female patient with a discolored abutment on tooth 11 previously masked with composite. Tooth 11 was restored with a three-quarter bonded restoration and tooth 21 with a no-prep veneer, both made of lithium disilicate glass-ceramic (Initial LiSi Press; GC). This material family is particularly suitable for bonded partial restorations. Dental technicians: Luc and Patrick Rutten (Dental Team, Tessenderlo, Belgium).

tential high occlusion over time, abrasiveness (particularly in lithium-reinforced glass-ceramics),[20] excessive stiffness compared with enamel (100 vs 80 GPa; enamel itself being stiffer than dentin at ≈ 20 GPa), absence of stress-damping capacity, limited ease of adjustment and repair, and significantly higher cost compared with direct composites.

3. Zirconia

Zirconia is widely recognized for its biocompatibility, which represents one of its most significant advantages in implant-based restorations. This material promotes soft tissue adhesion on the transmucosal portion of the implant prosthesis, contributing to the establishment of a biologic seal that protects periimplant tissue.[21,22] In immediate loading protocols employing customized zirconia abutments, favorable peri-prosthetic soft tissue healing and stable attachment can be established immediately after surgery (Fig 8).

Several generations of yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) are currently available. The first generation, 3Y-TZP, remains the most resistant ceramic material, with flexural strength values around 1200 MPa due to transformation toughening. More recent materials incorporate higher concentrations of yttrium oxide (4Y- or 5Y-TZP; Table 1).[23] While the increased yttria content improves translucency, with the aim of producing monolithic restorations, it reduces mechanical resistance, necessitating a balance

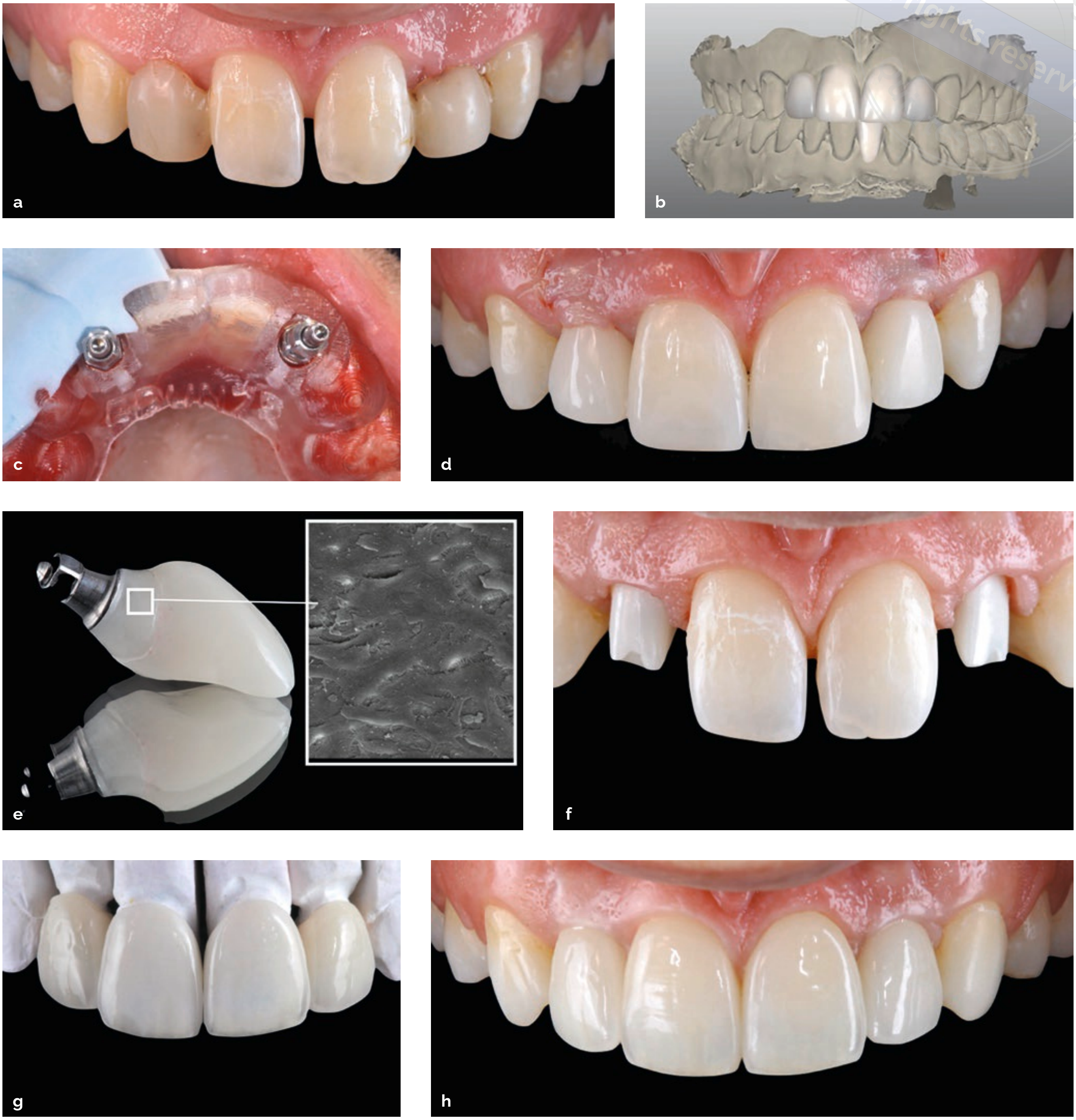

Fig 8a to h Clinical case of a young male patient with agenesis of the two maxillary lateral incisors and a diastema between the central incisors (a). Digital setup (b). Guided surgery (c). Frontal view on the day of surgery after placement of customized zirconia abutments covered with CAD/CAM polymethyl methacrylate (PMMA) provisional crowns and provisional no-prep veneers in CAD/CAM PMMA (d). Schematic representation showing epithelial cells on the transmucosal part of a zirconia abutment (e). View of zirconia abutments before placement of the final restorations (f). Final restorations: no-prep feldspathic ceramic veneers on the central incisors, and zirconia-based (3Y-TZP) crowns with enamel layering on teeth 12 and 22 (g). Final view after placement of restorations (h). Surgery: Prof Eric Rompen (Liège, Belgium). Dental technicians: Luc and Patrick Rutten (Dental Team, Tessenderlo, Belgium).

Table 1 Summary of the different generations of zirconia materials, including their composition, mechanical properties, and clinical indications according to manufacturer

Zirconia	Composition	Characteristics/mechanical properties	Manufacturer's indications
1st generation Opaque	3Y	Flexural strength: 1000–1500 MPa (manufacturer's data)	Framework for veneered restorations
2nd generation Translucent	3Y	Flexural strength: 900–1300 MPa (manufacturer's data)	Monolithic or veneered posterior restorations
3rd generation Highly translucent	4Y 5Y	Flexural strength: 400—< 1000 MPa (manufacturer's data)	Monolithic single-unit restorations Maximum three elements—bridges?

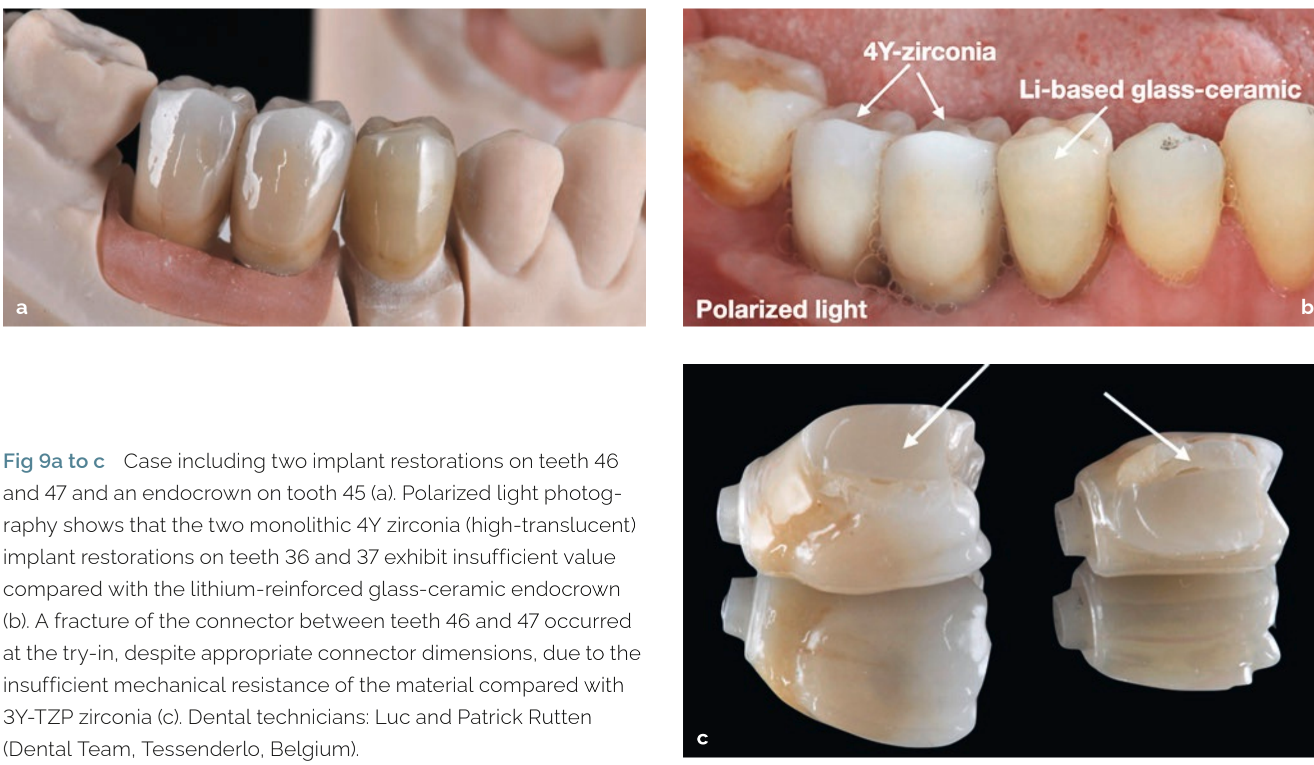

Fig 9a to c Case including two implant restorations on teeth 46 and 47 and an endocrown on tooth 45 (a). Polarized light photography shows that the two monolithic 4Y zirconia (high-translucent) implant restorations on teeth 36 and 37 exhibit insufficient value compared with the lithium-reinforced glass-ceramic endocrown (b). A fracture of the connector between teeth 46 and 47 occurred at the try-in, despite appropriate connector dimensions, due to the insufficient mechanical resistance of the material compared with 3Y-TZP zirconia (c). Dental technicians: Luc and Patrick Rutten (Dental Team, Tessenderlo, Belgium).

between these two properties. High-translucency zirconia materials (4Y- or 5Y-TZP) are typically restricted to single-unit restorations due to their lower strength. The choice of zirconia is therefore critical, as the use of inappropriate materials may result in clinical failures such as fractures (Fig 9). Furthermore, despite improvements, the optical properties of highly translucent zirconia remain inferior to glass-ceramics, which provide more natural esthetics[24] (see Fig 9). Zirconia has a high refractive index, producing strong light reflection and an opaque appearance, often resulting in an unnatural smile in daylight. In graded zirconia systems, compositions may consist solely of 4Y- or 5Y-TZP. When 3Y layers are incorporated, as required for FPD applications, ensuring that critical connector regions remain within the 3Y zone is challenging.

Although in the past two decades zirconia has been introduced as the strongest ceramic material, higher strength does not always correlate with superior clinical performance. Zirconia exhibits very high stiffness (≈ 250 GPa), far exceeding that of enamel (≈ 80 GPa) and dentin (≈ 18 GPa). Its hardness and rigidity result in minimal deformation and wear. Consequently, occlusal stresses are transmitted directly to the supporting structures (such as the root or implant) rather than being absorbed by the restoration.[25-27] While zirconia crowns are rarely fractured, the supporting teeth or implants may be compromised, particularly in patients with bruxism. In such cases, restorative materials with damping capacity should be considered. Clinical evidence on monolithic zirconia remains limited, with most studies showing short-term background and excluding bruxers from the analysis.[28,29] In a clinical study of 100 monolithic zirconia restorations (second-generation 3Y; Lava Plus; 3M, Seefeld, Germany), a 2-year survival rate of 93% was observed, with a lower success rate (80%) and higher complication rates in bruxers.[30] Failures included implant loss (2.7%), root fractures (1.3%), and antagonist tooth loss or restoration fracture.

Overall, zirconia offers multiple advantages: high fracture resistance (notably for 3Y-TZP, the only suitable material, or FPDs), biocompatibility, color stability, non-abrasiveness, and minimal operator dependence. However, its limitations are significant. Excessive rigidity prevents occlusal stress damping and increases the risk of overload on supporting structures. Its wear properties are inferior to enamel, contributing to high risk of occlusion. Surface aging (low-temperature degradation) has also been reported, which may contribute to both minor and major fractures.[31] Monolithic zirconia restorations must maintain at least a 1-mm occlusal thickness and require careful polishing or glazing to reduce abrasion. Optical properties remain suboptimal compared with glass-ceramics, with veneering remaining important in single-unit restorations and cases of high esthetics. Zirconia is difficult to adjust or repair and the material is also associated with high cost. Nevertheless, 3Y-TZP is particularly indicated in colored abutment teeth (due to its opacity) and cantilever resin-bonded FPDs[32] (Fig 10). Indeed, bonding properties have improved with the use of surface airborne-particle abrasion (2.5 bar) and primers containing 10-methacryloyloxydecyl dihydrogen phosphate (MDP). Zirconia is also the most valuable material for implant-supported restorations, provided its limitations are considered within the broader biomechanical context.

4. Dispersed filler CAD/CAM composites and PICN (hybrid ceramic)

The last family of materials—dispersed filler CAD/CAM composites and PICN (hybrid ceramic)—exhibit high machinability. They can be manufactured in low thickness rapidly and without edge chipping, thereby promoting minimally invasive restorations. Compared with direct composites, they present a high degree of polymerization, improved homogeneity, and fewer flaws, resulting in enhanced overall properties. The higher polymerization rate improves not only mechanical performance but also chemical stability and biocompatibility in terms of monomer release. Flexural strength remains relatively low and inferior to pure ceramics; however, this limitation is compensated for by other advantages such as reduced stiffness and the ability to dampen occlusal stress.

Two main classes of CAD/CAM composites are available. The first includes dispersed filler CAD/CAM milled composites such as Cerasmart (GC), Grandio (Voco), Tetric CAD (Ivoclar), Lava Ultimate (3M), Brilliant (Coltene), and Shofu Blocks (Shofu). These materials are composed of glass fillers combined with monomers, similar to direct composites but polymerized under high temperature. The second class consists of PICN, also referred to as hybrid ceramic (Fig 11). These are based on a feldspathic ceramic network that is partially sintered and subsequently infiltrated with monomers polymerized under high temperature and pressure.[13,33] Since this process is patented, Vita Enamic (Vita Zahnfabrik, Bad Säckingen, Germany) is currently the only PICN available on the market.

PICN constitutes an intermediate material between pure ceramics and dispersed filler composites, whether direct or CAD/CAM. Their stiffness lies between that of dentin and enamel, and they demon-

Fig 10a to f Typical clinical indications for zirconia, particularly 3Y-TZ. Crown on tooth 11 on a discolored abutment: The 3Y-TZP zirconia framework masks the discoloration due to its opacity (a to c). Resin-bonded fixed partial denture (no-prep zirconia bridge) in a young female patient: 3Y-TZP zirconia was selected for its high mechanical resistance, ensuring reliable connector strength and allowing the fabrication of very thin wings, thus enabling a truly no-prep approach; a connective tissue graft was also performed in this case (d to f). Connective tissue graft in Case 2: Prof France Lambert (Liège, Belgium). Dental technicians: Mirko Picone (Liège, Belgium) for Case 1; Luc and Patrick Rutten (Dental Team, Tessenderlo, Belgium) for Case 2.

strate superior bonding properties compared with dispersed fillers due to their specific microstructure, as demonstrated in clinical and in vitro studies.[34,35] Their biocompatibility is satisfactory, with no reported monomer release.[22] Their wear behavior is enamel-like, with resistance close to enamel and superior to dispersed fillers, while remaining less abrasive than lithium-reinforced glass-ceramics.[20,36]

Clinical studies on dispersed filler CAD/CAM composites remain limited, but short-term results are positive in partial coverage restorations and tooth wear cases, with the exception of Lava Ultimate, which has shown debonding, minor chipping, and occlusal surface degradation in ultrathin occlusal veneers.[37-39]

PICN has demonstrated favorable long-term outcomes in partial-coverage restorations and tooth

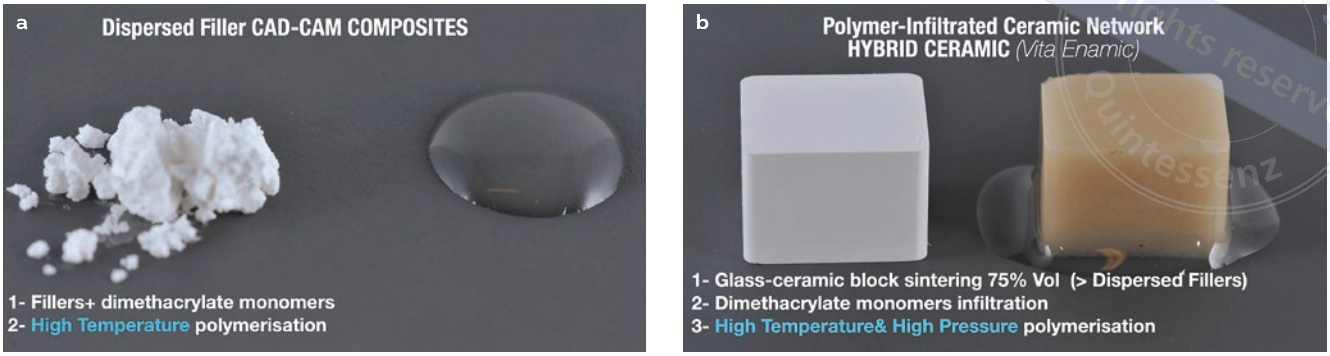

Fig 11a and b Comparison between dispersed filler CAD/CAM composites and polymer-infiltrated ceramic network (PICN/hybrid ceramic), highlighting differences in both the composition and manufacturing processes, which account for their distinct properties.

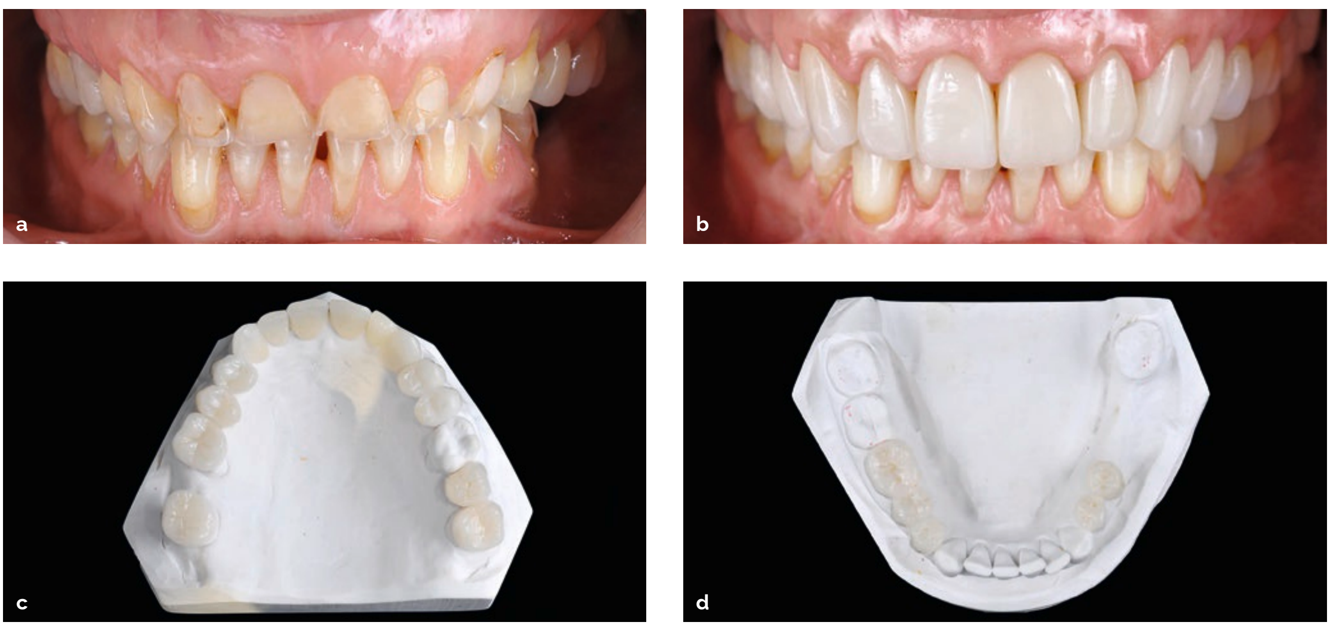

Fig 12a to d A 52-year-old female patient suffering from generalized severe tooth wear. Frontal views before and after (a and b) treatment with the One-Step No-Prep technique using Vita Enamic multiColor blocks (c and d). In this case, in addition to the palatal veneers from teeth 14 to 23, lithium-reinforced glass-ceramic buccal veneers (Initial LiSi Press; GC) were subsequently placed in view of the buccal erosion and the patient's esthetic demands, using an approach known as the "sandwich technique." Direct composite restorations (Inspiro, Edelweiss) were placed to restore the minor tissue loss from teeth 33 to 43 and on teeth 38, 46, and 47. No restoration was placed on tooth 26, and a table-top was placed on the implant crown on tooth 27. Dental technician for PICN restorations: Jean-Michel Paulus (Liège, Belgium). Dental technicians for LiSi glass-ceramic veneers: Luc and Patrick Rutten (Dental Team, Tessenderlo, Belgium). Mucogingival surgery (crown lengthening on tooth 21 and soft tissue graft on tooth 24) and implants on teeth 36 and 37: Prof France Lambert (Liège, Belgium).[41]

wear management[36,40-42] (Figs 12 and 13). A 9-year study of the One-Step No-Prep technique using PICN reported a survival rate of 98.4% in 580 restorations, with a success rate of 79.7%. When minor chipping requiring only polishing was not considered a failure, the success rate reached 86.7%.[42] Minor chipping represented the most common cause of failure, with a significantly higher risk observed in the posterior regions (9.2 times), particularly in first and second molars or when the restoration thickness was < 0.56 mm.

Fig 13a to f A 49-year-old female patient with localized severe anterior tooth wear. The patient was referred by her orthodontist after undergoing orthodontic treatment to align the teeth. Palatal veneers with buccal margin coverage were placed from teeth 13 to 22. Direct composites were placed on tooth 23 and from teeth 43 to 33 (Inspiro). Simple orthodontic extrusion (e) was then performed for 5.5 months. In this particular case, additional orthodontic treatment with brackets and wire was performed for 3 months to lower the cervical margins of teeth 12 and 22 for esthetic reasons. Frontal views before (a) and after (e) treatment with the orthodontic-assisted One-Step No-Prep technique using Vita Enamic multiColor Blocks (b to d). Dental technicians: Jean-Michel Paulus (Liège, Belgium). Orthodontics: Dr Jean-Claude Bernard (Liège, Belgium).[41]

Apart from fractures, clinical evaluations showed favorable outcomes, with most restorations rated as excellent. Results remained stable over time, including luster and color, with no staining. Vita Enamic multiColor Blocks demonstrated superior esthetics compared with monochromatic versions, and patient satisfaction was high. An increase in surface roughness over time was reported by other authors.[40]

CAD/CAM composites and PICN present several advantages. They are particularly suitable for minimally invasive partial-coverage restorations, with PICN allowing no-prep posterior restorations as thin as 0.6 mm, even in bruxism cases, which is remarkable for an indirect material in high-risk conditions. The ability to dampen occlusal stress is particularly valuable in bruxism, tooth wear, and single-unit implant restorations. PICN exhibits excellent bonding properties, stiffness between enamel and dentin, wear behavior similar to enamel, antagonist-friendly abrasion, resistance to aging (as compared with a direct composite),

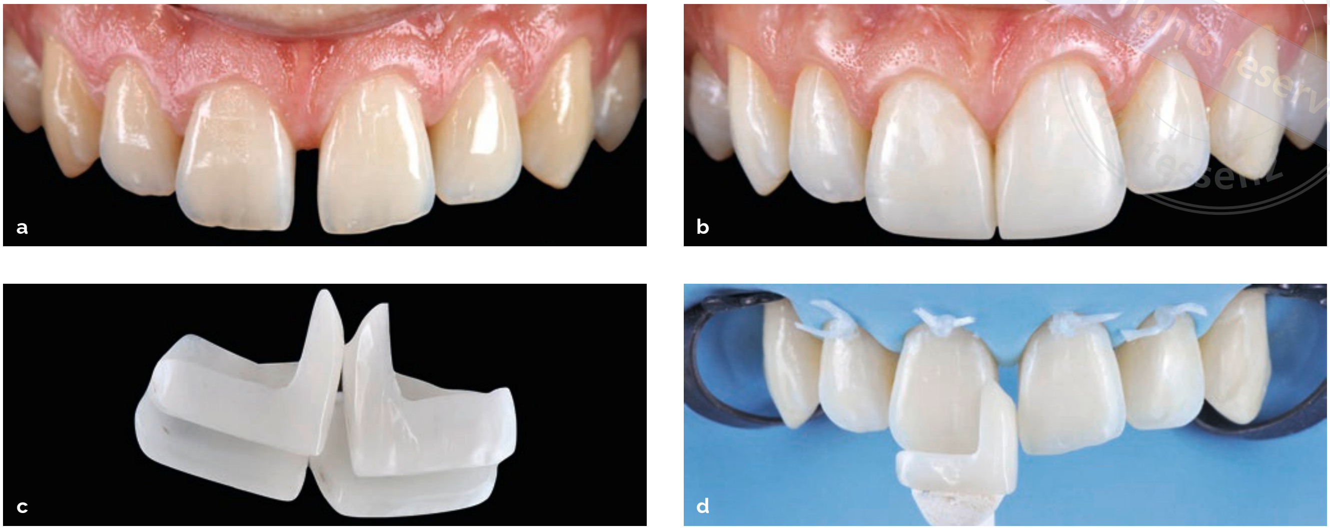

Fig 14a to d Chips in PICN (Vita Enamic multiColor Block) used to close a diastema between teeth 11 and 21 in a young patient. The patient also underwent bleaching before bonding of the restorations. These noninvasive restorations combine the advantages of direct composite and indirect glass-ceramic restorations: compared with composites, they offer easier achievement of the desired anatomy and greater resistance to wear, staining, and fracture; compared with pure ceramics, they are lower in cost and provide easier adjustment of margins. Dental technician: Jean-Michel Paulus (Liège, Belgium).

and the absence of staining. For dispersed fillers, long-term effects of aging still require investigation. Mechanical resistance is significantly superior to that of direct composites, with PICN demonstrating excellent wear resistance. Optical properties are favorable, with a "chameleon effect" due to resin content and translucency, enabling shade blending with the tooth structure. These materials are easy to adjust and repair, demonstrate satisfactory biocompatibility (well established for PICN but not yet studied for dispersed filler materials), are not operator-dependent, and are more cost-effective than pure ceramics. Clinical indications include partial-coverage restorations, thin noninvasive restorations (Fig 14), tooth wear management, bruxism cases including single-unit implant restorations, and chairside systems. It must be noted that survival rates of PICN palatal veneers in tooth wear cases have been reported at 100%.[36] PICN has also contributed to the development of innovative noninvasive treatment strategies for tooth wear (see Fig 13).

The main limitation of PICN is minor chipping of very thin posterior restorations, with a minimum required occlusal thickness of 0.6 mm. Fracture resistance remains insufficient for multi-unit restorations. Occlusal gloss is lower than in pure ceramics, although PICN multiColor Blocks achieve superior esthetic outcomes compared with monochromatic versions. Dispersed filler composites are too soft, with wear rates exceeding enamel and resembling those of direct composites. Their cost is higher than that of direct composites but lower than that of ceramics. PICN can be regarded as an intermediate restorative option, integrating the benefits of both direct and indirect approaches while exhibiting comparatively limited drawbacks.

Future perspectives

While few significant developments are anticipated in the field of pure ceramics, composite materials in general—whether direct or indirect—appear to have a promising future, as they provide minimally invasive, efficient, and cost-effective restorative solutions with considerable potential for further improvement of their properties.

3D-printed composite materials are currently under active development and represent a rapidly evolving field with encouraging perspectives. A major advantage is the substantially lower initial investment required for a printing system compared with milling machines, although consumable costs are not reduced, and challenging restoration cleaning before polishing is needed. However, the available scientific evidence does not support the use of current materials for definitive restorations. Their filler content and mechanical properties remain limited and significantly inferior to milled composites, restricting indications to long-term provisional restorations.[43-45] Furthermore, some products have been reported to exhibit cytotoxicity, and concerns persist regarding long-term biocompatibility.[46] These materials are also susceptible to staining over time.[47] Future developments are expected to yield materials with enhanced properties and broader clinical applicability.

Finally, standardized definitions of failure, long-term randomized trials, and inclusion of high-risk patients are critical to advancing clinical evidence.

Conclusions

There is no universal or ideal biomaterial, and in the absence of strong scientific evidence, clinical decision making should be guided by sound judgment and relevant clinical parameters, particularly patient-specific factors and the mechanical and chemical constraints to which the material will be exposed. The choice of restorative material should also be founded on the fundamental principle: first, do no harm. Restorations must be adapted to the tooth, not the tooth to the restoration. Tooth longevity should take precedence over restoration longevity.

The concept of "ethical esthetics" should therefore be promoted. Ethical esthetics involves selecting materials and techniques that prioritize long-term oral health, personalized treatment, sustainability, and adherence to the principle of informed patient consent, particularly regarding risks, maintenance, and long-term performance.

Acknowledgments

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Disclaimer

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