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IMPACT OF IMMERSION IN DIFFERENT STORAGE MEDIA ON COLOR STABILITY, SURFACE ROUGHNESS, AND SURFACE MICROHARDNESS OF DIFFERENT FLOWABLE RESIN COMPOSITES: LITERATURE REVIEW

Hend Yousri Abd-Elfattah*, Mohamed Elshirbeny Elawsya** *and* Abeer ElSayed ElEmbaby***

ABSTRACT

Objective: This study aims to investigate the influence of different storage media on the color stability, surface roughness, and surface microhardness of different flowable resin composites.

Abstract: Flowable composites were released into the market with great expectations to address the drawbacks of packable composites, such as material adaptability. These materials can flow thanks to the low filler loading and high monomer content of these flowable composites, although frequently at the price of inferior physical qualities. It is generally acknowledged that a resin composite's mechanical behavior improves with increasing filler content, which in turn increases the restoration's potential longevity. As a result, resin composites with a very high filler content have arisen, and manufacturers may emphasize the filler content as a marketing point. However, one of the main techniques employed by manufacturers to increase the flowability of a resin composite is to reduce the filler content, which may have an impact on the mechanical properties of the material. Nonetheless, resin composites described as both flowable and having high filler content have been introduced. The color stability, surface roughness, and microhardness of resin composites have previously been found to be significantly influenced by parameters related to composition, filler size, weight, volume, thickness, polymerization quality, and polishing quality. In the current study, different flowable resin composites were immersed in different storage media to evaluate and compare their color stability, surface roughness, and surface microhardness. Additionally, the impact of these storage media on the mechanical properties of the tested composites was examined.

* MSc Student, Department of Conservative Dentistry, Faculty of Dentistry, Mansoura University, Mansoura, Egypt.
** Lecturer, Department of Conservative Dentistry, Faculty of Dentistry, Mansoura University, Mansoura, Egypt.
*** Professor, Department of Conservative Dentistry, Faculty of Dentistry, Mansoura University, Mansoura, Egypt.

Research strategy: The websites SciVersa, Scopus, ISI Web of Science, and the National Library of Medicine (MEDLINE/PubMed) served as the foundation for the online database used in this investigation. These websites were used to search for research conducted up until 2025. Any published information regarding the materials used in this study, such as their composition, usage guidelines, and clinical performance, is included in the search. The published articles that examined their color stability, surface roughness, and/or surface microhardness are also included in the search, the number of the related articles are approximately 21. The following search terms were used: Flowable composite, nanohybrid composite, color stability, surface roughness and microhardness, and composite immersion in storage media.

KEYWORD: Storage media, color stability, surface roughness, surface microhardness, flowable resin composites

INTRODUCTION

Flowable resin composites are commonly utilized in clinical practice as they are easy to employ with a direct application syringe to fill cavities. A flowable resin composite's initial use in a clinical setting was restricted to the cavity's base and lining due to its poor mechanical qualities compared to the universal resin composite.[1] However, by using novel monomers and nanosized filler particles, flowable resin composites have enhanced their mechanical properties and are used in a variety of clinical contexts for cavities.[2-5] Certain flowable resin composite products are utilized to restore occlusal cavities and, thanks to mechanical advancements, exhibit great color stability, surface roughness, and surface microhardness comparable to universal resin composites.

Currently, there are numerous clinical applications for nano-flowable composites with various filler size formulations, which exhibit excellent mechanical and physical qualities.[6] Their high flowability and low viscosity provide improved adherence to the walls of the inner cavity, accessibility to the parts of the preparation that are hard to reach, and relative simplicity of use (e.g., utilizing fine-gauge needles to dispense material).

Over the years, RBCs were altered to have improved optical characteristics and a greater selection of translucent and opaque shades, since it has long been difficult to match the color of the restoration to the tooth substrates and maintain stability.[7] Shade selection is an extremely complex process because of the variety of shades available and technique sensitivities; it heavily relies on the dentist's competence, prejudice, and desired results. Under some circumstances, dentists are forced to experiment, which can result in an unsatisfactory shade that necessitates redesigning the procedures at the cost of the dentist's chair time. As a result, the optical properties for these groups are not standardized, and the outcomes could be unexpected or unsatisfactory.[8]

One of the main causes for failures requiring the replacement of restoration has been identified as superficial staining of esthetic restorations. Both external factors as the absorption of colors from drinks and food, and intrinsic factors relating to the material, can cause discoloration. However, because of the nature of their resin matrix, even the newest composite resin materials are more susceptible to the penetration of various pigmenting agents because they absorb more moisture than ceramics.[9, 10] Furthermore, the surface topography of the restoration is one of the most important variables that determine its esthetics since a smooth surface prevents discoloration and staining and improves optical compatibility with the enamel tissue and surface gloss.[11]

Both extrinsic and intrinsic factors can cause tooth-colored resin-based materials to become discolored. The matrix's composition (percentage of bisphenol A-glycidyl methacrylate (Bis-GMA), urethane dimethacrylate (UDMA)), the kind of bonding between the fillers and matrix, etc., all affect the intrinsic factors. For esthetic restorations, external factors like the absorption or adsorption of extrinsic pigments provide a significant challenge. The younger generation consumes more alcoholic and carbonated drinks, including cola. These drinks are often drunk often and between meals, which makes composite restorations more likely to discolor.[12-14]

One of the causes of external discoloration is surface roughness.[15] One significant aspect of the color stability and surface integrity of resin composites is their chemical composition, which may also have an impact on their capacity to absorb water.[16] As dental resin composites deteriorate, inorganic fillers separate from the resin matrix and form a gap, roughening the surface and increasing the likelihood of external pigments.

Various food and liquid ingredients, as well as organic acids, can soften resin composite filler components. They are exposed to a wide range of chemicals, including salts, acids, alcohols, alkalis, etc., while eating and drinking, and the frequency of these drinks is also a direct factor.[17] This could alter microhardness, a crucial restorative quality that directly influences physiochemical characteristics, including compressive strength and abrasion resistance. Consequently, the restoration's quality is compromised, and the need for replacement is accelerated.[18, 19]

The filler's content and particle size possess a significant influence on the mechanical characteristics of composite resin.[20, 21] Particle sizes in hybrid and microhybrid resin composites vary widely; macrofillers typically range in size from 0.1 to 6.0 µm, while microfillers range from 0.01 to 0.05 µm.[22] As a result, permit large filler loading for increased strength.[23]

In order to meet the need for a universal restorative material, nanofilled composites were recently created to offer optimum mechanical and physical qualities; as a result, they were recommended for both anterior and posterior teeth. These composites' improved resilience to chemical challenges in the oral environment can be linked to the distribution and packing of nanofillers.[24]

Resin-Based Composites

A resin composite is described as a three-dimensional structure that is formed of two or more various chemical components. Moreover, it can be defined as a combination of a resin matrix and hard inorganic filler particles.[24] Inorganic filler particles, resin matrix, initiator-catalyst systems with pigments, modifiers, and coupling agents make up the resin composite. The primary factors influencing the color outcomes of composites are the fillers' size, volume, shape, and refractive index.[25] In addition to fillers, the kind of monomers present in the matrix, the degree of conversion, and the photoinitiator system used in the formula also influence the composite's optical properties.

The Organic Resin Matrix

The matrix is mostly comprised of organic monomers together with photopolymerization initiators. When these monomers come into exposure to blue light, they can polymerize to produce fillers.[26] Significant polymerization and cross-linking rates are essential for dental composites so as to enhance the mechanical characteristics of the polymer. Additionally, High biocompatibility, minimal shrinkage to avoid microleakage, and low absorption of water to prolong longevity.[27]

Dimethacrylates, such as ethoxylated bisphenol A dimethacrylate (EBPDMA), Bis-GMA, triethylene glycol dimethacrylate (TEGDMA), and UDMA, have been the monomers most frequently utilized in recent years.[27] Because of its strong reactivity, low volatility, and comparatively low polymerization shrinkage, Bis-GMA was the most extensively utilized monomer. However, the development of alternative monomers was prompted by the discovery of bisphenol A (BPA) as a contaminant or a byproduct of dental resin degradation. Studies have discovered BPA in patients' saliva and urine, which is concerning because it might have estrogenic effects, particularly in young patients. Additionally, they may cause cytotoxicity and genotoxicity, most likely by causing DNA damage, preventing the production of cytokines, and causing necrosis and apoptosis. [28, 29]

With a lower viscosity and no BPA core, UDMA is an alternate base monomer for dental resin composites. Even though Bis-GMA forms a stronger intermolecular hydrogen bond, UDMA's adaptability makes crosslinking more efficient. UDMA is found in certain materials; nevertheless, it is still mixed with hydrophilic co-monomers of low molecular weight, such as TEGDMA.[30]

The Inorganic Fillers

Dental composites' mechanical qualities and polymerization shrinkage can be improved by the inclusion of fillers, which are distributed throughout the resin matrix.[31]

The following categories apply to the most widely used fillers:[32]

1) Oxide fillers primarily consist of silica, alumina, titania, and zirconia, having a chemical composition of M_XO_Y. Silica was the first filler utilized in composites.

2) Alkaline silicate glass fillers, which mostly consist of barium and strontium glass, have a chemical composition of $M_XO_YSiO_2$. Many commercially available dental composites contain these fillers, which are typically combined with other oxide fillers.

3) Biomimetic fillers primarily refer to hydroxyapatite (HAp), which has the chemical composition $Ca_5(PO_4)_3OH$. It is estimated that HA makes up about 70 weight percent of dentin and 96 weight percent of enamel. As a result, dental composites supplemented with HA may exhibit superior remineralization behavior and bioactivity.

4) The Fraunhofer Silicate Research Institute was the first to create and patent organic–inorganic hybrid fillers for organically modified ceramics. These fillers have an oxide–polymer chemical composition. Dental composites containing this kind of filler have superior compressive strength and surface wetting characteristics.

Even though a lot of work has gone into investigating novel monomers and fillers, the primary problems that still need to be addressed are secondary caries and fractures in composite restorations. According to earlier research, Filler aggregates and inadequate filler/matrix interaction might lead to undesired failures.[33] As a result, a number of modification techniques have been put forth and used to enhance dental composites' final performance.

Coupling Agents

They are adhesion promoters, which chemically unite disparate materials to create composites with adequate mechanical properties. It is crucial that the filler and matrix have a strong link. Absence of the bond will cause stress to transfer within the filler, making the resin inefficient. Consequently, the resin matrix will bear the majority of the stress. Consequently, wear will cause excessive creep, which will ultimately lead to fracture. Additionally, inadequate bonding will result in crack initiation sites. Composites are capable of fatigue failure because resins do not promote a high resistance to crack propagation.[34]

For more than 50 years, silanes have been utilized in industrial plastics and, subsequently, in dental materials to chemically coat the surface of fillers and boost their strength. Their hydroxyl group on one side, which is attached to the identical group on the glass's surface, is the reason they were selected. The methacrylate group on the opposite side can attach itself to the resin's carbon double bond. As a result, a condensation reaction at the interface attests to their covalent bond with the glass surface.[35]

Silanes consequently have drawbacks. Because of their sensitivity to moisture, their binding deteriorates, resulting in wear, color instability, and ultimately loss of filler. Additionally, they become less effective and age quickly in a bottle. Therefore, there have been modifications to the matrix and filler to enhance the quality of the interaction between the resin and filler.[36]

Photointiator Accelerator System

Light energy is utilized in photopolymerization to initiate chemical and photochemical processes in the organic oligomers. As the monomer is converted to polymer, the photoinduced new polymeric material has a higher molecular weight. Moreover, crosslinking of generated macromolecules that are maturing or already exist.[37] Additionally, strengthening photo-polymerization is critical for improving mechanical properties, biocompatibility, color restoration, and stability. The primary photoinitiator system in resin composites is still camphorquinone (CQ) combined with a tertiary amine.[38] CQ has an unbleachable chromophore group and is a solid yellow component. As a result, increasing their presence in resin compositions results in a yellow color, which diminishes the final appearance of the cured material. As a result, there is a significant chance of material discoloration.[39] New photosensitizer molecules, which are derivatives of phosphine oxide, were employed to overcome the esthetic issues with this system. Thus, one structure seen in certain recent composites is the diphenyl (2.4.6-trimethylbenzoyl phosphine oxide) (TPO). It has shown higher curing efficiency and color stability than CQ.[40]

Pigments

For resin composites, the pigments are crucial components. They are required to match the natural color of teeth. They must therefore be kept immutable in the oral environment with long-lasting shade. The most often used oxidic pigments are ferric hydroxide (yellow) and ferric oxide (Fe_2O_3, red).[41]

The Evolution of Dental Composites

Dental composites are one of the most widely used materials for fillings and have been widely used in clinical settings for about fifty years. They were initially used in dentistry in the late 1950s and early 1960s, and their evolution and progression depend on acrylate. Bowen initially described the successful production of a composite by adding inorganic fillers to a monomer called bisphenol-A diglycidyl methacrylate.[42]

Classification of Dental Composites

According to several classification systems, there are numerous varieties of composite products that are used in clinical settings. Based on their various compositions and performance attributes, composites can be categorized into the subsequent groups.

According to Filler Particle Size

In the majority of classification systems for composites, the distribution and average size of the filler particles are taken into consideration.[43, 44] Composites can be categorized as macrofilled, microfilled, hybrids, modern hybrids, and nanofilled composites. Conventional or macrofilled composites, which consisted of filler particles ranging in size from roughly 10 and 50 µm, possessed mechanical strength, yet they had trouble polishing and maintaining a good match in color. Subsequently, “microfill” composites were introduced by including amorphous spherical silica of about 40–50 nm.

These composites were more esthetically pleasing, but they also displayed a considerable anatomical form loss as a result of wear and a significantly higher number of fractures. The hybrid composites were created by reducing the size of particles of traditional composites in order to meet the crucial issue of esthetics and mechanical characteristics. Among the best materials for posterior restorations is a hybrid composite.

The latest hybrid composites have greater polishing performance, reduced shrinkage, and better esthetics. They contain a few micrometers or less of glass filler particles and trace amounts of colloidal silica particles (10–50 µm and 10–50 nm). Modern hybrid composites (0.5–1.0 µm and 10–50nm) are preferred for esthetic needs because they come in a wide range of hues with customized translucency and opacity, unlike the limited shade selection of early macrofilled and microfilled composites.[45] Additionally, nanofilled composites with inorganic phases of distinctive dimensions in the range of 10–100 nm emerged with the development of nanotechnology.[44] Nanofilled composites provide strength and esthetics while reducing polymerization shrinkage due to their increased filler loading and decreased resin matrix content.[46]

According to Clinical Applications and Functional Requirements

1. Packable Composites

As an amalgam substitute for posterior restorations, packable composites are a popular type of dental resin composite. Packable composites, which initially became available in the late 1990s, are simpler for clinicians to manage than standard composites because they are firmer and less sticky. Compared to conventional composites, these materials have superior operational performance and are easier to shape.[47] They can create good proximal contact points if they are packed or forced with an instrument. Their mechanical or physical qualities, however, are not better than those found in conventional composites.[48] It is still necessary to conduct extended clinical performance evaluations of packable composites.

2. Flowable Composites:

Since their 1996 debut in dentistry, flowable composites have garnered a lot of concern. The filler loading has been lowered from 50–70% (volume) to 37–53% (volume) in these conventional composites.[49] Using an injection syringe to inject flowable composites into small cavities or fissures makes handling them easier and reduces working time because the flowability is enhanced and the viscosity is decreased. However, as shrinkage is an important material quality associated with clinical performance, flowable composites typically exhibit more shrinkage than conventional composites. Because of the reduced filler loading and low modulus of elasticity, the first-generation flowable composites were utilized as pit and fissure sealants and cavity lining agents. It is advised that flowable composites be used exclusively for restorations in low-stress bearing locations and not for posterior restorations because of their diminished filler content, physical characteristics, and wear resistance.

Because of their relatively low viscosity, adding nanoparticles to flowable composites is a noteworthy method of enhancing their mechanical properties. By adding inorganic nanoparticles, conventional composite mechanical characteristics, radiopacity, and optical properties have been enhanced. The two most prevalent particles that were added to the resin composite are silica and titanium dioxide.[50]

The variety of applications for flowable composites has expanded with the latest generation, as Class V abfraction lesions, minimally invasive Class II restorations, and preventative resin restorations, in addition to enhancements in resin matrix and filler systems.[49]

According to the Restorative Procedure

Direct and indirect resin composites are two categories of dental composite restorative materials. Direct composites are frequently utilized by dentists to repair damaged anterior teeth in a clinical setting, whereas indirect composites are cured outside of the mouth or need laboratory preparation. This is thought to be technique sensitive and can be challenging.[51]

1. Direct Resin Composites

They have been used for almost 50 years as dental restorative materials because of their superior optical and mechanical qualities, as well as the rising demand from patients for dental composites.[52] In the 1980s, Touati and Mörmann.[53] Developed indirect composites for posterior inlays and onlays, providing a more esthetically pleasing option for big posterior restorations.

2. The Indirect Resin Composites

They are quite sophisticated and fascinating, because of the improved and more thorough curing techniques, such as a range of combinations of heat, pressure (in a nitrogen environment, water, etc.), light, and vacuum, outside the mouth cavity, indirect composites, for instance, significantly reduce polymerization shrinkage, but when they were originally launched, they also had a lot of shortcomings, like a high rate of bulk fracture, marginal microleakage, and adhesive failure.[54] While many advancements were made with the creation of novel second-generation indirect composites, it has been demonstrated that increasing the filler load can enhance mechanical characteristics and wear resistance, while reducing the matrix can reduce polymerization shrinkage.

According to Curing Modes

The majority of dental composites cure by converting monomers into polymers by radical chain polymerization. A free radical that starts the polymerization process can be produced using a variety of initiation systems and activation techniques. They significantly alter the polymer structure and polymerization kinetics, which impacts a number of the composites' characteristics.[55] Composites can be classified as chemically initiated/self-cured, light-activated, heat-cured, or dual-cured composites based on the initiation systems or cure methods.[56] When powder-liquid or paste-paste ingredients are combined to create self-cured or chemically-cured composites, an oxidation-reduction initiator system at room temperature starts the polymerization process.

1. Self-cure composite resin

They are made up of a base component that contains a tertiary amine and a catalyst part that contains benzoyl peroxide (BPO). In self-cure composites, the tertiary amines N, N-dimethyl-p-toluidine (DMPT) and N, N-dihydroxyethyl-p-toluidine are also frequently utilized. The radicals created by the reaction between the BPO and amine can react with the monomers that will eventually undergo polymerization when the two components are combined. Instead of being employed directly for restorations, the majority of self-cure composites are now utilized as core materials or luting cements based on resin.[56]

2. Light-cure composite resin

On the other hand, the light-cured approach promotes the start reaction of resin polymerization by using ultraviolet (UV) or visible light. At wavelengths between 410 and 500 nm, light-activated composites are polymerized by irradiation through a blue-light-curing device.[56] Nowadays, practically all dental restorative composites are visible light-cured, which is safer than UV-curing systems, and feature CQ/amine complex initiation. One-component systems are also less common. The BPO/amine chemical starting system and the CQ/amine system operate via separate mechanisms.

The CQ is first excited by energy absorption when exposed to visible light. In the excited triplet state, the CQ molecule quickly forms an excited complex with an amine through electron transfer, and then it takes hydrogen out of the amine to create a new compound. The α-amino-alkyl radical is more effective in starting polymerization than the comparatively inactive CQ-ketyl radical, and the excitation energy is transmitted to the amine molecule during the process.[57] Extra-oral curing with heat polymerizes heat-cured composites, which may help decrease the number of lingering double bonds and improve mechanical characteristics. Furthermore, another type of dual-cured composites that combine different curing techniques to create polymers still exists.[56, 57] They are frequently utilized to create core buildups and cement endodontic posts.

1. Dual- cure composite resin

The dual-cured resin composites were designed to overcome the lack of light accessibility in deep cavities and to have the same rapid and on-demand curing properties as light-cure resin composites. Dual-cure resin composites combine independent light curing with the use of photoinitiators and a chemical reaction to initiate a self-cure reaction from mixing two components.[58] Consequently, the self-cure mode of dual-cure resin composites may allow for the achievement of unlimited curing depths.[59] However, prior research has demonstrated that underexposure to light may prevent dual-cure resin composites from achieving their maximal mechanical characteristics because the monomers may not reach their maximum degree of conversion.[60]

Modification Technologies to Improve the Matrix/Filler Interface of Dental Composites

As dental composites have developed, numerous investigations have shown that their compositions and the matrix/filler interaction significantly impact their service performance.[61] In addition to well-researched resin matrix and filler compositions, some earlier research also discovered that the strong interaction and the outstanding compatibility of the matrix/filler phase are advantageous for the extended performance of composites.[62-64]

The bond on the surface of the commonly used oxide fillers causes filler agglomerations when they blend with the matrix, which lowers the fracture resistance of resin composites. Consequently, surface modification of fillers has become crucial to enhance the efficiency of dental composites as it stops fractures from spreading through these interfacial boundaries, also, it modifies the rheology of composite pastes and limits filler loadings.[43]

Incomplete surface modification, on the other hand, can also result in filler aggregation and inadequate bonding, which can make composites more viscous and less mechanically effective. The mechanical qualities of the finished composites deteriorate as a result of an overly altered surface, which also produces a layer of poorly absorbed fillers. As a result, the filler surface must have an optimal modifying layer.

Both chemical and physical methods have been used to alter the surface of the fillers.[65] Porous fillers are typically used to create a micromechanical resin matrix/filler interlocking in dental composites, whereas chemical modification mostly entails the reaction of fillers with coupling agents, polymers, and tetraethylorthosilicate (TEOS) coatings.

The Influence of Coupling Agents on the Matrix/Filler Interface

The coupling agent has a substantial impact on the filler/matrix interfacial bonding and the extended stability of the resin composites, even though its content is lesser (≤10 wt% of fillers; for example, 0–10 wt% for silane coupling agents, 0–2 wt% for titanate coupling agents (TCAs), and 0–4 wt% for zirconate coupling agents).[34]

The following is the goal of using coupling agents to surface treat inorganic fillers:

1) Lowering the resin pastes and the surface energy of fillers to enhance more uniform distribution of filler particles in the resin.
2) Adding functional groups to the surface of the filler to enhance interfacial bonding and to chemically bond to the resin matrix through covalent interactions.
3) Enhancing the structural integrity and physical-mechanical characteristics of composites.[66]

An ideal filler reinforcement can also be formed by using the right coupling agents to create the proper transmission of stress from the matrix to the fillers. The chemical structures of silane, titanate, and zirconate, three of the many coupling agents presently used methods for treating fillers in composites.

Effect of Filler Matrix Modifications on Resin Composite Color Stability

Numerous factors affect the likelihood of staining in restorative materials. Oxidation or hydrolysis in the filler material matrix can lead to intrinsic resin matrix degradation.[10, 67] Furthermore, the degree of discoloration is largely determined by the size, distribution, and structural characteristics of the filler in the matrix as well as the resin matrix monomers. It was observed that the resin matrix exhibited reduced hygroscopic water absorption after the incorporation of inorganic nanoparticles (NPs), which reduced the color change. Nonetheless, the uptake of staining agents from dietary sources and beverages can also result in extrinsic discoloration.[68]

Numerous earlier investigations have demonstrated that different beverages may induce variable levels of staining when light-cured composite material is submerged in them. Their characteristics and composition, staining agent concentration, and exposure duration are the key contributors behind this variability. The integration of nanofillers, which improve the mechanical, physical, and optical qualities of composite filling, represents one of multiple advancements developed to enhance its properties.[29, 69]

When used in dental restorations, NPs can have a number of benefits. Compared to bulk-size particles, their smaller size allows for a greater specific surface area, which results in distinctive characterisation.[70] NPs' tendency to aggregate, however, could obstruct their ability to interact chemically with the organic substrate. This limitation was addressed by treating the inorganic filler with a silane-coupling agent, which strengthened the link between the NPs and the resin matrix and improved the nanocomposite's characteristics.[71]

This improvement prompted the researchers to add several NPs, including as silicon dioxide (SiO_2), titanium dioxide (TiO_2), and zirconium dioxide (ZrO_2), to dental biomaterials to increase their qualities.[72] TiO_2 is preferred in the dentistry industry because of its many advantages, such as its inexpensive cost, high microhardness, corrosion resistance, and sufficient antibacterial qualities. Furthermore, adding TiO_2 to polymeric materials can improve the nanocomposite's mechanical, physical, and optical characteristics. Due to its superior strength, excellent wear resistance, biocompatibility, and esthetic appeal, ZrO_2 is a white crystalline metal oxide that finds extensive use in dentistry. It has been utilized in numerous prior studies to reinforce RBCs and acrylic resin denture base materials. [73]

Likewise, the SiO_2-incorporated nanocomposites that were evaluated demonstrated suitable thermal stability and abrasion resistance. The acrylic resin denture base's wear resistance was enhanced prosthetically by the inclusion of SiO2 nanoparticles, which also demonstrated increased color stability following immersion in several drinking solutions.[74] According to Azmy et al.[75] and Liu et al.[32] adding NPs to dental restorations may enhance a variety of their characteristics, including wear resistance, hardness, and flexural strength.

The longevity of dental fillings and patient satisfaction largely depend on the color stability of the restorative material. When evaluated in earlier investigations, NPs containing restorative ingredients showed better optical characteristics. The results demonstrated improved color appearance and increased light transmittance since the NP dimension is smaller than the visible light wavelength.[76]

Effect of Filler Modifications on Resin Composite Surface Properties

In the field of dental composites, the enhancement of nanofilled RBCs was said to enhance surface quality.[77] Increased filler loading, exceptional physical characteristics, and superior polish that could compete with early microfill RBC were made possible by the introduction of nanoclusters. Additionally, it is suitable for application in both anterior and posterior dental restorations due to its generally favorable physical characteristics. Resin composites containing 100% supra-nano spherical fillers have recently been developed with the goal of dispersing and refracting light to produce lifelike opalescence and preserve high gloss retention. This creates a smooth surface for the restorations that looks very natural by providing excellent margin blending without creating any obvious demarcations.[78]

Immersion in Different Storage Media

There are numerous elements in the oral cavity that can lead to the breakdown of composite filling, and chemical degradation may occur in places that are not subjected to compression and abrasion. Water, saliva, beverages, and food can all alter the dental composite restoration's mechanical and physical characteristics. [79]

Because of chewing patterns, food, humidity, microbes, and temperature changes, the oral cavity is a dynamic habitat. Each of these elements influences how long resin composite materials can last. The durability of the restoration is assessed in vitro using a variety of artificial aging techniques, such as mechanical loading, thermocycling, storage in water, and degeneration utilizing different enzymes or chemicals. Therefore, these in vitro tests offer comprehensive information about how materials behave in the oral environment as well as the mechanisms underlying failure or degradation.[80]

Consuming specific beverages may alter the appearance and physical characteristics of RBCs and may also have an impact on their clinical performance.[81] Beverages include chemicals that can erode the restoration's surface and cause wear. Additionally, frequent drinking of low pH soft beverages has been linked to RBC discoloration and surface roughness.[82]

Badr et el.[83] investigated the influence of diverse storage media and time intervals on the mechanical behavior of dental composite resins. This study concluded that exposure to various immersion media may lead to changes in mechanical properties, potentially compromising the durability and structural integrity of dental composites in clinical use.

Bétrisey et al.[84] investigated the effect of immersion environments on the stability of the color of resin composites measured by ΔE and ΔE00 values. According to the study results, immersion media positively affected the stability of the color of the tested composites. A high degree of correlation was observed between ΔE and ΔE00, both of which resulted in comparable statistical outcomes.

El-Rashidy et el.[85] assessed the comparative effects of two aging procedures on color stability and gloss of resin composites with different shade formulations.. The study revealed that both resin-composites exhibited clinically unacceptable discoloration and gloss reduction following exposure to tea and red wine, whether through immersion or thermocycling protocols simulating one year of clinical service. Compared to thermocycling, immersion resulted in a more pronounced aging effect, particularly in terms of color change and gloss degradation of the dental restorations.

Color Stability Test

A number of chromatic properties, mostly derived from resin composites and teeth, influence color matching. These qualities include fluorescence, opalescence, translucency, hue, chroma, and value. Furthermore, light diffusion and transmission depend on the luster and texture of the surface. Making an esthetic restoration is always difficult because the natural tooth is polychromatic. Using the concepts of mimicking the correct color, form, and function of natural teeth, a direct esthetic anterior composite restoration is performed. Thus, recent resin composites' technological advancements were primarily focused on two areas: the application technique to facilitate simpler handling and insertion, and the material structure to produce a wide range of colors with optical qualities comparable to those of natural teeth.[86]

Color Matching Evaluation

In dentistry, color matching assessments are generally classified into two main categories:

1. Visual Technique

One well-liked method for assessing visual color is the Munsell color system, which uses three-dimensional characteristics. First, value (lightness) is introduced by selecting a tab that primarily corresponds to the color's lightness or darkness.[87] It varies from white (10/) to black (0/). Next, chroma is represented with tabs, whereas close to the selected value, with high color saturation. The range of chroma is: achromatic (/0), high color saturation (/18). Last but not least, hue is assessed using color tabs that match the previously selected "value" and "chroma." A scale from 2.5 to 10 is used to study the ten families of hue colors (red R, yellow Y, green G, blue B, purple P, yellow-red YR, green-yellow GY, blue-green BG, purple-blue PB, and red-purple RP) in increments of 2.5.[88] The most common technique in clinical dentistry is visual color assessment of the tooth. However, it has been shown that visual shade determination is unreliable and inconsistent. Evaluations of visual color rely on the observer's physiological and psychological reactions to stimuli by radiant energy. Thus, uncontrollable elements, including illumination, weariness, emotions, aging, prior eye exposure, metamerism, and the position of the item and light source, can all have an impact. Therefore, a more reliable and scientific method of determining shade matching in dentistry is needed.[89]

2. Instrumental Technique

The three primary coordinates that make up this system's color space are L*, a*, and b*. The lightness coordinate is first determined by L*, and then its value is added from 0 (black) to 100 (white). In the red-green axis, a* is a chromaticity coordinate. Positive a* values denote the red color range, while the green color range is reflected by negative values. Lastly, b* is an additional coordinate for the chromaticity of the yellow-blue axis. The blue color range is reflected by negative b* values, while the yellow color range is determined by positive b* values. Furthermore, after evaluating the differences in these coordinates (L*, Δa*, Δb*) brought on by UV light exposure, the sum color change (ΔE*ab) can be calculated using a certain formula.[90]

A new color difference formula, ΔE00, was developed by the CIE in 2000 to adjust the lightness inaccuracies. This formula takes into account L*, which is crucial in dentistry, and provides extra color qualities. Additionally, based on the variation in color values, perceptibility and acceptability thresholds have been proposed for clinical assessment.[91] When 50% of observers see a color shift between two items while the other 50% find no color change, this is known as a 50:50% perceptibility threshold. Additionally, it has a 50:50% acceptance criterion, meaning that 50% of raters find it acceptable.[92]

Consequently, instrumental color analysis is an objective approach. Therefore, it is superior to employing visual color establishment because the readings can be quantified, standardizing the results, obtaining them fast, reducing errors, and improving communication between the dentist and the laboratory technician.[92] In order to overcome the limitations of visual shade matching in restorative dentistry, colorimeters and spectrophotometers have been improved.

Colorimeters

Three or more silicon photodiodes with spectral correction filters are used in filter colorimeters. They are thought of as analogue function generators that strictly enforce the spectral properties of the light reaching the surface of the detector.[93] Due to their inability to perform the responsibilities of a typical observer, filter colorimeters are not regarded as scanning instruments such as spectroradiometers and spectrophotometers. However, these devices can be used to control the quality because of their quick and reliable sensing capabilities. One kind of colorimeter that relies on the idea of natural color is called Shade Eye.[94]

Spectrophotometers and Spectroradiometers

The devices that aim to replicate color measurements with high accuracy are spectrophotometers and spectroradiometers. The stability of the light source is the primary distinction between spectrophotometers and spectroradiometers. As a result, this equipment mostly uses two kinds of basic designs.[95] A single detector photodiode in conventional scanning equipment measures the intensity of light across individual wavelengths. As light passes through a monochromator, it is dispersed into short-wavelength segments. A newly developed system utilizes a diode array in which each detector element corresponds to a distinct wavelength. Consequently, this design allows for the concurrent detection of all wavelengths. Nonetheless, both types exhibit slower performance relative to filter colorimeters, which are the most widely used color measurement tools.[96]

Al-Dharrab et al.[97] assessed the color stability of a nanofilled composite resin subjected to immersion in three types of energy drinks after different aging intervals. The study revealed that the energy drinks used had a discoloring impact on the resin composite used. A time-dependent increase in discoloration toward yellowness was observed; nonetheless, the change was not visually perceptible in any of the specimens after 60 days.

Ferooz et al.[98] evaluated the color stability and surface microhardness of five resin composites treated with distinct polishing procedures and subsequently immersed in distilled water and lactic acid for a three-month period. This study concluded that the low-pH environment did not have a negative effect on color stability or microhardness of the tested composites. In addition, a mild reverse correlation between the color change and the microhardness of both immersion media.

Korkut et al.[99] conducted a study to assess the color stability of flowable composite materials at varying viscosities in different staining solutions. The results of this study showed that viscosity was identified as a key factor influencing the color change of RBCs, and the new generation of high viscosity flowable composites demonstrated good color stability comparable to conventional composites. The resin composite specimens in red wine showed the highest degree of color change, this was followed by exposure to coffee, tea, coke, and a physiological solution. The repolishing step was effective for reversing the color change of the resin composites.

Noufal et al.[100] investigated the impact of carbonated drinks on the color stability of bulk and flowable resin composites. According to the study results, bulk fill composites revealed higher color change when compared to flowable composite resin material. Thus, the flowable resin composite specimens were more color-stable.

Hamdi et al.[101] investigated a study to assess the impact of various types of mouthwash containing different ingredients on color stability and surface microhardness of nanohybrid composite. According to the study's findings, the bleaching mouthwash had a substantial decrease in surface microhardness of nanohybrid composite in comparison to the chlorohexidine and green tea-containing mouthwashes. The resin composite's color change was not accepted in chlorohexidine and green tea containing mouthwashes.

Al-Shami et al.[102] conducted a study to assess the color stability of microhybrid and nanohybrid restorative composites following immersion in different media at different time intervals. The study concluded that the nanohybrid composite exhibited greater color stability compared to the microhybrid composite. It also revealed that a reduced filler particle size enhances resistance to color change.

Selivany et al.[103] evaluated the color stability of two nanofilled and nanohybrid composite resins under various polymerization modes, after immersion in different solutions, both before and after brushing. This study showed that the nanofilled composite resin exhibited greater color stability than the nanohybrid composite resin, irrespective of the staining media. Both staining solutions significantly affected the color change, with tea causing more staining than cola.

Uctasli et al.[104] investigated the color stability of six commercial composites following their immersion in different beverages. It also evaluated the repolishing effect on the stained resin composites. According to the study's findings, all the media used affected the stability of the color of the tested composites, with coffee and wine showing the highest effects. The color change also depended on the resin composite. Dentists should be aware of the chemical interactions that occur between various drinks and different types of resin composites. Additionally, repolishing had an effect on the reduction of discoloration of the tested resin composites.

Surface Roughness

A surface's natural characteristics are referred to as its surface topography. A smooth surface encourages clinical durability, excellent esthetic view, surface gloss, and strong optical compatibility with enamel. Additionally, it has a high luster and glossy appearance due to its high light reflection. Additionally, avoiding discoloration and staining of the restoration because rough surfaces of restorative materials cause more plaque to build up and absorb more food coloring and water.[105]

The composition of the material and the polishing method employed determine the RBC's surface quality. Furthermore, the restoration's capacity to withstand the severe conditions of the oral cavity determines how long the surface will last.[106] The surface topography of the composite resin restoration is impacted by various aspects, including the size, shape, composition, and interparticle spacing of the filler. Additionally, the type of monomer, the degree of curing, and the filler matrix bonding.[107] Consequently, raising the weight of fillers and decreasing their size has greatly enhanced surface roughness.

Microfilled resin composites with filler sizes between 0.02 and 0.04 µm have had the smoothest surface for decades, but because of their low filler content and poor physical characteristics, its usage has been restricted. A hybrid resin composite was introduced and sold in an effort to combine the benefits of good polishability and acceptable mechanical qualities. Since then, the majority of resin composite formula changes have concentrated on increasing filler loading and decreasing filler particle size.[46] This has resulted in the introduction of several microhybrid and later nanohybrid resin composites to the market. The combination of nanofillers and nanoclusters increases the endurance of the surface polish by minimizing the gaps between filler particles while supplying the maximum filler load.[108]

The polishability of resin composites using various polishing techniques has been the subject of numerous reports. After polishing, some research has found that the nanohybrid resin composite has a roughness that is comparable to or less than microhybrid resin composite.[108] Other studies have found no significant difference. In contrast to nanohybrid and/or microhybrid resin composite, the majority of authors observed greater roughness average (Ra) values for the hybrid resin composite.[109]

The ultimate surface properties of restorations are significantly influenced by the abrasive structures' grit size, shape, and hardness, as well as the flexibility of the solid matrix in which the abrasive material is introduced. These days, a variety of polishing techniques are used, ranging from "multiple-step" processes that require a variety of tools to "one-step" systems that depend on the use of specialized tools like rubberized cups, silicon carbide brushes, and diamond dust-permeated tips.[110]

Surface Roughness Measurements

Surface roughness can be measured in a variety of ways, but the Ra value is the one most frequently used in dentistry. When a mean line extends on the trace from the top and bottom of the undulations, it can be described as the arithmetic mean of the profile departure.[111] Its drawback is that it is a two-dimensional measure that only gives roughness height; it provides no information regarding the surface profile.[112] Other spacing factors are also thought to be beneficial for other characteristics, bacterial adhesion or optical qualities.

Surface roughness is a three-dimensional parameter. As a result, their measurement can reveal a surface's natural characteristics, something that 2-D measurement cannot do. Furthermore, 3-D profiles yield more precise parameters than 2-D profiles. Because it is taken into consideration in a single sampling area, and can replicate a 3-D model.[113] 3-D mapping is more representative of the surface, leading to more dependable results than 2-D measurements based on sample lengths. Because the root mean square roughness (Rq) is sensitive to surface peaks and valleys, and the mean roughness depth (Rz) is particularly sensitive to the distribution of peaks and valleys, it is recommended to employ a variety of roughness metrics. As a result, Rz can minimize the possibility of the Ra parameter being misinterpreted.[114] Many techniques have been introduced for the assessment of dental materials' surface topography.

Qualitative techniques include optical electron microscopy and scanning. Furthermore, quantitative techniques, including atomic force microscopy, optical/laser noncontact profilometry, and contact stylus profilometry, are demonstrated.[115] Several optical characteristics, including interferometry, focus detection, and light scattering, are essential to optical profilometry. Additionally, they have a greater effective range for amplitude measurements, which makes them very useful for examining the surface topography of dental materials.

The device uses a mean line between the roughness profile's peaks and valleys to provide four measures of a specimen's topography along its reading track. Rv is the profile's maximum depth in the valley, or beneath the sampling range's mean line. The highest profile height over the mean line between the sample range, or the peak, is known as Rp. When determining the length of the profile, these two variables are utilized to compute Rt or Rmax, which is the maximum peak-to-valley distance (Rt = Rv + Rp). The arithmetic mean of the absolute deviations from the roughness profile's mean line is known as the "average roughness reading," or Ra.[116]

Tantanuch et al.[117] examined the effects of immersing nanohybrid and nanofilled resin composites in red and white wine on their surface roughness and erosion. According to the study results, both the physical and chemical composition of the resin composite and the immersion media affected the surface roughness and erosion of the tested composites.

Alifen et al.[118] analyzed the surface roughness of nanohybrid composites following exposure to varying concentrations of citric acid. The study revealed that varying citric acid concentrations had no effect on the surface roughness of nanohybrid composites, even after prolonged immersion.

Biçer et al.[119] investigated the impact of simulated intraoral aging through immersion in different solutions, brushing, and thermal cycling on the surface roughness of various resin composites, including both flowable and conventional types from the same manufacturers. The findings revealed that the type of composite, the specific product group, and the immersion solution all significantly influenced surface roughness after the aging process.

Ipek et al.[120] evaluated the surface roughness and color changes of single shade and nanohybrid resin-based restorative materials subsequent to immersion in beverages across a range of pH values. According to the study results, the acidic solutions increased the surface roughness and discoloration of the tested composites. Furthermore, the color changes were more pronounced in coffee and cola beverages. The color stability and surface roughness of the tested composites were closely related to filler size and shape.

Surface Microhardness

Surface microhardness is the ability of a solid to resist exhibiting localized deformation or persistent indentations.[121] Another definition of material hardness is the relationship between the applied indentation force and a parameter that indicates the residual impression area. The two most often used microhardness tests are Vickers microhardness (VMH) and Knoop microhardness (KMH).[122] Using a diamond tip that exerts a certain force for a predefined period of time, these methods create an indentation.[123]

In terms of the basic units of mass, length, and time, it is not a material feature that can be precisely described.[124] The material's hardness is affected by the form of the indenter and the hardness calculation technique. Measuring the area or depth of an impression formed by a specifically shaped indenter after applying a specified force for a specific amount of time is the most used method of determining hardness.[124]

A square-based pyramid with an angle, ψ, of 136° between its two opposing sides serves as the indenter in the VMH test. As a result of its pyramidal configuration, the Vickers indenter causes elastoplastic or plastic stress in the tested material at relatively low surface load levels. The following equation is used to determine the Vickers hardness number.[125]

$$HV = (1000P)/A$$

Where P = test force in kg and A = surface area of indent in mm^2.

The KMH test used the lozenge-based pyramid, where the angle ϕ between the other two faces was 130◦ and the angle θ between the two opposite faces was 172.5◦. Knoop hardness, which is determined using the following formula.[125], denotes the proportion between the applied load and the indentation area.

$$KHN = \frac{L}{I_2 Cp}$$

Where L = the applied load in kilograms, I = the length of the long diagonal of indentation (mm), and Cp = a constant related to the area of the indentation (0.07028).

A material's wear, polishability, and abrasive impact on neighboring teeth can all be inferred from its microhardness data.[126] A structure's hardness value indicates how readily it may be completed and how scratch-resistant it is when in use.[127] A material is often more resistant to wear if its surface hardness is higher.[121] A direct relationship exists between dental restorative RBCs' hardness and inorganic filler content.[128] The mechanical properties and the filler fraction generally have a significant relationship.[127]

The hardness, which serves as an indirect measure of the degree of cure, is tested by longitudinally sectioning a specimen from the top to the bottom of the restoration. The inadequate polymerization of bottom surfaces increases the likelihood of both bulk and marginal fractures.[129]

As previously proposed by certain publications, VMH tests were carried out on the irradiated (top) and non-irradiated (bottom) surfaces of the specimens to guarantee adequate polymerization throughout the RBCs.[129-131] Some researches have used a hardness ratio of 0.8 or 80% as the threshold for an acceptable cure because of material and light-curing restrictions.[132] Consequently, it seems that determining the hardness at the top of the restoration alone is not a reliable way to determine the hardness at the bottom.

Khan et al.[133] studied the impact of various pH solvents on microhardness and surface topography of nano composites. This study revealed that the daily consumption of certain drinks has a deleterious effect on the hardness and surface degradation of the nanofilled composite. In comparison, nanofilled composites, due to the higher surface area-to-volume ratio of their filler particles, may exhibit greater surface roughness than other types of resin-based composites.

Nair et al.[134] compared the color stability and surface microhardness of methacrylate-based flowable nano composite with methacrylate-based packable nano composite. This study concluded that the highest color stability and surface microhardness values were seen in Filtek Z350XT, followed by Tetric N-Ceram, and the lowest values were seen in G aenial Universal Flo.

Tanthanuch et al.[135] assessed surface roughness, hardness, and morphology changes of different bulk-fill resin composites subjected to erosion from multiple food-simulating liquids and beverages. According to the study results, acidic food-simulating liquids and beverages led to elevated surface roughness and diminished surface microhardness in bulk-fill resin composites after being immersed for 28 days.

Islam et al.[136] investigated the optical and physical stability of resin composite materials with different filler characteristics. It was concluded that filler properties can influence the optical and physical stability of resin composites.

Hamdy et al.[101] evaluated the impact of various mouthwashes on the surface microhardness and color stability of nanohybrid composites. The study concluded that the surface microhardness of the nanohybrid resin composite was influenced more by the chemical composition of the mouthwashes than by their pH. Despite having a neutral pH, the bleaching mouthwash caused a significantly greater reduction in microhardness compared to both the acidic mouthwash and the green tea-based mouthwash. After exposure equivalent to two years of clinical use, all mouthwashes induced color changes in the resin composite. These changes were considered clinically acceptable for the bleaching mouthwash, but not for the other two.

Bengal et al.[137] evaluated surface roughness and microhardness of Bulk-fill and nanohybrid composite after being exposed to various drinks at varying periods. The study revealed that both composite types exhibited a significant increase in surface roughness when immersed in all tested beverages, with the greatest increase observed in nanohybrid resin composites exposed to soft drinks. Similarly, a significant reduction in microhardness was observed across all beverages, again with the most pronounced effect seen in nanohybrid composites immersed in soft drinks. The findings further indicated that bulk-fill resin composites demonstrated superior resistance to surface roughness and retained higher microhardness compared to nanohybrid composites. Additionally, prolonged exposure to acidic beverages had a markedly negative impact on the physical properties of both resin composites.

Despite their widespread use, limited data are available on how different immersion media influence the surface properties and color stability of these materials. This study was conducted to fill this gap by assessing the effects of various media on the color stability, surface roughness, and microhardness of a recently introduced flowable nano-hybrid composite. Understanding these effects is crucial for predicting the material's durability and esthetic longevity in the oral cavity, thereby guiding clinicians in material selection and patient dietary advice.

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