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Review article

Components of Dental Resin Composites: A Literature Review

Saad Alsharif[1]*, Ahmed Alhareb[1], Asam Abudalazez[2]

[1]*Department of Dental Technology, Faculty of Health Sciences, University of Elmergib, Alkhoms, Libya*
[2]*Department of Dental Technology, Faculty of Health Sciences, University of Sirte, Sirte, Libya*

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Corresponding Email. saadelsharif@yahoo.com

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ABSTRACT

During the mid-1900s, dental resin composites (DRCs) were created in order to overcome the limitations of amalgam restorative material. This study aimed to review the primary constituents of DRCs using published scientific studies. The focus was on prominent dental journals, utilizing computer-based online searches to uncover their composition. The search was conducted for period from January 2000 to August 2023, using four search engines: PubMed, Science Direct, Scopus, and Google Scholar. The study also manually searched citations from relevant articles and examined the references of selected articles. The DRCs consist of organic phase such as Bis-GMA, UDMA, and TEGDMA; inorganic particles such as zirconium, silica, quartz, and barium are frequently utilized. Coupling agent such as 3-MPS are used in order to strengthen the adhesion between the filler and the resin matrix; photo-initiator and an accelerator of curing, with camphor quinone being the commonly employed photo-initiator. The accelerators in the DRCs are either diethyl-amino-ethyl-methacrylate (amine) or diketone; Inhibitor such as BHT is utilized to hinder untimely polymerization when the DRCs is subjected to ambient light in the dental practice, and pigments are introduced into DRCs to produce restorative materials with clinically acceptable colors. The mechanical and physical properties of DRCs are significantly impacted by their composition. This variability directly affects the quality and clinical success of the treatment, making it crucial for manufacturers to provide clear and accessible information for proper clinical application of the material.

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INTRODUCTION

The introduction of DRCs to the dental field occurred during the mid-1900s. Since their inception, acrylic-based materials have played a vital role in restorative and prosthetic dentistry. They are frequently utilized in dentistry to create aesthetically pleasing replacements that closely resemble natural teeth [1]. DRCs find applications in various dental procedures such as restorative materials, orthodontic devices, veneers, crowns, endodontic sealants, and pit and fissure sealants. Additionally, there are commercially available DRCs with different curing systems, namely self-cure and dual-cure, which cater to specific requirements [2]. These acrylic resins offer advantages such as cost-effectiveness, natural appearance, and ease of use.

The design of DRCs is a multifaceted problem. In an environment as demanding as the oral cavity, there are numerous factors that need to be balanced. Water sorption, toughness, degree of cure, viscosity, wear resistance, and aesthetics are some of the numerous factors that have to be balanced. Every decision involving the composite's design or the clinical material selection will entail a trade-off in properties. Ensuring that a composite's qualities align with the clinical criteria is crucial. Adjusting the ratio of filler to resin and the individual components can modify the composite's overall qualities. Composites are frequently selected over polymer-based materials because the pure polymer phase's mechanical properties are insufficient for the intended purpose [3]. Generally, a significant amount of stiff filler is added to polymeric materials to provide reinforcement in order to solve this issue.

The incorporation of filler particles is essential for improving the mechanical and physical properties of resins as they effectively occupy the spaces between polymer chains, thereby enhancing their properties [4]. While there are numerous review articles available on DRCs that explore various aspects such as monomers, initiators, fillers, and their impact on physical, mechanical, antibacterial, and self-healing properties [5-8], there is a lack of research that provides a comprehensive composition of DRCs.

Therefore, the present study aims to review the literature on DRCs, with a focus on their primary components, to provide an overview of the subject and facilitate the development of practical applications for dental composites, as well as support the advancement of DRCs in the future.

METHODS

Study design

In order to reveal the of DRCs components, the systematic review using computer online search was conducted. A thorough electronic search was conducted across the four most widely used search engines, namely PubMed, Science Direct, Scopus, and Google Scholar, using multiple terms. This was followed by a manual search of the references cited in relevant articles. Additionally, a thorough examination of the references cited in the chosen articles was conducted. The searches were carried out encompassing the timeframe spanning from January 2000 to August 2023. To identify the pertinent publications, the combination of the specified terms "Dental resin composite composition" was employed. Upon scrutinizing the articles, an additional exploration was conducted by utilizing the "related articles" feature, along with a manual search, to finalize the literature investigation.

The criteria for the collection of samples

In order to ascertain the significance of each published study, inclusion and exclusion criteria were established. Where inclusion criteria included: studies related to DRCs; sufficient data on the DRCs composition; and articles written in English. On the other hand, exclusion criteria included: studies not related to the DRCs; articles related to the clinical handling of dental composite resins; studies with insufficient methodology data; and articles that were authored in other languages than English. The relevance of each article was initially assessed by perusing the title and subsequently the abstract.

Development of DRCs and their using

The initial identification of Bisphenol A (BPA) dates back to 1891 when it was first observed by a Russian chemist during a chemical reaction. Subsequently, in 1905, the synthesis of BPA was accomplished by condensing acetone with two phenol equivalents, aided by an acid catalyst like hydrochloric acid or sulphuric acid, as reported by [9]. BPA is an artificial organic chemical that dissolves quite well in several organic solvents but not well in water. It has been used commercially to create polycarbonates and epoxy resin since 1957. Since the early 20th century, there has been a rise in the need for cosmetic restoration materials. The process of creating dentures with poly-methyl meth acrylate (PMMA) was first used in a practical setting in 1936 [10]. The initial forms of PMMA utilized in the fabrication of denture bases necessitated heat processing. Subsequently, through extensive research, a novel technique called auto-polymerizing acrylic resin emerged. Nevertheless, the auto-cured acrylic resin initiates the setting process immediately upon mixing, thereby significantly restricting the duration available for manipulation. They are capable of setting on their own without the addition of additional heat. Once more, a new technology known as light-cured acrylic resin was created. A tool is required to initiate the curing reaction, such as light emitting diode, plasma arc lamp, argon ion lasers, and quartz tungsten halogen, for the polymerization of the composite resins [11].

The chemical composition of resin-based dental composites has undergone significant transformation since their introduction to dentistry over six decades ago. In 1951, the initial dimethacrylate molecule was developed by Oscar Hager, a chemist from Switzerland. This groundbreaking invention played a pivotal role in enabling the formation of a cross-polymerized matrix. Michael Buonocore established in 1955 that enamel that has been acid-etched creates the best connections with PMMA restorations [12]. Dr. Bowen's contribution to the world of resin-based dental materials is noteworthy. He substituted epoxy resin for methacrylate to create dimethacrylate, which is commonly known as Bis-GMA or "Bowen's Resin". This material has been widely used since 1960 and is considered the most popular resin material in the field [13]. Bis-GMA is composed of glycidyl methacrylate and BPA. Due to its multitude of advantages over other dental monomers, it is widely recognized as the most commonly utilized monomer in DRCs. Higher viscosity of Bis-GMA causes handling problems and reduces the degree of vinyl double-bond conversion after curing [14]. Because of its high viscosity, which is brought on by strong intermolecular interactions and the production of hydrogen bonds between macromolecules, low-viscosity monomers are required to dilute Bis-GMA and achieve desired properties. Triethylene Glycol Dimethacrylate (TEGDMA), is extensively employed as a diluent. Moreover, Bis-GMA is considered an optimal selection for dental composites owing to its elevated refractive index in comparison to other monomers, as highlighted in Table 1.

Table 1. Basic properties of resin monomers

Monomer	Molecular Weight	Concentration of double bonds (mol/kg)	Viscosity (Pa.s)	Refractive index	Density
Bis-GMA	512.59	3.9	700	1.5497	1.16
Bis-EMA	540	3.7	3	1.532	1.12
TEGDMA	286.3	6.99	0.05	1.46	1.09
UDMA	470	4.25	8.5	1.485	1.12
HEMA	130.14	*	*	1.452	1.07
PPGDMA	600	*	0.09	1.45	1.01

** Not known.*

Dentists can work for longer periods of time when using light-cured resin composite, as it solidifies only when exposed to blue light. When compared to amalgam restorations, resin composite fillings' lifetime in back teeth is two to three times lower. By modifying various parameters such as the dimensions of filler particles, the efficiency of coupling agents, and the technique of activation, the properties of DRCs can be adjusted to accommodate a wider array of uses. Depending on these specific characteristics, DRCs can be employed in different regions of the oral cavity. DRCs with a higher proportion of microfil particles, commonly referred to as hybrids, are commonly employed in the anterior teeth due to their excellent polishability. On the other hand, DRCs that contain a higher amount of macrofil particles are commonly employed in posterior teeth because they exhibit higher tensile strength. In cases where there is a need for extensive restorations in posterior teeth, nano-filled resin composite is often the preferred choice due to its exceptional ability to be polished, its strength, and its reduced shrinkage [15, 16]. As a posterior restorative, modern composite formulations can be employed since they have improved mechanical and physical properties. Because of their better mechanical and physical qualities and superior aesthetics, DRCs are becoming more and more popular.

Composition of DRCs

DRCs consist of three separate constituents, specifically an organic matrix, filler or disperse phase, and an organosilane coupling agent responsible for binding the filler particles to the organic matrix. The addition of fillers is the primary method employed to enhance the insufficient mechanical and physical properties of the resin matrix. In order to strengthen the adhesion between the filler and the resin matrix, it is necessary to utilize a surface coupling agent, while an initiator is necessary to initiate the polymerization process when an external energy source is employed. Furthermore, the resin matrix can be supplemented with an inhibitor to hinder untimely polymerization when the dental material is subjected to ambient light in the dental practice. Furthermore, colored pigments are introduced into DRCs to produce restorative materials with clinically acceptable colors.

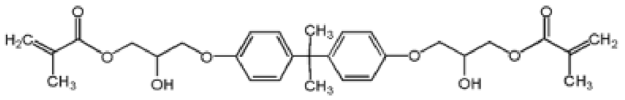
Resin matrix

The commonly utilized dimethacrylate monomers include urethane dimethacrylate (UDMA), bisphenol A diglycidildimethacrylate (Bis-GMA), bisphenol A ethoxylate dimethacrylate (Bis-EMA), TEGDMA, and bisphenol A diglycidildimethacrylate (Bis-GMA) [17]. Among these, bis-GMA is recommended due to its high reactivity, low volatility, and minimal polymerization shrinkage [18]. Although bis-GMA offers excellent hardness and strength, its elevated viscosity hinders the incorporation of inorganic fillers, resulting in a reduced degree of conversion (DC). To address this issue, diluted monomers are used to increase the material's mechanical properties. These monomers have reactive (C=C) bonds at each end, which can undergo addition polymerization, increasing their reactivity and DC.

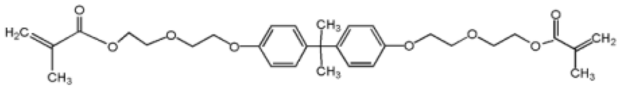
TEGDMA is a widely used diluent due to its low molecular weight, which results in a lower viscosity and enhances reactivity and the DC. Alternatively, Bis-GMA can be replaced entirely by other methacrylate-based monomers, such as UDMA, or used in combination with Bis-GMA.

The incorporation of the urethane group in UDMA monomer provides enhanced functionality, resulting in increased hardness and flexibility of the monomer backbone. The copolymerization of UDMA leads to improved DC, impact resistance, and hardness.

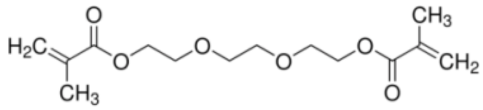
Bis-EMA, on the other hand, can be utilized as a base or diluting monomer, and its addition can enhance the mechanical performance of the material. Bis-EMA contains a rigid central phenyl ring core, which contributes to its bulky nature. When using a mixture of Bis-GMA and Bis-EMA, there is no need for a reactive diluent. Although Bis-EMA has a molecular weight similar to Bis-GMA, its viscosity is significantly lower due to the absence of hydroxyl groups [19]. The monomer 2-hydroxyethyl methacrylate (HEMA), which is derived from methacrylic acid, is commonly utilized in the field of dentistry as a diluent for the production of biomaterials such as composite resins. Additionally, it is a frequently employed component in dental adhesives. HEMA serves to decrease viscosity, enhance the wettability of acid-etched dentin, and reinforce the bond between dentin and co-monomer. Figure 1 illustrates the molecular structure of frequently employed monomers in DRCs. The process of polymerization is initiated by the resin matrix materials through the utilization of photo-initiators like CQ in combination with co-initiators such as DMAEMA or EDMAB when exposed to light sources, as stated by [20].



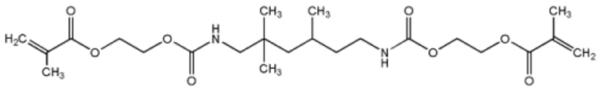
Bis-GMA



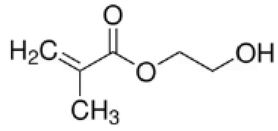
Bis-EMA



TEGDMA



UDMA



HEMA

Figure 1. The molecular structure of frequently employed monomers in DRCs

Filler content

To enhance the properties of DRCs and reduce polymerization shrinkage, inorganic filler particles are incorporated. The filler content typically varies from 50 to 85 weight percent or 30 to 70 volume percent of DRCs. These fillers include borosilicate, aluminum silicate, quartz, ytterbium fluoride, lithium aluminum silicate, barium, zirconium, strontium, and zinc glasses [21]. According to [22]., the incorporation of fillers results in an elevation of radiopacity, hardness, and strength, while causing a reduction in polymerization shrinkage, thermal expansion and contraction, water sorption, staining, and softening. Ultimately, this leads to an enhancement in workability.

The DRCs properties are susceptible to the impact of multiple factors, including the dimensions, configuration, dispersion, and quantity of filler particles. It has been noted that the quantity and dimensions of filler content play a vital role in determining the material's mechanical and physical properties. Hence, in order to attain the desired characteristics, it is imperative to have a substantial amount of filler incorporated. Scientists and scholars have dedicated their efforts towards enhancing the filler particles, aiming to develop materials that possess superior mechanical and physical attributes. However, the incorporation of filler volume fraction is limited due to the relatively small size of filler particles. The type of filler particle also plays a significant role in determining the properties of the DRCs. Additionally; the filler morphology affects the rate of filler content, subsequently impacting the DRCs characteristics [23, 24]. As the filler content increases, so does the hardness of the composites. The addition of fillers to dental composites also enhances their ability to resist wear. However, it is worth noting that there is a tendency for increased wear as the filler level increases.

Filler size

The final efficiency of dental composite materials is influenced not only by the quantity of fillers but also by their size and distribution. In hybrid composites, the size of filler particles varies from 0.04 to 20 micrometers, while in micro-hybrid composites, the range is from 0.7 to 3.6 micrometers. Recent advancements in dentistry have introduced new fillers with sizes ranging from approximately 5 to 100 nm. Hence, these particles possess the capability to be employed in the manufacturing of nano resin composites [25].

The impact of the filler particles' size in the DRCs on the penetration of light is noteworthy. A study conducted by [26] demonstrated that enlarging the particle size from 50 nm to 2000 nm led to a reduction in the depth ratio of the cured material. Furthermore, the size of the filler particles was found to have a significant influence on the rate of DRCs polymerization. In order to expedite the polymerization conversion and enhance the performance of the DRCs, it is crucial to reduce the particle size of the filler below the wavelength of visible light curing, which is used to activate the CQ. This research finding emphasizes the importance of controlling the filler size to optimize the polymerization process and ultimately enhance the overall performance of the resin composite.

Distribution of filler particles

The way filler particles are arranged inside DRCs greatly affects their characteristics. The size distribution of the fillers determines the packing structure of the filler phase, which is a critical factor affecting the mechanical characteristics of DRCs. Furthermore, the mechanical characteristics of DRCs are impacted by the way the fillers aggregate, which results in decreased strength and stiffness after aggregation. Furthermore, the mechanical characteristics of DRCs are influenced by the filler dispersion within the organic matrix. Increased strength and stiffness are the results of a consistent filler distribution, according to [27].

The arrangement of fillers within the resin matrix is of utmost importance in establishing the harmonious interaction between particles and the encompassing polymer. In composite materials, the presence of large agglomerates can impede the fracture resistance, especially when the particles are aggregated. The number of aggregates has a direct impact on the decline in fracture resistance, which has been observed to be significant [28]. When nano-sized inorganic particles are dispersed within a polymer matrix, a molecular level mixing occurs between the polymeric chains and the particles. This mixing is further enhanced by modifying the particle surface with chemical reactive groups, which promotes interfacial coupling of the nanoparticles. As a result, the DRCs properties are improved due to the reinforcement of the polymeric matrix [29]. However, it is important to note that the application of coupling agents should be done adequately. Inadequate application can lead to filler aggregation, insufficient bonding, increased viscosity, and ultimately inferior mechanical properties of the final product. On the other hand, over-application of coupling agents can also have a detrimental effect on the mechanical properties and should be avoided.

Filler shape and morphology

Scientific research has primarily concentrated on enhancing the morphology of filler particles and, more recently, altering the organic matrix, in order to advance the properties of resin composite materials. The integration of nanotechnology in DRCs can be traced back to the 1970s, when colloidal silica with a particle size of 100 nm was first introduced [30]. This technology has been employed in both homogenous and heterogeneous microfills. It is worth noting that the smallest filler size in these DRCs is not significantly different from that of current nanohybrid types. The literature has been discussing whether there is a significant enhancement in material properties in comparison to conventional types. Nevertheless, the ideal structure of the filler, combined with a wide variety of filler particle sizes (often displaying a bimodal distribution), and a smaller average particle size, play a crucial role in minimizing polymerization shrinkage and improving the mechanical and aesthetic characteristics of the material [31, 32].

When examining fillers that have the same amount of filler material and similar sizes, it was observed that irregular morphology exhibited better durability in terms of wear resistance when compared to spherical morphology. This can be attributed to the uneven shape of the filler particles, which results in a larger surface area. As a result, the connection between the filler and the surrounding material becomes stronger [33, 34]. Nevertheless, it is crucial to acknowledge that the potential benefits of a broader range of filler sizes in terms of enhancing packing efficiency were not accounted for in the analysis. Conversely, research conducted by [35] indicates that composites containing spherical filler particles exhibit lower levels of shrinkage-stress when compared to composites containing irregular filler particles.

Effect of fillers

The size of filler particles in resin composites has progressively decreased over time, leading to the emergence of nanofilled or nanohybrid resin-based composites. The size, quantity, shape, and composition of the filler have a big influence on the DRCs properties. The filler particles can be made smaller in order to improve the dispersion and enhance the interfacial area between the particles and polymer matrix. When it comes to mechanical qualities, dental nanocomposites with less filler than microfilled dental composites are superior. Several aspects affect the effect of nanoparticles: the kind of silane utilized, the volume fraction of filler particles, the uniform dispersion of nanofillers within the polymer matrix, and the mechanical characteristics of inorganic nanofillers [36]. The composites were classified into four distinct groups by the researchers, namely prepolymerized, irregularly shaped, a combination of prepolymerized and irregularly shaped, and round particles. The results indicated that the loading of the filler was influenced by its morphology. Moreover, it was observed that both the morphology and loading of the filler had an impact on the flexural strength and modules. with the highest filler amount the DRCs displayed the highest hardness, flexural strength, and flexural modules. Furthermore, a comparative analysis conducted by [37] revealed that microfine composites with the lowest filler content exhibited the lowest flexural strength and modules.

In 2007, Beun et al., conducted a research study comparing the physical characteristics of nanofilled, universal hybrid, and microfilled composites [15]. The results revealed that nanofilled composites had a higher elastic modulus, while all tested materials demonstrated comparable flexural strength. Microfilled composites exhibited the least favorable physical properties. The study concluded that the mechanical properties of nanofilled resin were at least equivalent to those of the universal hybrid composite. Additionally, the nanocomposites demonstrated compressive strength, diametral tensile strength, and fracture resistance that were equivalent to or greater than those of other commercial composites tested. Moreover, the nanocomposites exhibited superior polish retention compared to hybrids and microhybrids, even after extended brushing periods, as reported by [16]. In an investigation carried out by [38], showed a significant association between the evaluated mechanical properties and the weight content of the fillers. Notably, the microfine composite, characterized by the lowest filler weight, demonstrated the least robust mechanical properties. On the other hand, the universal hybrid composites displayed statistically different results in terms of flexural strength and elastic modulus. The nanofilled composite yielded interim results. The study's conclusions thus showed that the filler content significantly affects the composites under investigation's flexural strength and elastic modulus [38].

Silane coupling agents

The combination of the matrix phase and the reinforcing phase is achieved through the application of a coupling agent. The most commonly employed coupling agent in this process is γ-methacryloxypropyltrimethoxysilane (3-MPS) [39]. The silanol group is produced by hydrolyzing the alkoxy group. Silane coupling agents have gained widespread popularity due to their simple process and lack of special equipment requirements. The purpose of employing these agents is to improve the adhesion between the organic resin matrix and the inorganic material.

In the production of DRCs, a commonly used coupling agent is utilized. This coupling agent consists of a molecule that contains silanol groups (Si-OH) on one end and methacrylate groups (with C=C) on the other end. These molecules possess the ability to form covalent bonds with both the silicon-oxygen groups present in the silica-based fillers and the methacrylate groups of the resin matrix. The interaction between these components is depicted in Figure 2. In order to attain favorable mechanical characteristics in dental composites, it is imperative to establish a robust covalent connection between the inorganic fillers and the organic matrix. This connection is established through the utilization of a silane coupling agent that possesses functional groups capable of chemically bonding the filler and the matrix upon application. The amphiphilic surfactant known as the silane coupling agent demonstrates reactivity with both inorganic particles and polymers when it undergoes hydrolysis. Through research conducted by [40], it has been confirmed that this agent significantly improves the properties of interfaces between nanoparticles and polymers. Silanes exhibit remarkable versatility as compounds, offering immense value across various industries. They serve as crosslinking agents, coupling agents, adhesion promoters, dispersing agents, and surface modifiers, making them indispensable in numerous applications.

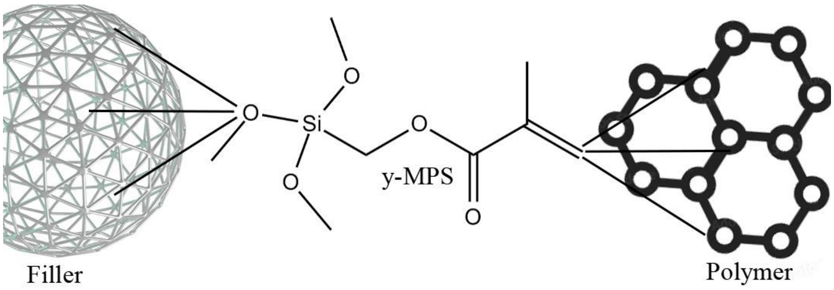


Figure 2. Bonding of silane between filler particles and polymer matrix

Photoinitators

Photopolymerization involves the use of an external light source to initiate the formation of free radicals, which then initiates the polymerization process. This mechanism enables the material to be promptly manipulated upon exposure to light. Hence, the utilization of photopolymerization in lieu of chemical curing affords enhanced adaptability in regulating clinical work duration. The photoinitiator system, which is predominantly employed in dentistry, comprises two constituents, namely, photoinitiator and co-initiator. The addition polymerization of resin monomers in dental resin formulations is initiated by the absorption of light by the photoinitiator. The absorbance profile of CQ prior to, during, and following polymerization of light-curable resin-based materials is an important consideration, as it can affect the esthetic quality and light transport through the material thickness

Photoinitiator systems can be classified based on the mechanism of free radical generation. Type I systems involve the fragmentation of the photoinitiator molecule following light absorption, resulting in the formation of radicals. On the other hand, type II systems require the excitation of photoinitiators by light and their interaction with a co-initiator to generate free radicals [41]. CQ, which is widely utilized as a photoinitiator in resin composites, demonstrates an absorption spectrum that aligns with visible blue light, specifically within the wavelength range of 400 to 500 nm. The absorption peak of dental resins has been reported to occur at 470 nm, according to a study conducted by [42]. The amount of CQ present in these resins can range from 0.03% to 1.03% by weight of the resinous component. The composite resins with microparticle properties require a lower quantity of CQ compared to conventional particles due to improved light transmission [43]. Increasing the CQ content in dental resins enhances both the DC and mechanical properties. However, there is no further improvement beyond the optimal level of CQ.

Inhibitors

It is a widely adopted technique in dental procedures to incorporate inhibitory molecules into the DRCs. The purpose of this procedure is to prevent the material from prematurely polymerizing when exposed to ambient light. Notably, hydroquinone (HQ), eugenol, and oxygen are known to be effective in inhibiting or slowing down the rate of polymerization, especially when used in substantial amounts. Hence, a finite quantity of HQ is employed to obstruct the untimely polymerization of the methacrylate and enhance the durability of the monomer. The Butylhydroxytoluene (BHT) is the most commonly used polymerization inhibitor in commercial composites, with a concentration of approximately 0.01% in terms of weight in resin composites [44]. BHT hinders the process of polymerization by interacting with the radicals responsible for initiating and propagating the reaction. As a consequence, these radicals undergo a conversion into either non-radical species or species with remarkably diminished reactivity, thereby rendering them incapable of engaging in the propagation reaction. The principal mechanism responsible for this inhibitory effect is the transfer of hydrogen to the reactive radical, leading to the generation of a free radical with an unpaired electron that is dispersed over a wide spatial extent. Consequently, this free radical loses its ability to initiate the polymerization reaction and rupture the double bond.

The deceleration of polymerization occurs in the presence of inhibitors until their concentration is reduced, which enables the polymerization and propagation mechanisms to intensify and counteract inhibition. In order for an inhibitor to be efficacious, it must exhibit a greater reactivity towards free radicals than monomers, as stated by [44].

Classification of resin composites

During the 1970s and 1980s, the main emphasis in the advancement of novel DRCs revolved around the quantity and dimensions of filler particles. Generally, composites are categorized according to the composition, quantity, and dimensions of the inorganic filler. The categorization of DRCs is established based on the dimensions of the filler material, which includes microfill, macrofill, hybrid, and nanofill.

Macrofilled DRCs

From the mid-1960s to the late 1970s, the first macrofilled composites were introduced, starting with self-cured materials and ending with ultraviolet (UV) light-cured and visible light-cured substances. The initial composite resin utilized larger filler particles, which ranged in size from 10 to 100 µm.

Macrofiller composites usually have a rough surface roughness because of the filler particles' large size and severe hardness. In practical practice, these kinds of composite restorations are no longer used, nevertheless [45]. The coarse surface roughness is exacerbated by the resin matrix wearing down more quickly than the filler particles. An external stain's ability to discolor the restoration is increased when it has this kind of surface roughness.

Macrofilled DRCs are a type of dental material that is composed of filler particles that occupy a significant portion of the volume, approximately 80%. The filler particles present in these composites are significantly larger in size compared to those found in microfilled systems. This larger size contributes to the improved wear resistance of the material. The radiopacity of the material is typically attributed to the type of filler used, as these composites are mainly utilized for posterior restorations. However, the large size of the particles poses a challenge when it comes to polishing these composites, resulting in a rough surface. Additionally, as the filler particles are lost or the resin wears off, the larger particles become exposed. Due to their roughness and tendency to wear quickly, macrofilled composites are no longer widely used. Quartz, strontium, and barium glass are the most commonly employed fillers in these composites. Despite their limitations, macrofilled composites still exhibit greater strength than microfilled composites and are primarily used for stress-bearing restorations [45].

Considerable progress has been achieved in enhancing the properties of these composites in contrast to unfilled acrylic materials, particularly in terms of compressive strength, hardness, and elastic modulus. These advancements have led to a decrease in polymerization shrinkage and thermal expansion. Nevertheless, conventional RBCs have exhibited insufficient wear resistance due to differential wear, resulting in rapid resin loss compared to the filler. According to observations of [46], this process has led to the creation of extensive wear facets and the dislodging of filler particles from the surrounding matrix.

Microfilled DRCs

During the late 1970s and early 1980s, the commercial market witnessed the introduction of microfilled composites. These composites differed from macrofilled composites due to their utilization of smaller fillers, with a filler particle volume ranging from approximately 35% to 50%. As stated by [47], the microfill particles had an average diameter of 0.04 µm and a size range spanning from 0.03 to 0.5 µm. Despite the advantage of multiple microfill particles offering a larger total surface area compared to a single large particle of similar weight, their increased surface area posed a challenge in effectively incorporating a significant volume of them into the resin matrix. Consequently, the composite material exhibited suboptimal physical properties, including heightened polymerization shrinkage and reduced wear resistance. Due to the substantial proportion of resin matrix, the particle arrangement, and the diminutive particle dimensions of less than 1 µm, this resin composite can be effortlessly polished and attains a remarkable shine [48]. Microfilled DRCs can be proficiently employed in regions where heightened wear and stress are expected. These substances were formulated to supplant the coarse surface attribute of traditional composites with a sleek, glossy surface akin to dental enamel.

Microfilled DRCs were introduced to overcome macrofilled composites' drawbacks and achieve aesthetic polishable composites. Microfilled composites have a polished surface, unlike macrofilled composites with a coarser texture. While they have high aesthetic appeal, their strength is limited, and they shrink during polymerization. Hence, they are suitable for low-stress situations with high aesthetic standards, as highlighted by [49].

Hybrid DRCs

Hybrid DRCs emerged in the late 1980s as a result of their distinctive makeup, encompassing both sizable fillers ranging from 2 to 4 µm and minuscule fillers measuring 0.04 to 0.2 µm. By combining these two filler sizes, a robust composite material is achieved, which can be easily polished. The microfine particles effectively occupy the spaces between the larger particles, enabling a greater filler content of 70-80% by weight [45].

DRCs consist of a significant amount of filler particles that offer durability and strength, as well as small filler particles that enable a compact particle arrangement, minimizing shrinkage during polymerization and enhancing polishability in comparison to macrofilled composites.

The macrofill and microfill composites combination makes hybrid composites a highly desirable option for dental restorations that demand both durability and an aesthetically pleasing finish [48]. These composites are considered highly versatile and are often used as universal composites due to their ability to incorporate the advantages of macrofilled composites. The larger filler size in hybrid composites contributes to their superior mechanical properties, allowing them to withstand the forces exerted during chewing, making them particularly suitable for posterior fillings. Additionally, these composites possess exceptional optical properties and can be polished effectively, thanks to the smaller particles in their composition. As a result, they are well-suited for restoring anterior teeth [50]. The term "hybrid" is no longer exclusively used to describe these composites, as the majority of dental composites now consist of hybrids that contain particles of various size ranges.

Microhybrids.

The integration of particles that are less than 1 µm in size by 75% has led to the improvement of hybrids, which are now known as microhybrids. Microhybrids are composed of a blend of tiny particles, with sizes varying from 0.04 to 1.0 µm, and even smaller microfine particles, ranging from 0.01 to 0.1 µm. The inclusion of microfine particles within the interstitial gaps among the small particles enables microhybrids to effectively hold a substantial amount of filler material, reaching up to 70% of the total volume [47].

The amalgamation of minute particles in microhybrid composites results in enhanced polishing and handling properties when compared to hybrid composites. Furthermore, microhybrid composites exhibit greater durability than most microfilled composites, making them a viable option for use in both front and back teeth. As a result, microhybrid composites can serve as versatile and multi-purpose composite resins.

Nanohybrids

Following the introduction of microhybrids, the subsequent development of nanohybrids ensued. Nanohybrids are essentially microhybrids that incorporate particles of nanoscale dimensions, ranging from 0.005 to 0.020 µm. The incorporation of a greater number of filler particles in nanohybrids results in a reduction of the amount of resin required. This reduction in resin content leads to a decrease in the degree of shrinkage observed upon polymerization. The reduction in shrinkage of previous composites, which was around 2% to 3%, has been diminished to approximately 1% in certain nanohybrids. These nanohybrids demonstrate exceptional strength and possess the ability to maintain a glossy appearance after polishing, surpassing the performance of earlier composites [47].

Nano-composites

With the advent of resin composites, the sizes of filler particles have undergone a reduction. In more recent times, nanofilled composites, consisting of exceedingly minute filler particles, have been introduced. Nanocomposites, a recent innovation, incorporate nano-sized filler particles, which are either dispersed individually or in the form of agglomerations, referred to as nanoclusters. The aforementioned DRCs possess strength owing to their high filler content, and are also capable of being polished due to the presence of small particles. A recent investigation carried out by [50] revealed that the incorporation of nanoparticles in dental composites leads to improved mechanical characteristics in comparison to micro-composites. The inclusion of nanoparticles into DRCs not only enhances their aesthetic and optical properties but also strengthens their tensile strength and resistance to fracture. Furthermore, this incorporation of nanoparticles helps in reducing polymerization shrinkage. Nano composites with filler particle sizes smaller than or equal to 100 nm, offer aesthetic and strength advantages compared to traditional micro filled and hybrid resin composites.

Nano-composites are characterized by the presence of filler particles that exhibit a size range of 5 to 75 nanometers. This is in stark contrast to conventional fillers, which are approximately 1 µm in size [47]. The production of these particles differs from other fillers that depend on grinding larger pieces of glass, quartz, or ceramic materials to generate particles. The minute size of these filler particles allows for a higher number of them to be incorporated into the resin, resulting in a higher filler content and a more compact arrangement. The consequence of this is a decrease in the contraction of polymerization and an enhancement in the durability and resistance to fractures of the substance, rendering it appropriate for utilization in both anterior and posterior applications. Additionally, these composites exhibit remarkable ability to be polished and maintain their luster over an extended period of time, owing to their enhanced resistance to wear.

Polymerization process of composite resin

The production of composite resin involves a significant step known as the polymerization process. This process entails the chemical reaction of monomers to form a polymer network, which ultimately leads to the hardening of the resin. The initiation of this process is usually done through the application of a curing agent, which could be a light source or chemical catalyst. The resulting composite resin material is highly sought after in different industries, including construction and dentistry, due to its desirable properties such as strength, durability, and aesthetic appeal.

The polymerization process of DRCs offers several advantages. Firstly, it provides excellent aesthetics as DRCs can be customized to match the individual's tooth shade. This makes them visually appealing for a range of treatments, such as crowns, veneers, and orthodontic brackets. Additionally, the use of dental resin composites in DRCs allows for the conservation of tooth structure. Compared to alternative restorative materials, these composites enable the retention of a greater amount of natural tooth structure. Moreover, DRCs are repairable, allowing dentists to easily fix them without compromising the structural integrity of the tooth. Furthermore, DRCs have the ability to bond strongly with the tooth structure, providing additional support and stability. Lastly, DRCs are an economically viable option for various dental treatments, making them more accessible to patients.

The disadvantages of the polymerization process of DRCs include the need for a high level of skill and precision in their placement and handling, which can pose a challenge for certain dentists. Additionally, during the polymerization process, DRCs may experience shrinkage, resulting in stress on the tooth structure and the formation of marginal gaps. Furthermore, DRCs may not possess the same level of strength as other restorative materials like metal or ceramic, making them more susceptible to wear and fracture over time. In terms of composite resin, it is categorized into two types, namely chemically activated and light activated, based on the activation energy required for their polymerization [51].

Chemically activated DRCs

The initiation of polymerization in composite resin necessitates the use of two separate tubes, each containing a distinct paste, which are combined through chemical means. The amalgamation of these two elements results in the formation of a free radical, which serves as the catalyst for the polymerization process [51, 52]. The chemically activated DRCs and chemical polymerization are two different concepts related to polymers. Chemically activated DRCs refer to a type of chemical reaction that can cause dynamic topology changes in a polymer in response to a specific stimulus, while chemical polymerization refers to the process of combining monomers to form a polymer with specific properties.

Light activated DRCs

Light activated DRCs are one kind of dental material is which is made up of a single paste that is confined in a syringe. Light activated composite resin is a type of dental material that is composed of a singular paste contained within a syringe. This paste is made up of a photo-initiator and an accelerator, with camphorquinone being the commonly employed photo-initiator. The accelerator found in light activated composite resin can either be diethyl-amino-ethyl-methacrylate (amine) or diketone.

Compared to chemically activated composite resin, the curing time of light activated composite resin is generally faster. This is due to the interaction between the photo-initiator and accelerator when exposed to light, which initiates the polymerization process and leads to rapid curing. The faster curing time of light activated composite resin can be advantageous in dental applications, as it allows for more efficient and time-saving procedures. It is worth mentioning that adequately cured light activated composites exhibit properties that are comparable to those of chemically activated composites. To enhance the rate of polymerization, tertiary amines can be employed as co-initiators in radical photopolymerization. Various amines, including N-phenylglycine (NPG), ethyl-4-dimethylaminobenzoate (EDAB/EDMAB), DMAEMA, N,N-dimethylptoluidine, and dimethylbenzoate, are utilized as photosensitizers for CQ. Typically, the co-initiator or photosensitizer functions as a tertiary aliphatic amine reducing agent, which reacts with camphorquinone in its excited triplet state to generate free radicals. While certain amine reducing agents can supply electrons for charge transfer during the initiation process, DMAEMA is commonly employed [42].

Curing of DRCs

Measurement of conversion

The DC serves as a numerical indicator to assess the extent to which carbon-carbon double bonds have been converted into single bonds during the formation of a polymeric resin [51]. In the evaluation of dental composite restorative materials that are based on dimethacrylates, the DC serves as a highly valuable parameter. It provides crucial information regarding the effectiveness of the curing process. However, it is important to note that the conversion process is not entirely complete, and the final polymerized resin composite will inevitably contain some residual carbon double bonds. The achieved DC within a composite material holds significant importance as it greatly influences various characteristics of the cured substance. The determination of the DC, which involves the conversion of monomers to polymers, is subject to various influences. These influences include the chemical structure of the monomers and the concentration of the diluents, as indicated by [53].

There are multiple variables that can impact the DC of DRCs. These variables encompass the light source type, power density, and light-tip size. Additionally, the wavelength of the light, irradiation duration, and photo-activation method play a role. The composition of the organic matrix, distribution and quantity of inorganic fillers, type and amount of the photo-initiator, as well as the color of the composite resins, are also influential factors. A previous study found that increasing the curing time with a constant irradiance can increase the percentage of DC [54]. However, another study suggests that very short curing durations may result in a higher percentage of DC in bulk-fill composite resins, depending on the specific photoinitiator used in the resin [55]. Different techniques are employed to determine the DC of DRCs, and FTIR is widely used due to its simplicity and dependable results. In addition to these direct methods, DC can also be indirectly assessed through microhardness measurements, specifically using the Vickers and Knoop methods. It has been generally observed that there is a strong linear correlation between DC and microhardness values [56].

Depth of cure

Generally, the depth of cure pertains to the thickness of a resin-based composite that has been adequately cured. However, this depth is constrained by factors such as the absorption and scattering of light within the material, which are affected by different components as: quantity, size, shape of fillers, and shade of the DRCs, the photoinitiator system employed, the refractive index mismatch, as well as the light source and duration of exposure to light.

Insufficient polymerization of DRCs has been proven to lead to a decline in their physical and mechanical properties [57]. To ensure satisfactory polymerization, three essential elements must be present: adequate radiant intensity, the correct wavelength of visible light, and the appropriate curing time. Different methods have been utilized to assess the extent of solidification. The dental composites ISO standard 4049 proposes the utilization of scraping to eliminate the unset substances right after exposure to radiation, then measuring the length of the solidified sample, which is subsequently divided in half. As the intensity of light passing through DRCs diminishes, the level of DC decreased as the depth increases. [58]. This phenomenon can be attributed to the decrease in light intensity as it travels through the majority of the composite resin, caused by light scattering and absorption. Consequently, this may result in a reduction in the effectiveness of polymerization. The transmission of light through the composite resin affects the depth of cure.

Crosslinking

Crosslinking is a widely used technique in dentistry that aims to improve the adhesive strength between composite resin and dentin. By employing crosslinking agents, a three-dimensional framework of chemical bonds is formed, effectively connecting the polymer chains within the resin composite. This process enhances the durability of the composite, making it less prone to deterioration, while simultaneously improving its mechanical properties [59]. In the field of dentistry, various types of crosslinking agents are utilized to enhance the bond strength and mechanical characteristics of DRCs.

Thylene Glycol Dimethacrylate (EGDMA) is a commonly employed agent that has been extensively studied for its effectiveness in enhancing the DRCs properties. Another agent, TEGDMA, has also exhibited its capability to improve the DRCs properties. Furthermore, collagen cross-linking agents, such as proanthocyanidins, have been discovered to enhance the durability and strength of the resin-dentin bond [60]. Lastly, Tetrafunctional Methacrylate Quaternary Ammonium Salt Monomers have been identified as potential crosslinking agents in the field of dentistry. In addition to their mechanical benefits, crosslinking agents used in DRCs have been found to possess antibacterial properties, further contributing to their overall effectiveness [61]. Glutaraldehyde, a crosslinking agent, has been explored in dentistry to enhance the tensile bond strength of DRCs. Another crosslinking agent, grape seed extract, has exhibited the capability to enhance the tensile bond strength of DRCs [62].

CONCLUSION

In conclusion, DRCs consist primarily of several components, including an organic matrix, inorganic phase, an organosilane, a photo-initiator, accelerator, inhibitors, and pigments materials. The development of different composites in dentistry has been influenced by factors such as the size and shapes of the fillers. Among these factors, the characteristics of the inorganic phase have a more significant impact on the mechanical properties of DRCs, such as modulus, strength, fracture toughness, fatigue life, hardness, and wear resistance, compared to the organic resin matrix. It is widely acknowledged that the content, size, distribution, shape, porosity, and surface modification of filler particles are crucial in achieving substantial enhancements in the mechanical properties of DRCs. Presently, the most recent versions of DRCs provide excellent performance materials for restorations involving direct placement in both anterior and posterior regions. When choosing composite resins, it is imperative to consider several key factors. These include the ability to achieve a highly esthetic shade match, as well as possessing desirable levels of translucency and fluorescence. Additionally, the resin should exhibit a high degree of polishability, ensuring a smooth and refined finish. The resin should also offer favorable handling characteristics, allowing for ease of use during the application process. Moreover, it is important for the composite resin to exhibit excellent wear resistance, ensuring its longevity, low polymerization shrinkage and should possess radiopacity, enabling it to be easily detected on radiographs. Lastly, the DRCs should demonstrate biocompatibility, ensuring its compatibility with the surrounding oral tissues. The categorization of DRCs has experienced a gradual transformation in conjunction with the development of their material composition. Traditionally, this classification is based on the distribution of filler size and filler content. Micro-filled and nano-filled composites are distinguished by the exclusive presence of micro and nanofillers. However, the majority of modern dental composites fall into the hybrid materials category and are commonly marketed as nano-hybrids.

Conflicts of Interest

There are no financial, personal, or professional conflicts of interest to declare.

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مكونات مركبات الأسنان الراتنجية: مراجعة للأدبيات

سعد عمر الشريف[1]*، أحمد عمران الهارب[1]، عصام محمد عبد العزيز[2]

[1]قسم تقنية الأسنان، كلية العلوم الصحية، جامعة المرقب، الخمس، ليبيا
2قسم تقنية الأسنان، كلية العلوم الصحية، جامعة سرت، سرت، ليبيا

المستخلص

خلال منتصف القرن العشرين، تم إنشاء مركبات راتينج الأسنان (DRCs) من أجل التغلب على القيود المفروضة على المواد الترميمية الأملغمية. تهدف هذه الدراسة إلى مراجعة المكونات الأساسية لـDRCs باستخدام الدراسات العلمية المنشورة. كان التركيز على مجلات طب الأسنان البارزة، وذلك باستخدام عمليات البحث عبر الإنترنت المعتمدة على الكمبيوتر للكشف عن تركيبتها. تم إجراء البحث للفترة من يناير 2000 إلى أغسطس 2023، باستخدام أربعة محركات بحث: PubMed، وScience Direct، وScopus، وGoogle Scholar. كما بحثت الدراسة يدويًا في الاستشهادات من المقالات ذات الصلة وفحصت مراجع المقالات المختارة. يتكون الـDRCs من المرحلة العضوية مثل Bis-GMA، وUDMA، وTEGDMA؛ وكثيرا ما تستخدم الجسيمات غير العضوية مثل الزركونيوم، والسيليكا، والكوارتز، والباريوم. يتم إستخدام عامل اقتران مثل MPS-3 من أجل تعزيز الالتصاق بين مادة الحشو ومصفوفة الراتنج؛ البادئ الضوئى ومسرع المعالجة، مع كون الكامفوركينون هو البادئ الضوئى المستخدم بشكل شائع. أما المسرع الموجود في الـDRCs إما أن يكون ثنائي إيثيل أمينو إيثيل ميثاكريلات (أمين) أو ديكتون؛ يتم استخدام مثبط مثل BHT لعرقلة البلمرة غير المناسبة عندما يتعرض ال DRCs للضوء المحيط في ممارسة طب الأسنان، ويتم إدخال الأصباغ إلى ال DRCs لإنتاج مواد ترميمية بألوان مقبولة سريريًا. تتأثر الخواص الميكانيكية والفيزيائية لل DRCs بشكل كبير بتكوينها. يؤثر هذا التباين بشكل مباشر على جودة العلاج ونجاحه السريري، مما يجعل من الضروري بالنسبة للمصنعين توفير معلومات واضحة ويمكن الوصول إليها للتطبيق السريري المناسب للمادة.

الكلمات الدالة: مكونات, مركبات, راتنج, الأسنان, مراجعة.
