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POLYMERIC RESIN BASED COMPOSITES IN DENTISTRY -A REVIEW ARTICLE

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ABSTRACT
The present review outlines the applications of polymeric composite resins in dental area. The review also highlights the recent and ongoing research trends reported in the field of dental monomer systems. The monomer systems of most that are presently used in dental practice are in the form of resin composites that are generally based on BisGMA (bis-phenol A glycidyl methacrylate), developed some 40 years ago, or even the derivatives of BisGMA. In the remaining resin composites, urethane monomers or oligomers are widely used as the basis of the monomer systems. The main deficiencies of the currently used resin composites are polymerization shrinkage and insufficient wear resistance under high masticatory forces. Both factors are highly influenced by the monomer system, and therefore, considerable efforts have been made by polymer chemists around the world to reduce or eliminate these undesirable properties. The use of fluoride releasing monomer systems, some of which are under investigation, has been suggested to mitigate the negative effects of marginal gaps formed in consequence of polymerization shrinkage. The very crux of the problem has also been approached with the synthesis of potentially low shrinkage or non-shrinking resin composites involving the well-known ring opening or cyclopolymerizable monomers. By the use of additives with a supposed chain transfer agent function, monomer systems have been formulated in the literature to improve the degree of conversion of methacrylate double bonds and mechanical properties. Many promising monomer systems have been devised, the implementation of which may be expected to improve the longevity of resin composite fillings and expand the indications for resin composite.

KEYWORDS: Composite, resin, polymerization, shrinkage, shrinkage stress.

INTRODUCTION
Therapeutic success in most clinical restorative dentistry largely depends not only on the understanding of biological, physiological and pathological criteria, but also on a complete understanding of restorative materials used and their physico-mechanical properties.

Innumerable polymeric materials have been employed in contemporary restorative dental practice; most of these are resin-based composite materials. These tooth-colored materials consist of an organic resin matrix (dimethacrylate or siloxane resin polymers), inorganic fillers (zirconium-dioxide, silicon- dioxide and other glass particles), organo-silane coupling agent, photo-initiators and accelerators. These materials are based on photo-cured resin monomers, which harden after exposing to visible light. However, stability and mechanical properties of dental restorative materials are crucial in clinical practice. These materials under various stress conditions such as abnormal jaw movements and teeth contacts should retain their dimensional stability.

The physical as well as mechanical properties of dental composites depend on the resistance of its organic and inorganic components as well as the bond between these phases. The polymer structure and the degree of polymerization are important here as they can influence the overall material performance. These properties depend not only on the resin structure, but also on the type and distance of the light-curing source, on the light irradiance, exposure time, mode of photo-polymerization procedure, etc. In the past decades, several different light-curing modes have been introduced in dental practice, mainly to reduce the degree of polymerization shrinkage of composite materials.

Due to recent advances in polymer science and technology, innumerable resin-based composite adhesives have been developed and marketed in dentistry. Dental composite resins, mainly consists of

synthetic resins, which are used in dentistry as restorative materials or adhesives. Synthetic resins evolved as restorative materials since they are insoluble, aesthetic, insensitive to dehydration, easy to manipulate and reasonably inexpensive.

The polymer-based composites that are widely used as dental materials are mainly acrylic polymers such as polymethyl methacrylate (PMMA), polyvinyl ethyl methacrylate (PVEMA), bis-phenol A glycidyl methacrylate (Bis-GMA), urethane dimethacrylate (UDMA) and many other dimethacrylate monomers such as TEGDMA, UDMA, HDDMA using silica as a filler. In majority of applications, a photoinitiator such as dimethylglyoxime is generally introduced to achieve flow-ability, while physical properties can be tailored by formulating with unique concentrations of each constituent.

Composites mainly consist of three distinct phases, each with its own role in dictating material properties. These are: polymerizable resin, filler, and filler-resin interface. The resin phase consists of polymerizable monomers that can be converted from liquid to a highly cross-linked polymer upon exposure to visible light, which catalyzes the formation of active centers, typically radicals to induce polymerization. The filler has several roles, including enhancing modulus, altering thermal expansion behavior, and reducing polymerization shrinkage by reducing the resin concentration. The filler-resin interfaces thus serve as a bridge by coupling polymerizable moieties to the particle surface. Thus, each component represents an opportunity to improve the overall properties of the composite material. The present review deals with the recent research efforts made in this area and the materials used in dentistry. It also discusses and summarizes the advances made in the development of such materials in dentistry.

POLYMERIZATION SHRINKAGE

Polymerization involves a systematic growth of the chain by rapid sequential addition of monomer to the active centers via covalent bonds. During the process of formation of polymers, a volumetric contraction is likely to take place when small monomer units are converted into a single long polymer chain, called polymerization shrinkage. The shrinkage suffered by the composite during curing ranges from 1.35% to 7.1%. This, together with curing stress, leads to cohesion and adhesion failures, which are joined by the degree of monomer to polymer conversion as the main causes of composite resin restoration failures. The exothermic reaction formed during the process of polymerization produces volume reduction in the polymer chain, resulting in a decrease of molecular motions and intermolecular distances. Shrinkage in polymer chains depends solely on the organic matrix. It rises with the degree of conversion and falls with increasing monomer molecular weight. The manufacturers try to develop light sources that will give the greatest conversion i.e.,

polymerizations with the least curing stress, using "soft-start" lamps (whether halogen, conventional or high intensity, or LED curing lights), which gradually increase the light intensity, is very useful for reducing composite shrinkage.[1]

When a polymer is formed, resin matrix changes from a paste or pre-gel state to a viscous solid, which contract by about 1.5 to 6%. At the gel point, resin changes from a viscous paste to an elastic solid. At the gel point, stress is transmitted from composite resin to the surrounding tooth structures. As curing begins, the material flows from the unbound surfaces to accommodate for shrinkage. When the composite resin becomes more rigid due to increased modulus of the composite, the flow stops, and the bonded composite resin transmits shrinkage stresses generated to the surrounding tooth.

During the process of polymerization, the contraction stress is transferred to the tooth resulting in tooth deformation in enamel fracture, cracks etc. `Polymerization shrinkage stress also affects to initiate the failure of adhesive failure, a thin composite layer, when polymerization contraction exceeds that of dentin bond strength. These gaps between the resin and cavity walls may cause post-operative sensitivity, micro-leakage, and secondary forces.

The stress can initiate micro-cracking of the restorative material. If the bonding to the cavity walls is strong enough to avoid the gap formation during hardening, the stress may be concentrated inside the composite material, which would lead to the formation micro-cracks before the complete polymerization. Therefore, there is a greater risk of failure during the tooth's function. Shrinkage stress also depends on the size of restoration and therefore, on the thickness of the cavity wall. Larger restorations would result in lower stress levels in the restoration and tooth restoration interface but increase stress in the tooth**.**

POLYMERIZATION SHRINKAGE STRESS

The optimal performance of all these direct and indirect composite restorations depends on proper polymerization of the resin component, which is accompanied by volumetric reduction of the material. The polymer occupies lesser volume than the monomers, the effect of which is well known as polymerization shrinkage. During the process of polymerization, the distance between monomer chains is reduced when the weak van der Waals forces are converted into covalent bonds. A gradual increase in viscosity of the resin material results in a loss of its fluidity (gel-point) and flowing ability (vitrification). Prior to vitrification, these materials are able to flow and partially relieve stresses. After the polymerizing material loses its ability to flow, its elastic properties increase and, consequently, any restraints on the polymerization shrinkage will generate residual shrinkage stresses. Therefore, the material's composition, its degree of conversion and reaction

kinetics becomes aspects of interest, together with the confinement and compliance of the cavity preparation.

CLINICAL CONSEQUENCES OF POLYMERIZATION SHRINKAGE STRESS

Polymerization shrinkage stress of composites have been related to several unwanted clinical consequences, such as enamel crack propagation, cusp deflection, debonding along the restoration/tooth interface or at the restoration margins resulting in marginal and internal gaps, and decreased bond strength. Despite the absence of strong evidence relating polymerization shrinkage to secondary caries or fracture of posterior teeth, shrinkage stress has been associated with postoperative sensitivity and marginal stain. The latter is often erroneously used as a criterion for replacement of composite restorations. Therefore, an indirect correlation can emerge between shrinkage stress and the longevity of composite restorations or resin-bonded ceramic restorations,[2]

TYPES OF COMPOSITE RESINS

a) Direct composite resin - Condensable/Packable or Polymeric rigid inorganic matrix material (PRIMM)

This new concept that was developed earlier by Lars Ehrnford of Sweden in 1995 is composed of a resin matrix with inorganic ceramic component.[3] Rather than incorporating the filler particles into the composite resin matrix, he devised a unique system by which the resin can be incorporated into the fibrous ceramic filler network, consisting of aluminum oxide and silicon dioxide glass particles or barium aluminum silicate or strontium glasses. The glass particles were liquefied to form a molten glass, which is forced through a die to form thin strands of glass fibers.

b) Flowable composites

A newer type of composite was developed in 1996 called "flowable composite" because of its low viscosity and ability to be syringed into a cavity preparation with a needle tip.

Clinicians have found that a material that can flow into cavity preparations has an important role, especially where the deposition of material into a tight space is required. They were created by reducing the filler content of traditional hybrid composites and retaining the same filler size and adding increased resin to reduce viscosity of the mixture. Since the filler content was reduced in these composites, they lack sufficient strength to withstand high stresses and because of the increased resin content these composites show more polymerization shrinkage and have lower elastic moduli and high fracture toughness.

Indirect composite resins

Because of the major clinical problems clinicians have experienced with direct posterior composite resins, the indirect inlay or onlay systems were introduced. Indirect composite resin (ICR) has been widely used in prosthodontics, since these possess adequate flexibility, are easier to handle, and have lower costs than ceramics. Currently used composite resins have esthetic properties similar to ceramics. Furthermore, ICRs can bear more compressive forces than the porcelain and can prevent the propagation of harmful forces to the margins of the crowns, thus preventing marginal damage.

c) Artglass

Artglass is a non-conventional dental polymer marketed since 1995 and has been most commonly used in inlays, onlays and crowns. The resin matrix is composed of BISGMA/UDMA, which provides a higher level of cross linking and better control over the positions along the carbon chains where cross linking occurs. This helps to improve wear resistance and other physical as well as mechanical properties of the resin matrix.

d) Belleglass HP

Belleglass HP was introduced by Belle de St. Claire in 1996 as an indirect restorative material. The resin matrix contains Bis-GMA along with other fillers. The Belleglass is polymerized in the presence of nitrogen inert gas at high temperature. Oxygen if gets entrapped in the composite, it interferes with polymerization and reduces translucency. It is aesthetically appealing and highly wear resistant[4]

e) Stimuli-response smart materials

Stimuli response materials possess properties that may be considerably changed in a controlled fashion by external stimuli. These polymers significantly change their shape, mechanical properties, phase separation, surface, and permeability, optical and electrical properties upon small changes in environmental conditions such as temperature, electric field, pH, light, magnetic field, electrical field, sonic field, solvent, ions, enzymes, and glucose. Stimuli responsive dental composites may be quite useful for example for "release- on command" of antimicrobial compounds or fluoride to fight microbes or secondary caries, respectively.[5]

f) Self-healing polymers

One of the first self-repairing synthetic materials reported, interestingly shows some similarities to resin based dental materials, since it is resin based. This was an epoxy system which contained resin filled microcapsules. If a crack occurs in the epoxy composite material, some of the microcapsules are destroyed near the crack and release the resin. The resin subsequently fills the crack and reacts with a Grubbs catalyst dispersed in the epoxy composite, resulting in a polymerization of the resin and repair of the crack. Self-healing is demonstrated by three conceptual approaches viz., capsule-based healing systems, vascular healing systems, and intrinsic healing polymers.

g) Nanocomposites

Colloidal silica particles of a diameter of approximately 40 nm have been in use in dental micro-filled and hybrid

composites for more than 10 years. Nanoparticle-filled composites exhibit outstanding aesthetics that are easy to polish and possess an enhanced wear resistance. Nanoparticle fillers may include colloidal silica or Ormocers, such as in Ceram X from Dentsply. Similar particles may be used in resin-based bonding systems. Nanoparticle- filled dental composites have shown enhanced fracture toughness and adhesion to tooth tissue.[6]

h) Fiber-Reinforced Composite Resin
Fiber-reinforced composites have numerous industrial and aerospace applications because they are light, strong and non-flammable. However, with respect to clinical dentistry, they are relative newcomers into the spectrum of prosthodontic treatment options. Over the years, these materials have evolved to the extent that they can be used for both direct and indirect restorations.

i) Antimicrobial materials
Antimicrobial properties of composites may be accomplished by introducing agents such as silver or one or more antibiotics into the material. Microbes are subsequently killed on contact with the materials or through leaching of the antimicrobial agents into the body environment. Dental composites containing 1% (w/w) quaternary ammonium polyethylenimine (PEI) nanoparticles were tested for their antimicrobial activity. The antibacterial properties of these composites were based on contact mechanism rather than on leaching. The antimicrobial effect lasted for at least 1 month. Alkylated ammonium chloride derivatives and chlorhexidine diacetate have also been introduced as antimicrobial agent into dental composites.

RECENT TRENDS IN POLYMERIC RESIN COMPOSITES
Innumerable studies have been published on improving or modification of chemical and mechanical properties of composite polymeric resins.

METHODS TO REDUCE POLYMERISATION SHRINKAGE STRESS
Many clinical methods have been proposed to reduce shrinkage stress, such as the control of curing light irradiance, flowable resin liner application, and incremental layering techniques. However, no method has been shown to be totally effective in abating the effects of polymerization shrinkage.

a. Incremental layering technique
Since difficulties imposed by the cavity configuration (C-factor) play an important role in stress development, many researchers have suggested the use of "incremental layering techniques" for resin-composite restoration to reduce the polymerization shrinkage stress and cusp deflection. The rationale is that shrinkage maybe less detrimental when there are fewer bonded cavity walls involved at each stage of the restoration procedures.[7]
In class I cavity, for example, by using a single

increment, the resin composite would polymerize within five bonding surfaces (one base and four surrounding walls) while free shrinkage would only occur at the upper surface, producing a very high level of stress between the bonded surfaces. However, by using an incremental technique, the bonded/unbonded ratio would be reduced and, consequently, the stress level within the cavity might be lower, preserving the bonded area.

According to Park et al.[7] the bulk filling technique yielded significantly more Cuspal deflection than the incremental filling techniques, concluding that cuspal deflection resulting from polymerization shrinkage can be reduced by incremental filling techniques to obtain optimal outcomes in clinical situations. Lee et al.[8] observed that cusp deflection increased with increasing cavity dimension and C-factor, thus the use of an incremental filling technique or an indirect composite inlay restoration could reduce the cuspal strain.

Versluis et al.[9] assessed the developing stress fields for different incremental filling techniques by using a theoretical study with Finite Element Analysis (FEA) methods. It was concluded that the incremental filling technique increased the deformation of the restored tooth and could produce higher polymerization stresses at the restoration interface compared with bulk filling. According to Loguercio et al.[10], some evaluated effects of polymerization shrinkage such as gap width, adhesive bond, strength and the cohesive strength of the resin composite were not reduced by the filling technique under the different C-factor cavities.

Despite the controversy over the advantages of incremental build-up of resin composites, this technique has been broadly recommended in direct resin-composite restoration.

Stress Absorbing Layers with Low Elastic Modulus Liners
Flowable composites are low viscosity resin-based restorative materials, which differ from conventional resin composites in their filler load and resin content. These materials are less rigid and could have a modulus of elasticity 20–30% lower than conventional hybrid composites. The use of a flowable resin composite as an intermediate thin layer has been suggested as a mean of overcoming polymerization shrinkage stress based on the concept of an "elastic cavity wall" suggested for filled adhesives. According to the "elastic cavity wall concept" the shrinkage stress generated by a subsequent layer of higher modulus resin composite can be absorbed by an elastic intermediary layer, thereby reducing the stress at the tooth-restoration interface manifested clinically as a reduction in cuspal deflection.[11]

However, actual implementation of such a "stress absorbing" material is problematic. Restorative materials encompass a wide variety of shrinkage and elastic modulus values. Consequently, some combinations

might give reduced performance compared with the common restorative material applied alone.

b. Light Curing Procedures

Diverse photo-activation protocols have been advocated to reduce the polymerization stress. Initial light exposure at lower irradiance values might lead to the formation of a reduced number of polymer growth centres, reducing the reaction rate and decreasing stress development due to the increased opportunity for resin flow before the vitrification stage. There are many types of alternative light-curing methods. The "soft- start" protocol consists of initial light exposure with reduced irradiance for a certain period of time, followed by full irradiance.

Another protocol is "pulse-delay" method, where the clinician may apply the initial exposure with reduced light irradiance for a very short period of time of a few seconds and follows a waiting period without irradiance (seconds or even minutes) and fully irradiate later.

Although the alternative light-curing protocols may not significantly affect final properties of the hardened material, some considerations should be noted. (i) The flowability of a material, during an extended pre-set stage, may have minimal consequences, because most shrinkage stress is developed during and after the vitrification stage. Therefore, opportunities for polymer relaxation would be restricted during the short period of light activation. (ii) Concurrent experiments on degree of C=C conversion (DC) and stress development show that soft-start irradiation procedures give somewhat lower DC levels, associated with reduced stress; (iii) A reduced polymerization rate is associated with decreased cross-link density (CLD), manifest as greater solvent-softening and/or lower final elastic modulus.[12]

c.   Preheating

Recently, preheating resin composites have been advocated as a method to increase composite flow, improve marginal adaptation and monomer conversion. The benefits of preheating composites may have an impact on daily restorative procedures as well, with the application of shorter light exposure to provide conversion values similar to those seen in unheated conditions.

The reasons for increased conversion are based on many factors. Increased temperature decreases system viscosity and enhances radical mobility, resulting in additional polymerization and higher conversion. The collision frequency of unreacted active groups and radicals could increase with elevated curing temperature when below the glass transition temperature. Therefore, at raised temperatures, in theory, it would be possible to obtain higher degree of conversion before the vitrification point, decreasing the magnitude of stress. However, real benefits were not fully demonstrated and, until now, there are no published studies showing stress reduction by warming resin composites.[13]

Novel Formulations for Reducing Shrinkage Stress
The development of resin composite has mainly focused on filler technology, while the composition of the polymer matrix remained principally unchanged since the introduction of Bis-GMA resin by Bowen in the early 1960s. Shrinkage is an inherent property of dimethacrylate-based formulations. However, recently, novel monomer combinations and alterations of the resin-composite formulation have been developed and evaluated with the goal of decreasing polymerization shrinkage stress.

The most recent modification on the polymer matrix is based on using ring opening polymerization of the silorane molecules, instead of free radical polymerization of dimethacrylate monomers.[48] Silorane resin reveals lower polymerization shrinkage compared to the dimethacrylates. These "cyclic" monomers have provided particularly interesting and commercially viable results. Such monomers "open" their molecular structures with local volumetric expansion and this may partly or totally compensate for volumetric shrinkage from C=C or similar polymerization.[14]

Changes in the photoinitiator systems and polymerization inhibitors have also been reported. Braga and Ferracane[15] tested experimental materials with different concentrations of inhibitor (2,6-Di-*tert*-butyl-4-methyl-phenol = BHT) and showed that increased inhibitor concentrations reduced the rate of polymerization and the shrinkage stress without significantly compromising the final degree of conversion. Schneider et al.[16] found that phenyl-propanedione, substituting for part of the camphorquinone content, reduced the stress development rate without compromising the final degree of conversion and degradation resistance of the composite.

Besides changes in the resin matrix composition, studies have demonstrated reduced shrinkage stress through alterations in filler content. Condon and Ferracane[17] suggested that addition of non-bonded 40 nm colloidal silica might act as stress- relieving sites through plastic deformation. They also verified that composites with nano-filler particles treated with a non-functional silane developed 50% less stress than composites fully treated with the functional coupling agent. Another possible approach is inclusion of a component readily allowing plastic deformation during stress development, such as ultrahigh molecular weight polyethylene (UHMWPE) fibres.

METHODS OF EVALUATION OF POLYMERIZATION SHRINKAGE

Different methods such as Coordinate Measurement Equipment, Optical Coherence Tomography and Archimedes Principles were used to determine polymerization shrinkage of restorative materials. Several experimental methods have been developed to

measure polymerization shrinkage of composites and resin cements. Most methodologies record total shrinkage, which include both pre- and post-gel shrinkage. In contrast, the strain gauge technique was proposed to isolate the post-gel shrinkage, which is more directly related to shrinkage stress development. Experimentally, the effects of polymerization shrinkage and shrinkage stress can be studied by a method such as micro- CT to measure internal gaps, while forces exerted by polymerization shrinkage can be measured using load cells.

Conventional methods to measure polymerization shrinkage (dilatometer, bonded disc method, strain gauge analysis, and pycnometer), compressive stress (universal testing machine), and wear rate (profilometric analysis) are based on volume or density changes before and after curing. These methods are laborious, besides being sensitive to changes in temperature and specimen weight. Since polymerization stress is considered one of the major drawbacks of resin-composite applications, extensive efforts have been made to understand the phenomenon and to devise means for its reduction. Consequently, methods are essential for evaluation of shrinkage strain and shrinkage stress.

Shrinkage strain evaluation

One of the first methods used to measure the polymerization volumetric shrinkage was the mercury dilatometer[17] (Figure 1). This equipment evaluates the volume change of the mercury in a reservoir surrounding the resin-composite specimen trough a thin column and the results are registered according to the amplified linear height variations of this column. Since the temperature of the LCU may affect the results, a thermocouple is attached to the system and volumetric change caused by the temperature from the light source is discounted.

In 1991, Watts and Cash[18] described the bonded-disc method to evaluate volumetric shrinkage (Figure 2). For this method, a disc-shaped specimen of uncured resin composite is placed at the centre of a square cross-section brass ring, which is adhesively bonded onto a rigid glass microscope slide. Thus, the top edge of the ring and the disc specimen are covered by a flexible glass microscope coverslip and, over this set, a linear variable differential transformer (LVDT) probe is positioned to measure the plate deflection. The LVDT is connected to a signal conditioning unit and a computer unit that records data over time.

Lately, new powerful and promising techniques, such as the X-ray microtomography, have been employed to investigate polymerization shrinkage. Kakaboura et al. used the X-ray microtomography to evaluate the 3D-marginal adaptation to dentine versus shrinkage strain of two light-cured microhybrid resin composites. The authors used sequential sections of restorations to calculate the interfacial microvoid volume fraction and

compared the results with the bonded-disc method. As result, the authors found a strong correlation between the microvoid volume fractions with the data from the bonded-disc apparatus.

Shrinkage Stress

The "ring-slitting method" is a simple and inexpensive way to evaluate residual stress in ring-shape resin composite specimens[19] In this method, the resin composite is cured and the gap distance previously created in the ring is measured before and after the polymerization process. Photoelastic or finite element analyses (FEAs) are interesting methods to observe the spatial distribution and concentration areas of stress. While photoelastic analysis determines stress distribution through optical fringes created in specific resins,[20] FEA evaluates stress distributions by computer models. This method requires not only an anatomically accurate geometry but other input data, especially elastic moduli, Poisson's ratios, and shrinkage strain.

Although the previous methods brought important contributions for the current knowledge, it has to be stated that force transducers are the most widely used and versatile methods for analyses of stress development. The wide application of such equipment relies on the fact that it is possible to analyze the influence of important factors, like C-factor and mass of material, by simple variations in cylinder/disk size and aspect ratio. Although the basic principle is the same for all force transducers, there are different measurement approaches for each system, being the instrument compliance the most significant one. Unfortunately, outcomes seem to be dependent upon system compliance, which varies among different studies.

Universal testing machines modified with extensometers connected to a computer servo- control unit are very precise and can identify movement of extension caused by the polymerization shrinkage. As a feedback response, the system compensates deformations, and the sample remains constant. Thus, this kind of system presents very low compliance and, consequently, the registered values of stress tend to be higher than those by more compliant methods. Some variations may exist within this method, and a significant one is the kind of substrate to which the resin-composite sample is attached.[21] Figure 3 shows a picture from an extensometer apparatus used to analyze deformations from the resin-composite specimen.

There are also force transducers adapted to systems with unknown or calculated compliance. Figure 4 shows a controlled-compliance apparatus for contraction stress test developed by Sakaguchi et al.[22] The apparatus consists of a steel frame and a washer- type load cell through which a steel piston is inserted. The lower part of the frame held a circumferential glass plate that supports the resin-composite specimen. The surfaces of the piston and the glass plate are usually sandblasted and

coated with a silane coupling agent to improve the adhesion between the apparatus and the resin-composite specimen. The resin composite is then inserted between the glass and the steel piston and the material is photoactivated through the glass plate. As the materials shrinks, force is recorded and converted to nominal stress by dividing it by the cross-sectional area of the specimen.

Another apparatus developed for contraction stress test is the Bioman and was designed by Watts et al. (Figure 5).[23] The system is based on a cantilever load-cell fitted with a rigid integral clamp. The compliant end of the cantilever held a circular steel rod. The counter-face consisted of a removable rigid glass plate that is held rigidly relative to the base plate in a special clamp during measurement. The resin composite is then introduced between the treated (sandblast + silane) plate and vertical rod to form an uncured specimen disk. The resin composite is irradiated through its thickness dimension from below. The load- signal from the cantilever cell is amplified and the signal is acquired by a standard computer. The registered load is then divided by the disk area in order to obtain the stress values in MPa.3.

FIGURES

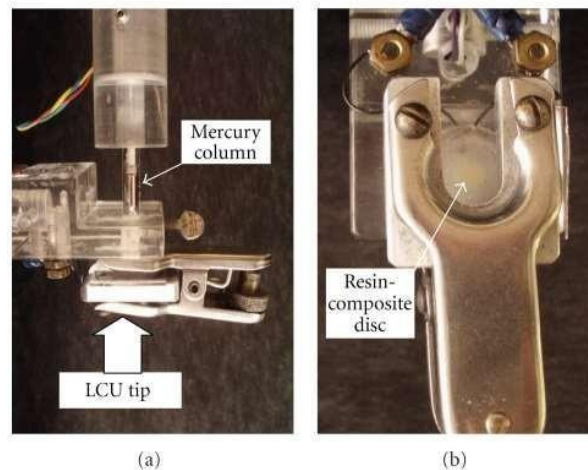(a)   (b)

Figure 1 – (a) Mercury dilatometer. It can be observed the mercury column, the clasp that holds the resin composite sample (b) and the place where the LCU is positioned.
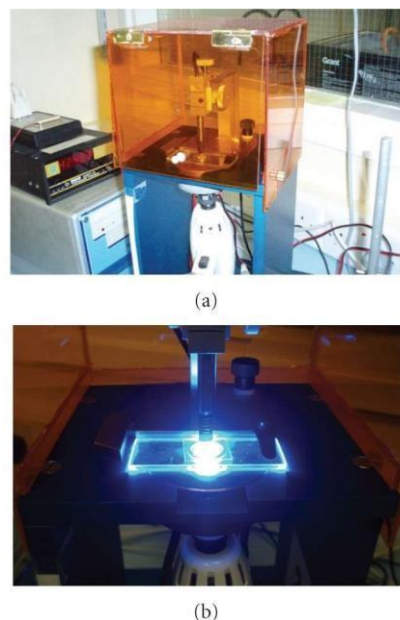

(a)

(b)

Figure 2 – (a) The "Bonded-disc" apparatus. (b) A close view of the LVDT probe in contact with the glass slide during the resin-composite photoactivation.
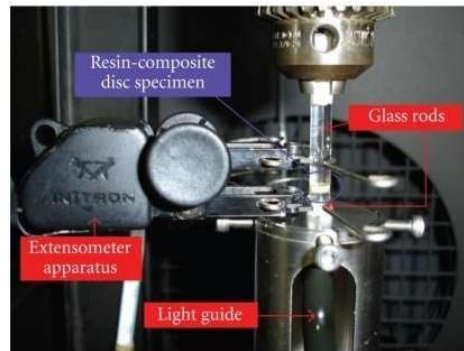
Figure 3 - Extensometer apparatus that is connected to a universal testing machine. As a feedback response, the system compensates deformations, and the sample remains constant. Consequently, this kind of method is known as a "low-compliant method.
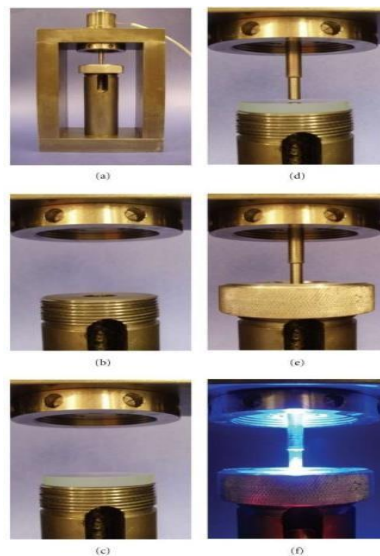

Figure 4 - Controlled compliance apparatus for contraction stress test. (a) The entire apparatus with a view of the steel frame and the upper load cell holder; (b) slot for light guide; (c) glass plate positioned; (d) steel piston in position and the space where the resin- composite specimen is positioned; (e) equipment ready for use; (f) light curing procedure during the experiment.
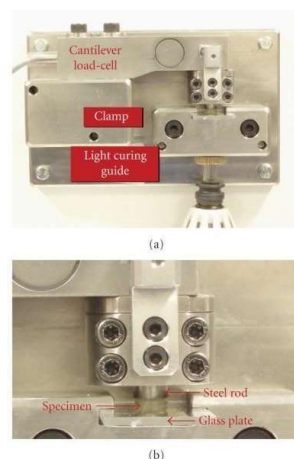

Figure 5 - (a) The Bioman stress measurement device. (b) A close view of the resin- composite specimen.

CONCLUSION

Within the framework of this review, we have compiled the available literature materials regarding light-curing polymeric resins that are widely used in dentistry. Further research in this area needs to be defined for the selection of appropriate dental materials and recommend the suitable dental composite material for effective clinical work. Further, future investigations should focus on the overall assessment of the effects of certain polymerization methods on material properties, and to

define the optimal material properties to be achieved taking into account the oral environmental conditions.

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