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Comprehensive Dental Restorative Materials: A Narrative Review

Dr. Althaaf Khan*

BDS (SMU), AssocFCGDent (UK), Private Practice, South Africa

*Email: khanalthaafy@gmail.com

ABSTRACT

Background: Restorative dentistry relies on a diverse and rapidly evolving range of materials, and clinicians must balance mechanical performance, adhesion, aesthetics, biocompatibility, longevity and cost when selecting among them.

Objective: This narrative review summarises the composition, properties, indications, limitations and recent developments of the principal direct and indirect restorative materials used in contemporary clinical practice.

Methods: Peer-reviewed literature, systematic reviews, consensus statements and international policy documents on dental amalgam, resin composites, glass ionomer cements, resin-modified glass ionomers, compomers, bioactive and ion-releasing materials, dental ceramics, CAD/CAM blocks and cast metal alloys were identified and synthesised qualitatively.

Results and Discussion: Resin composites are now the dominant direct restorative material, supported by improving filler technology, bulk-fill systems and adhesive protocols, although polymerisation shrinkage and technique sensitivity remain important concerns. Glass ionomer-based materials offer chemical adhesion and fluoride release and are central to minimally invasive and public health approaches. Dental amalgam is declining under the Minamata Convention on Mercury, yet it retains a role where moisture control and cost are limiting. Indirect ceramics, particularly lithium disilicate and zirconia, combined with digital workflows, provide high strength and aesthetics. Bioactive materials show promise but require stronger long-term clinical evidence.

Conclusion: No single material is universally superior. Optimal outcomes depend on case-specific selection, strict adherence to manufacturer and adhesive protocols, and integration of preventive care, while sustainability and the amalgam phase-down are reshaping material choice worldwide.

Keywords: dental restorative materials; resin composite; glass ionomer cement; dental ceramics; dental amalgam; adhesive dentistry

1. Introduction

Dental caries and its sequelae remain among the most prevalent health conditions worldwide, and the restoration of lost tooth structure is a core activity of general dental practice [1]. Restorations are also a recurring burden: the replacement of failed restorations accounts for a large proportion of operative dentistry, with secondary caries and restoration fracture the most frequently reported reasons for replacement [2]. Contemporary care is guided by minimal intervention principles, which favour preventive, tooth-preserving and adhesive approaches over extensive mechanical cavity preparation [3].

The materials available to the clinician have changed profoundly over the past seven decades. Buonocore's description of acid etching of enamel in 1955 [4] and Bowen's development of the bis-GMA resin and silanised filler system in the early 1960s [5] laid the foundation for adhesive dentistry and modern resin composites. Since then, advances in glass ionomer chemistry, ceramic processing, digital manufacturing and bioactive filler technology have widened the choice of materials considerably.

Regulatory and environmental developments have also reshaped practice. The Minamata Convention on Mercury obliges its parties to phase down the use of dental amalgam [6], and the European Union has gone further by prohibiting the use of amalgam from 1 January 2025 except where the practitioner deems it strictly necessary for the specific medical needs of the patient [7]. These changes place greater reliance on mercury-free alternatives and on a sound understanding of their strengths and limitations.

The resulting abundance of materials, each with its own composition, handling characteristics, evidence base and cost, presents a practical challenge. Clinicians must choose among them in a way that is consistent with the clinical situation, the patient's caries risk and expectations, and the available resources, and must judge outcomes against standardised criteria [8]. The rationale for this review is to bring together the principal restorative material classes in a single clinically oriented synthesis. Its objective is to describe the composition, properties, indications, limitations and recent developments of direct and indirect dental restorative materials, and to outline principles that support evidence-informed material selection.

2. Materials and Methods

Study design. This article is a narrative review. A narrative design was chosen because the topic spans several material classes, laboratory and clinical study designs, and policy documents that cannot be pooled quantitatively. Reporting was guided by the SANRA scale for narrative reviews [9].

Information sources and search strategy. The literature was identified through PubMed/MEDLINE, Scopus and Google Scholar, supplemented by hand-searching of reference lists and by international policy documents from the World Health Organization, the United Nations Environment Programme and the European Union. Search terms combined the names of each material class (for example, amalgam, resin composite, bulk-fill, glass ionomer, resin-modified glass ionomer, compomer, giomer, bioactive glass, lithium disilicate, zirconia, CAD/CAM, cast alloy) with terms such as clinical performance, longevity, survival, adhesion, biocompatibility and sustainability.

Selection of sources. Priority was given to systematic reviews, meta-analyses, randomised and prospective clinical trials, consensus statements and authoritative narrative reviews. Laboratory studies were used to explain composition, mechanisms and properties. Foundational publications were retained for historical context. Articles not available in English, and case reports without a broader evidential contribution, were not considered.

Synthesis. Findings were synthesised qualitatively and organised by material class, then by cross-cutting themes (adhesion, selection, biocompatibility and sustainability). No statistical pooling, risk-of-bias scoring or meta-analysis was undertaken.

Ethical considerations. This review used only published literature and involved no human participants, patient data or animal experiments. Ethical approval and informed consent were therefore not required.

3. Results and Discussion

The evidence is presented by material class, followed by adhesion, selection principles and sustainability. A comparative summary is given in Table 1.

3.1 Dental amalgam

Dental amalgam is formed by combining a silver-tin-copper alloy powder with liquid mercury, which makes up roughly half of the set material by weight [10]. It has been used for more than a century because it is inexpensive, forgiving of moisture and technique, and mechanically robust in load-bearing cavities. Systematic reviews of posterior restorations have generally reported longevity for amalgam that is comparable to, or slightly better than, that of resin composite [11]. A Cochrane review likewise found that composite restorations in posterior teeth tended to fail more often than amalgam, mainly through secondary caries, although the certainty of the evidence was limited [12].

The disadvantages are the absence of adhesion, the need to remove sound tooth structure to create retentive form, poor aesthetics and mercury release. Mercury vapour exposure from amalgam restorations has been quantified and is generally well below levels associated with adverse systemic effects [13]. A scientific committee opinion for the European Commission concluded that systemic disease from amalgam is unlikely, with local reactions such as lichenoid lesions and hypersensitivity being uncommon [14]. The decline of amalgam is therefore driven chiefly by environmental considerations and by the Minamata Convention rather than by evidence of widespread harm to patients [6,7,14].

3.2 Resin composites

Resin composites consist of a polymerisable organic matrix, typically based on dimethacrylate monomers such as Bis-GMA, UDMA and TEGDMA, a dispersed inorganic filler, a silane coupling agent that bonds filler to resin, and a photoinitiator system, most commonly camphorquinone [15,16]. Filler size, shape and loading govern strength, wear resistance, polish retention and shrinkage. Developments from macrofilled and microfilled materials to hybrid, nanohybrid and nanofilled composites have allowed a single material to combine adequate strength with durable polish, which explains their use in both anterior and posterior teeth [16].

Polymerisation shrinkage and the stress it generates at the tooth-restoration interface remain the central limitation. Stress development depends on the volumetric shrinkage, the elastic modulus of the material, the cavity configuration and the rate of cure [17]. Although stress can contribute to marginal gaps, post-operative sensitivity and cuspal deflection, its clinical importance is still debated, and the relationship between laboratory stress measurements and clinical outcome is not straightforward [18]. Incremental placement, appropriate light curing and the use of low-shrinkage monomers or stress-relieving fillers are the principal mitigation strategies.

Bulk-fill composites, which can be placed in layers of 4 mm or more, simplify placement and reduce chair time. A systematic review and meta-analysis found that the clinical performance of bulk-fill and conventional composites in posterior teeth was similar over the follow-up periods studied [19]. Across the wider literature, posterior composite restorations show low annual failure rates, with fracture predominating as a reason for early failure and secondary caries as a reason for later failure [20]. Meta-analytic data for Class II restorations reinforce the importance of operator skill, patient caries risk and the number of surfaces restored in determining longevity [21].

3.3 Adhesive systems

The success of resin-based and many indirect restorations depends on bonding to enamel and dentine. Adhesive technology has progressed from the acid-etch technique to etch-and-rinse systems, self-etch systems and, more recently, universal or multi-mode adhesives that can be applied in either mode [22]. Enamel bonding is highly reliable after phosphoric acid etching, whereas dentine bonding is more demanding because of its moisture content and organic composition, and bond durability is challenged by hydrolytic and enzymatic degradation of the hybrid layer [22].

A systematic review of adhesives in non-carious cervical lesions concluded that three-step etch-and-rinse and two-step self-etch systems, particularly mild self-etch adhesives, provide the most reliable retention, with simplified one-step approaches performing less consistently [23]. Selective enamel etching and strict adherence to manufacturer instructions are practical measures that protect the bond irrespective of the adhesive chosen.

3.4 Glass ionomer-based materials

Conventional glass ionomer cements (GICs). GICs set by an acid-base reaction between a fluoroaluminosilicate glass powder and an aqueous polyalkenoic acid. They bond chemically to enamel and dentine through ionic interaction with calcium, are biocompatible, have a coefficient of thermal expansion close to that of tooth structure, and release and take up fluoride [24]. Their weaknesses are brittleness, lower wear resistance and early moisture sensitivity, which limit their use in high-stress areas [24]. High-viscosity formulations have improved strength and wear, and underpin the atraumatic restorative treatment approach used in community and resource-limited settings [3,24].

Resin-modified glass ionomer cements (RMGICs). RMGICs incorporate hydroxyethyl methacrylate and other resin components that allow light activation, which improves early strength, handling, aesthetics and resistance to early moisture contamination while retaining fluoride release and adhesion [25]. Concerns include water sorption and dimensional change, and the release of unreacted resin components.

Clinical performance. An updated meta-analysis comparing resin-based and glass ionomer posterior restorations reported that glass ionomer materials generally perform best in small, low-stress cavities and primary teeth, and that resin composite is preferable in larger, multi-surface, load-bearing situations [26]. GIC-based materials are also useful as liners, bases, luting agents, fissure sealants, core build-ups and interim restorations.

Compomers and giomers. Compomers (polyacid-modified composites) combine a dimethacrylate resin with ion-leachable glass, set by light activation and absorb water after placement to start a limited acid-base reaction; they require a separate adhesive and release less fluoride than glass ionomers [27]. Giomers contain pre-reacted glass ionomer (PRG) particles within a resin matrix, offering fluoride release and recharge with the handling and polish of a composite [28]. Both are used mainly in paediatric dentistry and in low-stress restorations.

3.5 Bioactive and ion-releasing materials

Bioactive restorative materials are designed to interact with the oral environment, for example by releasing calcium, phosphate, fluoride or hydroxide ions that may buffer acid, promote remineralisation and inhibit bacterial growth [29]. Categories include calcium silicate-based materials, bioactive glass-containing composites and resin-modified or glass ionomer systems with added bioactive fillers. Bioactive glass has been incorporated into composites and adhesives to confer ion release and antibacterial potential, but its effect on mechanical properties, ion-release longevity and clinical benefit varies between formulations [30].

Nanotechnology has contributed nanofillers, nanoclusters and antibacterial nanoparticles that can improve strength, polish and biological activity, although long-term safety and clinical data remain limited [31]. At present, the evidence for bioactive materials rests largely on laboratory studies and short-term clinical trials, and well-designed long-term randomised trials are needed before they can replace established materials in routine posterior restorations.

3.6 Dental ceramics

Dental ceramics are commonly grouped by microstructure into glass-matrix ceramics, polycrystalline ceramics and resin-matrix ceramics, a classification that helps predict strength, translucency and bonding behaviour [32]. Their appeal lies in aesthetics, chemical stability, wear behaviour compatible with enamel (when well polished) and good tissue response [33,34].

Glass-matrix ceramics. Feldspathic and leucite-reinforced porcelains offer excellent translucency but modest strength, and are best suited to veneers and conservative inlays and onlays that are adhesively bonded. Lithium disilicate offers a flexural strength several times higher while retaining good translucency, and is used for single crowns, partial-coverage restorations, veneers and short-span anterior bridges [34,35]. Glass-matrix ceramics are bonded by etching with hydrofluoric acid, silanisation and a resin cement [34].

Polycrystalline ceramics. Yttria-stabilised zirconia has flexural strength in the region of 900 to 1,200 MPa and fracture toughness far above that of glass ceramics, enabling monolithic crowns and multi-unit bridges with minimal tooth reduction [35]. Newer, more translucent generations improve aesthetics through higher yttria content, at some cost in strength, and the susceptibility of zirconia to low-temperature degradation and the need for appropriate sintering and surface treatment remain areas of attention [36]. Bonding to zirconia generally relies on airborne-particle abrasion and phosphate-monomer-containing primers or cements rather than acid etching [34].

Clinical performance. Systematic reviews report high survival for all-ceramic single crowns, broadly comparable to metal-ceramic crowns, with differences in the type of complication: chipping and framework fracture are more characteristic of veneered ceramics, whereas monolithic designs reduce veneer chipping [37,38]. Meta-analytic data on partial-coverage restorations show that ceramic inlays, onlays and overlays achieve survival rates that are broadly comparable with, and often more favourable than, those of resin-based indirect restorations over medium-term follow-up [39].

3.7 CAD/CAM and digital workflows

Computer-aided design and manufacturing (CAD/CAM) has transformed indirect dentistry by enabling intraoral scanning, digital design and chairside or laboratory milling [40]. Block materials include feldspathic and leucite ceramics, lithium disilicate, zirconia and hybrid resin-ceramic materials such as resin-nanoceramics and polymer-infiltrated ceramic networks [32,40]. The hybrid materials have a lower elastic modulus than glass ceramics, are easier to mill and repair and are less brittle, although their long-term clinical data are more limited.

The benefits of digital workflows include reproducibility, reduced laboratory time, single-visit restorations and a more conservative design philosophy. Limitations include equipment cost, the learning curve, and the dependence of marginal and internal fit on scanner accuracy, milling strategy and operator technique. Additive manufacturing of permanent restorative resins is an emerging area, and its long-term clinical performance has yet to be established.

3.8 Metals and alloys

Cast alloys remain in use for inlays, onlays, crowns, bridges and frameworks. High-noble gold alloys have excellent castability, marginal adaptation, corrosion resistance and wear compatibility with enamel, and cast gold restorations are widely regarded as a benchmark for longevity [41]. Base-metal alloys, such as nickel-chromium and cobalt-chromium, are less costly and stiffer, but are technique sensitive, more difficult to cast and finish, and contain elements such as nickel and beryllium that raise biocompatibility and allergy considerations [41]. Aesthetic expectations and the cost of gold have reduced the use of cast metal restorations, although they remain valuable where occlusal forces are high, tooth reduction must be limited or aesthetics are secondary.

3.9 Biocompatibility and safety

All restorative materials interact with oral tissues, and their biological evaluation is based on cytotoxicity, sensitisation, genotoxicity and local tissue response in addition to clinical observation [42]. In resin-based materials, residual monomers and degradation products such as Bis-GMA derivatives, TEGDMA and HEMA can be released, particularly from inadequately polymerised material, and the quantities released depend on formulation, degree of conversion and storage conditions [43]. Allergic reactions to dental materials are uncommon but include contact hypersensitivity to methacrylates and to metals such as nickel. Good polymerisation technique, adequate polishing and appropriate liners in deep cavities help to minimise biological risk.

3.10 Principles of material selection

Material choice should follow a systematic assessment rather than habit. The main considerations are the size and location of the cavity, the amount of remaining sound tooth structure, occlusal load and parafunction, the ability to isolate the field, patient caries risk, aesthetic demands, patient preferences and cost [3,8]. In high-caries-risk patients, the fluoride release and adhesion of glass ionomer-based materials can be advantageous, whereas in low-risk patients with large load-bearing cavities, resin composite or indirect ceramic restorations usually give more durable results. Where moisture control is poor, a moisture-tolerant material or a staged approach may be more appropriate than an adhesive resin restoration placed under compromised conditions.

Table 1 summarises the main characteristics discussed above.

Table 1. Comparative summary of principal dental restorative materials

Material class	Main advantages	Main limitations	Typical indications
Dental amalgam	Durable, low cost, tolerant of moisture	No adhesion, poor aesthetics, mercury, environmental restrictions	Large posterior cavities where alternatives are unsuitable or unaffordable
Resin composite	Aesthetics, adhesion, conservative preparation, repairable	Polymerisation shrinkage, technique sensitivity, wear in heavy load	Anterior and posterior direct restorations
Conventional and high-viscosity GIC	Chemical adhesion, fluoride release, biocompatibility	Brittleness, wear, early moisture sensitivity	Small restorations, primary teeth, ART, liners, bases

Material class	Main advantages	Main limitations	Typical indications
Resin-modified GIC	Improved strength and handling, fluoride release	Water sorption, resin components	Primary teeth, cervical lesions, liners, bases
Compomer and giomer	Easy handling, some fluoride release	Lower fluoride release (compomer), limited long-term data	Paediatric and low-stress restorations
Bioactive materials	Ion release, remineralisation potential	Limited long-term clinical evidence	Selected restorations in high-caries-risk patients
Glass-matrix ceramics	Aesthetics, bondability, good tissue response	Lower strength than zirconia, brittle	Veneers, inlays, onlays, crowns
Zirconia	Very high strength, minimal reduction	Bonding more demanding, translucency trade-off	Crowns and multi-unit bridges
Cast alloys	Longevity, precision, strength	Aesthetics, cost, allergy concerns (base metals)	Crowns, onlays, frameworks in high-load situations

3.11 Sustainability, limitations and future directions

The amalgam phase-down is the most visible example of how environmental considerations now shape dental material choice [6,7]. Prevention, early detection of caries and minimally invasive treatment reduce the need for restorations and therefore for materials of every kind [3]. Reducing waste, improving the durability of restorations and managing amalgam and resin waste appropriately are likely to become more prominent concerns.

The evidence base also has limitations. Many clinical trials are small, short and conducted in academic settings, and results may not translate directly to general practice. Heterogeneity in study design, operator experience and outcome definitions complicates comparison across materials, which is why standardised evaluation criteria are important [8]. This review is narrative and did not apply formal risk-of-bias assessment, so the conclusions should be read as an informed synthesis rather than a quantitative estimate of effect. Future research should prioritise long-term randomised trials of bioactive and hybrid materials, practice-based evidence, and studies of the clinical performance of digitally manufactured restorations.

4. Conclusion

No single restorative material is universally superior. Resin composites are the dominant direct material, supported by advances in fillers, adhesives and bulk-fill systems, while glass ionomer-based materials remain essential for minimally invasive, preventive and resource-limited care. Ceramics, together with digital workflows, offer strong and aesthetic indirect options, and cast alloys retain a place where durability is paramount. Bioactive materials are promising but need stronger long-term clinical evidence. The decline of dental amalgam increases reliance on these alternatives and on correct adhesive and handling protocols. Evidence-informed, case-specific material selection, combined with prevention and minimal intervention, offers the best prospect of durable restorations and good patient outcomes.

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Conflict of Interest

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