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Stainability of Different Indirect Composite Materials Before and After Tooth Brushing

Rania Ali Emara, Tarek Salah, Maged Mohamed Zohdy, Sarah Mahanna

Department of Fixed Prosthodontics, Faculty of Dentistry, Ain Shams University, Egypt.

Abstract

Indirect composite restorative materials fabricated by computer aided design and computer aided manufacturing (CAD/CAM), whether milled or 3D printed, have become widely used alternative to conventional ceramics because of their favorable mechanical behavior, ease of intraoral repair, and shorter chairside workflow. However, their resin rich composition makes them more susceptible to discoloration than all ceramic restorations, particularly when exposed to chromogenic beverages and repeated mechanical tooth brushing. This narrative review aimed to evaluate the stainability and color stability of three indirect composite restorative materials: polymer infiltrated ceramic network (PICN), Milled composite material with dispersed fillers, and 3D printed composite materials with dispersed fillers following exposure to coffee and carbonated soft drink before and after simulated tooth brushing and summarizes the methods used to evaluate the color change, and the influence of staining solutions and tooth brushing on their color stability.

Keywords: (CAD/CAM), composite materials

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1. Introduction

Indirect restorative dentistry has evolved considerably since resin-based materials were introduced as an alternative to metal and ceramic restorations. Early direct composite resins, although esthetic, were limited intraorally by polymerization shrinkage, incomplete monomer conversion, and inferior mechanical strength, which translated clinically into marginal discoloration, rapid occlusal wear, low fracture toughness, and postoperative sensitivity [1]. These limitations were partly addressed by processing composite resin restorations indirectly in the laboratory under additional heat, pressure, or light curing, which improved the degree of conversion and reduced shrinkage stress compared with the direct technique [1]. The introduction of computer aided design and computer aided manufacturing (CAD/CAM) technology made it possible to fabricate indirect restorations digitally rather than by conventional laboratory casting or layering [1-2]. Polymer based restorations were introduced into this digital workflow soon afterward, the first commercially available CAD/CAM resin composite block, Paradigm MZ100 (3M), was launched around the year 2000, factory processed from an existing direct composite resin under industrial high temperature, high pressure polymerization to achieve a higher filler load and degree of conversion than could be obtained chairside [3]. Although ceramic materials remain a long-established standard for CAD/CAM indirect restorations owing to their superior esthetics, wear resistance, and high elastic modulus, their brittleness predisposes them to catastrophic, unrepairable fracture, while their hardness can accelerate wear of the opposing natural dentition [1-2].

Milling dense sintered ceramic blocks is also technically demanding and often requires an additional post milling crystallization or glaze firing cycle before the restoration reaches its final shade and strength [1-2]. Polymer based CAD/CAM restorative materials were therefore introduced to offer a more resilient, dentin like alternative: their comparatively low elastic modulus allows functional stresses to be absorbed and dissipated rather than transmitted rigidly to the underlying tooth structure, they mill more efficiently with less chipping and reduced bur wear, they eliminate the need for a separate firing step, and unlike ceramics they can be intraorally polished, adjusted, and repaired directly with resin composite [1-2-4]. Because color stability is one of the most important requirements for the long-term esthetic success of any indirect restoration, and because the different polymer based CAD/CAM material categories differ substantially in filler content, matrix chemistry, and manufacturing method, they may be expected to differ in their susceptibility to staining. This review summarizes current evidence on the classification of these materials, the mechanisms of their discoloration, and the effects of common staining beverages and simulated tooth brushing on their color stability.

2. Classification of Polymer Based CAD/CAM Restorative Materials

Polymer based CAD/CAM restorative materials are broadly classified according to their internal microstructure and manufacturing method into three main categories (Figure 1). The first consists of milled, resin composite with dispersed fillers blocks, in which inorganic filler particles are distributed throughout a highly crosslinked resin matrix, Brilliant Crios (Coltene) is a representative example of this "modified composite block" category, combining barium glass and silica filler with a methacrylate based matrix to improve strength and polishability over direct composites [1]. The second category comprises polymer infiltrated ceramic network (PICN) materials, exemplified by VITA Enamic (VITA Zahnfabrik), in which a porous, pre sintered feldspathic ceramic scaffold (approximately 86 wt%) is infiltrated with a crosslinked polymer network (approximately 14 wt%), producing two continuous, interpenetrating phases rather than dispersed filler particles [1-5]. The third and most recently introduced category consists of resins engineered specifically for additive manufacturing, such as Flexcera Smile Ultra+ (Desktop Health) and similar 3D printed ceramic reinforced composites, which are fabricated through layer by layer photopolymerization rather than subtractive milling [6-7]. Although Brilliant Crios and VITA Enamic are both machinable, industrially processed blocks, and 3D printed composites are built additively, all three categories are increasingly grouped together in recent literature as "ceramic reinforced composites", "resin matrix ceramics," or “Hybrid ceramics” reflecting their shared aim of combining esthetics and wear resistance of ceramics with repairability and reduced brittleness of resin-based materials [6].

3. Digital Fabrication Technologies

1) Subtractive Manufacturing

CAD/CAM milling remains the predominant technique for fabricating indirect dental restorations. However, it presents several drawbacks, including material waste, potential formation of microcracks and residual surface stresses, limited ability to produce complex geometries and rising maintenance expenses associated with bur wear [8].

2) Additive Manufacturing

As an alternative to subtractive techniques, additive manufacturing (3D printing) has gained considerable attention due to its capacity to conserve material, its suitability for constructing restorations with complex or intricate designs, its ability to fabricate several restorations concurrently, and its comparatively lower environmental burden [9].

4. Mechanisms of Discoloration in Indirect Composite Restorations

Discoloration of polymer based restorative materials can occur through both extrinsic and intrinsic mechanisms. Extrinsic staining results from the penetration of exogenous chromogenic pigments, such as those found in coffee, tea, red wine, and carbonated soft drinks, into the outer surface of the restoration, while intrinsic staining arises from chemical alterations within resin matrix itself, including oxidation of unreacted residual monomers, water sorption, and hydrolytic degradation of the silane coupling agent at filler matrix interface [10]. The extent of extrinsic staining is influenced by several material related factors, including surface roughness, filler type, filler content and particle size, degree of conversion, and water sorption or solubility of polymer matrix, all of which vary considerably among different types of polymer based restorative materials, hybrid ceramic (PICN), milled polymer based materials with dispersed filler, and the 3D printed polymer based materials with dispersed fillers [10-11].

5. Effect of Tooth brushing on Color Stability

Simulated toothbrushing has a well documented, though not always consistent, influence on the color stability of the indirect CAD/CAM restorative materials. Its effect appears to depend heavily on the sequence in which it is applied relative to the staining solutions, functioning either as a pre staining conditioning step or as a post staining stain removal procedure, each with a distinct underlying mechanism [12].

A) Tooth brushing Applied Before Staining

When simulated tooth brushing is applied prior to immersion in the staining solutions, using a tooth brushing simulator device (Figure 2), meaning it may have acted as a pre staining conditioning step rather than a stain removal procedure. Mechanical tooth brushing performed at this stage may influence subsequent stainability by altering the baseline surface roughness of the restoration before chromogenic exposure occurs, either by smoothing the surface and removing loosely bound manufacturing residue, thereby reducing the number of sites available for chromogen retention, or, conversely, by introducing the micro scratches that increase the surface roughness and create additional sites for the pigment retention once the staining exposure begins [13-14].

B) Toothbrushing Applied After Staining

In contrast, when tooth brushing is applied after immersion in the staining solution, it more directly represents a stain removal mechanism. In this sequence, brushing acts primarily to mechanically dislodge extrinsic pigment that has already been adsorbed onto or accumulated within the specimen surface, rather than to condition the surface in advance of staining. In a recent comparative study of resin composite CAD/CAM blocks and a polymer infiltrated ceramic network material, tooth brushing was performed every 24 hours throughout staining immersion period specifically to remove accumulated extrinsic stain, illustrating this direct post staining removal mechanism [15]. Other studies applying a similar post staining brushing sequence have reported measurable reductions in color change following brushing, particularly for materials with predominantly surface level rather than deeply intrinsic discoloration, supporting the interpretation that tooth brushing in this context primarily reflects the removal of accumulated extrinsic stain rather than a change in the material's underlying susceptibility to staining [12-16].

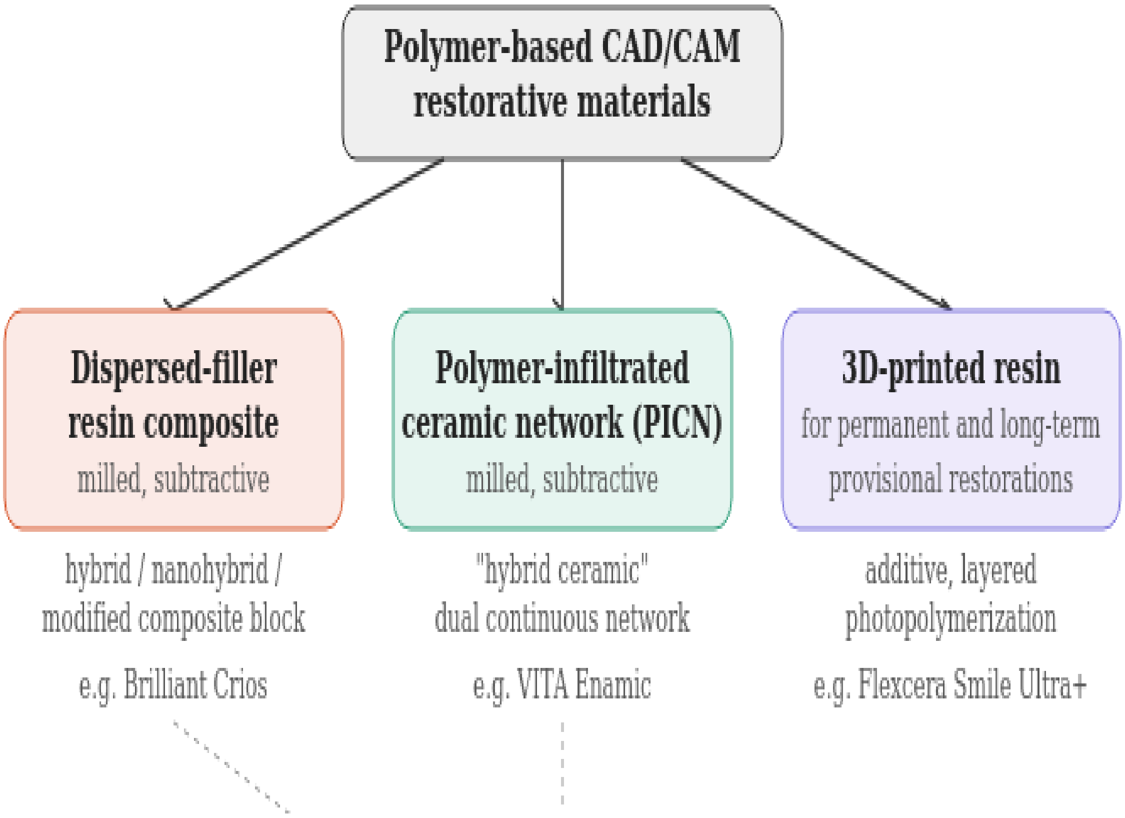

Figure 1: Classification of Polymer-Based CAD/CAM Restorative Materials.

Figure 2: ROBOTA chewing and tooth brushing simulator.

Figure 3: X-Rite Spectrophotometer.

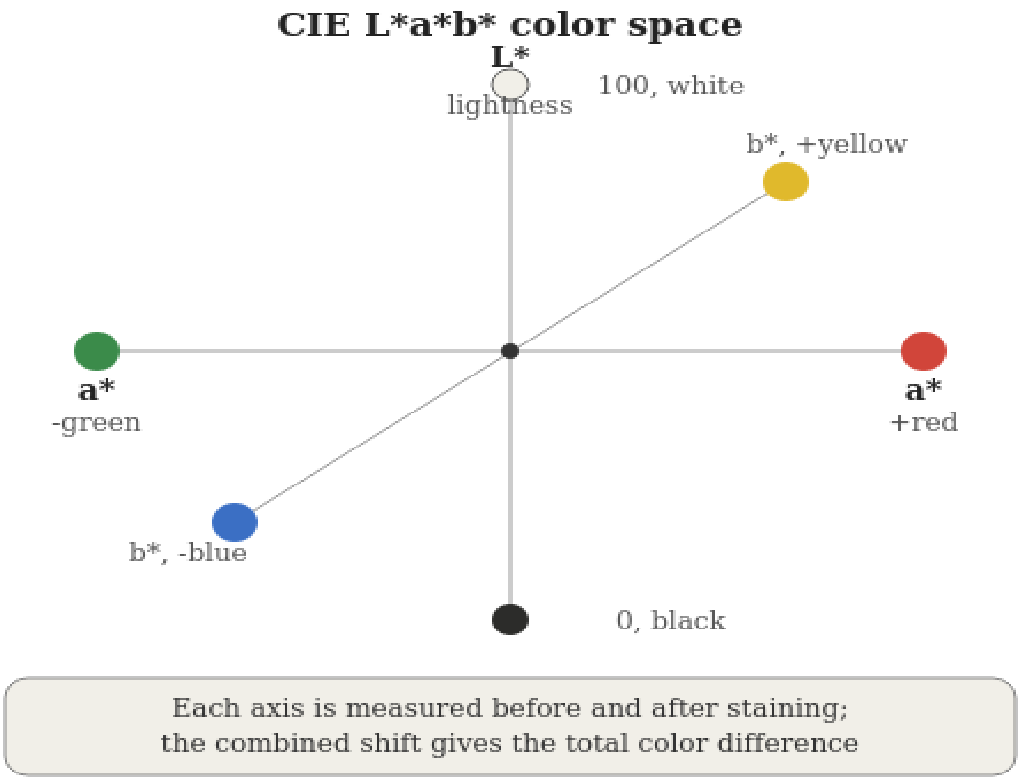

Figure 4: The CIE Lab color.

6. Color Measurement and Perceptibility/Acceptability Thresholds

Color stability is considered one of the most important requirements for the long-term clinical success of any esthetic restoration, since discoloration is one of the primary factors prompting esthetic failure [10]. Two main types of devices are used in dental research: colorimeters, which measure color as perceived under simulated standard illumination, and spectrophotometers (Figure 3), which measure the amount of light reflected from a surface at each wavelength across the visible spectrum and are considered the more accurate and reproducible [10]. Spectrophotometer measurements are most commonly expressed using the Commission Internationale de l'Eclairage (CIE) L*a*b* (CIELAB) color space (Figure 4), in which L* represents lightness, a* represents the red/green axis, and b* represents the yellow/blue axis, total color change between two time points is then calculated from the differences in these three coordinates before and after exposure to a staining or tooth brushing protocol [17]. To interpret whether a measured color difference is clinically meaningful, perceptibility and acceptability thresholds have been established in dental literature, below which color change is considered clinically undetectable or clinically tolerable, respectively [10].

7. Effect of Staining Solutions on Color Stability

Coffee is repeatedly reported as one of the most potent staining agents for indirect CAD/CAM restorative materials, owing to its high concentration of tannins, chlorogenic acids, and yellow colorants, which have a strong affinity for the organic resin matrix of composite materials and can produce deep, difficult to reverse discoloration [18]. There are other staining solutions such as Carbonated soft drinks, which are characterized by a low pH and erosive acids such as phosphoric and citric acid, which primarily attack filler particles and the resin matrix through surface softening and erosion rather than pigment deposition, this surface alteration changes light reflection and scattering, which can be registered as a measurable color change even in absence of a strong chromogen [15].

8. Conclusion

The color stability of indirect CAD/CAM restorative materials is influenced by multiple factors, including material composition, the type of staining medium, and mechanical cleaning procedures. Ceramic dominant materials with polymer infiltrated networks generally exhibit greater resistance to discoloration, whereas milled resin based and, particularly, 3D printed composites tend to be more susceptible to color changes, especially following coffee exposure. The effect of tooth brushing on color stability varies according to both the restorative material and the staining medium, rather than providing a consistent protective effect. These findings highlight the importance of considering both the intrinsic characteristics of the restorative material and extrinsic clinical factors when selecting indirect restorative materials and providing patients with guidance for maintaining long term esthetic stability.

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