Review Article

Factors Leading to Shrinkage Stress and Strain in Dental Composites: An Update

Abdul Khabeer, Muhammad Ali Faridi, Imran Farooq, Saqib Ali

ABSTRACT

The purpose of this review was to identify the various factors involved in polymerization shrinkage of dental composites and to discuss possible strategies of overcoming this drawback. The final setting reaction of dental composite material is followed by polymerization shrinkage of the material which leads to shrinkage stress and strain. This shrinkage stress and strain could result in debonding of the material, cuspal flexure, fracture of the tooth, microleakage and poor mechanical properties. PubMed and Google scholar databases were used to search through the past 30 years of literature using selected search criteria "Dental composite*[TW] AND (shrinkage*[TW] OR stress*[TW] OR strain*[TW])" to identify articles/book chapters discussing polymerization shrinkage and possible solutions. In total 46, articles/book chapters met the criteria for inclusion in the literature review.

There were multiple factors that were identified to have an impact on polymerization shrinkage and consequently shrinkage stress and strain, which included the composition and viscosity of the material, modulus of elasticity acquired by the material, rate of polymerization, configuration factor and degree of conversion. On the other hand, the methods which could help minimize shrinkage involved alteration to the material including change in particle size, incorporation of inhibitors, and addition of silorane as well as use of various clinical techniques. It can be concluded that various strategies have been implemented to overcome the shrinkage stress and strain related to dental composites, however, further research is required to help in the development of the material. In addition, improvement in the placement techniques of the material needs further exploration to reduce this complication.

KEYWORDS: Dental composites, Stress, Strain, Polymerization shrinkage, Marginal adaptation.

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INTRODUCTION

Dental caries could result in cavitations of the tooth structure necessitating its restoration[1]. Dental composite filling materials have been used in dentistry for the past few decades as they can be used to restore anterior and posterior teeth, have good adhesion properties, and easy application[2]. An ideal filling material should be free from marginal leakage, and should not undergo dimensional changes in order to adapt well to cavity walls[3]. However, none of the composite filling materials fulfill these properties and problems with marginal integrity of the restoration still exist[2]. The conventional composite filling materials undergo dimensional changes because during the transformation of monomer molecules into polymer molecules, there is reduction in the van der Waal spaces between the molecules resulting in contraction[4]. This contraction can be termed as polymerization shrinkage[3].

During shrinkage, stress and strain are developed in the restorative material and at the interface of the tooth-restorative material as the composite restorative material is bonded to the rigid tooth walls[3,4]. Stress can be defined as "when an external stimulus is applied to a specimen of material under trial, an internal force, equal in magnitude but opposite in direction, is set up in the specimen", while Strain can be defined as "the external force applied to a specimen resulting in a change in dimension"[5]. Moreover, stress and strain are related properties, therefore, stress produced in a material due to an external force may result in strain or change in dimension of the material[5].

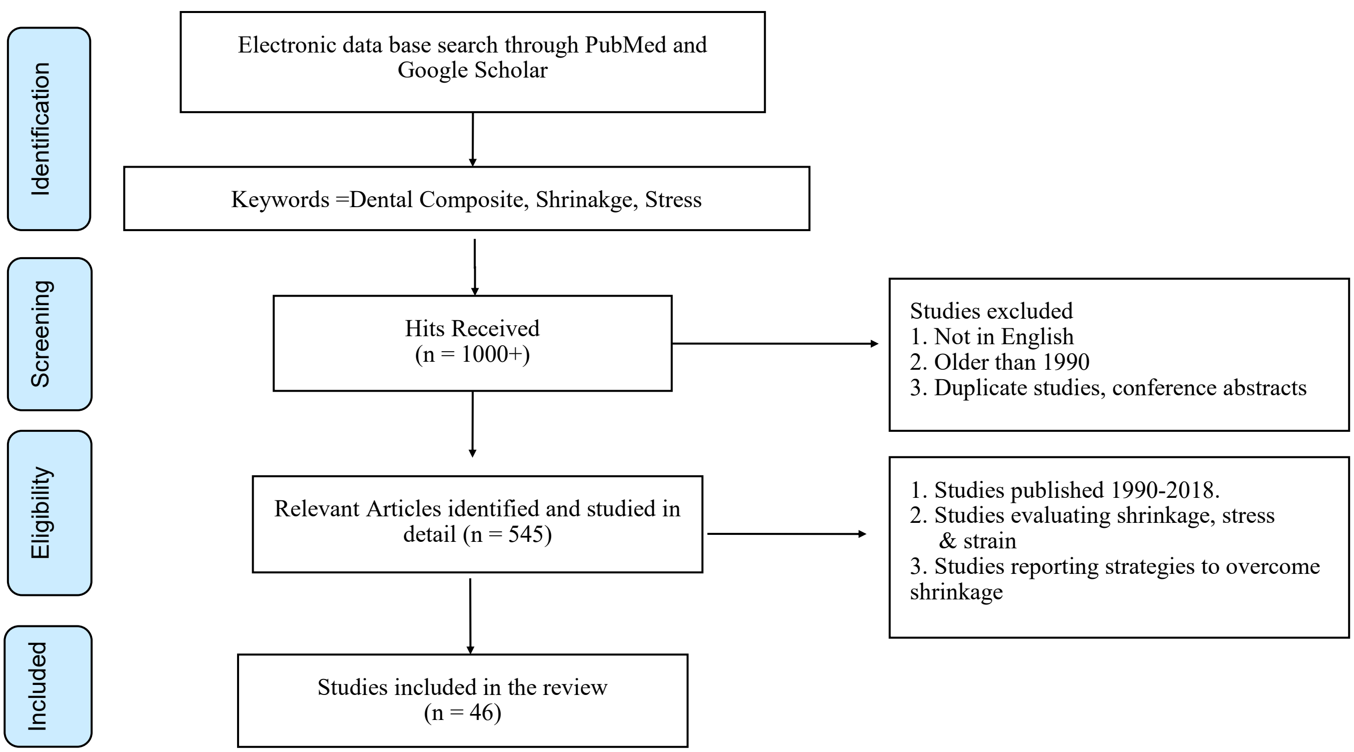
If the strength of the adhesive bond is not strong enough to resist the stress shrinkage produced, then there will be formation of a gap at the tooth-restoration interface which may result in possible microleakage, tooth sensitivity, and eventually secondary caries[6]. However, if the bond strength is high enough to prevent shrinkage stress, then there might be a cuspal deflection which can cause post-operative pain or in some cases fracture of cusps[7]. There are multiple factors that may have an impact on polymerization shrinkage and consequently shrinkage stress and strain, which may include the composition and viscosity of the material, modulus of elasticity acquired by the material, rate of polymerization, configuration factor and degree of conversion[8].

The purpose of this review was to summarize the information present in the literature regarding various factors that can affect polymerization shrinkage in dental composites and possible methods by which it can be reduced or minimized.

METHODOLOGY

Electronic search of PubMed/Medline and Google scholar databases was done. A total of 545 articles were evaluated and screened for parameters including the origin, methodology and invitro/invivo studies. The search was carried out using the following criteria "Dental composite*[TW] AND (shrinkage*[TW] OR stress*[TW] OR strain*[TW])". The studies that were duplicate, not in English language and not published in dental journals were discarded. Studies published between the years 1990 and 2018 that evaluated the polymerization shrinkage, stress and strain or reported strategies to overcome shrinkage, were finalized for inclusion. In the end 46 articles/book chapters were included in the study for review (Figure I).

FIGURE I: FLOW CHART SHOWING IDENTIFICATION, SCREENING, AND SELECTION OF STUDIES FOR THIS REVIEW



RESULTS AND DISCUSSION

Factors affecting polymerization shrinkage

Visco-elasticity

The quality and durability of dental restorations is affected by many factors[9]. One important factor is visco-elasticity. During the early setting reaction or pre -gel state of composite filling materials, the material undergoes some plastic flow which prevents the stress buildup. However, when the material cannot undergo further plastic flow also known as post-gel state, the modulus of elasticity increases significantly and stress starts to build up at the interface[10]. Hence, longer the material can undergo plastic flow, lesser will be the stress development, therefore, slower polymerization reaction may result in less stress generation and good marginal seal[11]. The composition and the filler component have an important part in defining the polymerization shrinkage found in the filling material and its ability to flow and relieve stress[10]. It has been shown that increasing the volume of inorganic filler content relates to a lower amount of resins, leading to less shrinkage which can be advantageous on one hand, while on the other side, this increase in filler content results in higher modulus of elasticity which can be a disadvantage as the flow of the material is decreased[4].

Rate of polymerization

Light activated composites generally undergo fast setting which results in insufficient period for the flow of the material and in shrinkage stress and strain. An *in vitro* study performed by Kinomoto in 1999 showed stress generation by light cured composites to be twice as high when compared to stress generated by chemically cured composites[12]. This increased stress generation was probably due to the speed of reaction which was faster for light cured composites than for chemically cured composites[13].

Degree of conversion

An important factor in determining the shrinkage stress, strain, and other physical properties of the material is the degree of conversion. Incomplete polymerization may also lead to poor biocompatibility due to secretion of free residual monomers in the oral environment which can have a toxic effect[14]. Bisphenol A-glycidyl methacrylate (BisGMA) is a commonly used monomer in dental composites having high viscosity of 500,000- 800,000m Pa·s[15], molecular weight of 512g/mol, and low degree of conversion[15]. Moreover, addition of filler contents is limited due its high molecular weight. Therefore, monomers like triethylene glycol dimethacrylate (TEGDMA) and urethane dimethacrylate (UDMA) with lower molecular weights (286–480g/mol) and lower viscosities (100–10,000 mPa·s) are added, which results in a desirable viscosity of dental composites and increased amount of conversion, but also leads to increased shrinkage and shrinkage stress[15-17].

Restrictions on the material

When a composite filling material is placed to restore a tooth, some restrictions are applied by the adhesives which may lead to stress development[18]. Apart from material properties itself, two variables are of great importance in the restriction of dental composites. Firstly, the geometry of the cavity walls in which the restoration is to be placed and secondly, the compliance of the substrate which can be characterized by stiffness and mobility of the tooth walls[16]. The dimensions of the geometry establish the configuration factor (C-factor) which can be defined as the ratio between bonded area in a cavity and unbonded free area[19]. The material normally flows towards the free area causing production of less stress at the interface[17]. Therefore, greater the contact area, the lesser will be the free area and thus greater will be the stress at the interface[17]. Moreover, a shallow cavity will have less C-factor when compared to a deeper cavity of the same designs[20].

Feilzer AJ 1987[21] performed an *in vitro* study in 1987 in which it was reported that restorations with C-factor of less than 1 were able to resist cohesive failures, restorations with C-factor between 1 and 2 showed some cohesive failures, whereas restorations with C-factor of more than 2 showed consistent cohesive failures from shrinkage stress during polymerization. When adhesives are used, the strain of the substrate material can help in reducing the shrinkage stress. A previous *in vitro* study performed by Alster D 1997[20], showed that when the compliance of the substrate was increased from 0.029 MPa to 0.150 MPa, the stress generation due to shrinkage decreased from 22 MPa to 7 MPa. Moreover, thinner composite films resulted in more stress relief and reliable bonds[22].

Strategies to minimize shrinkage stress and strain

Several approaches have been proposed to minimize the shrinkage of the material and shrinkage stress and strain. These approaches include the alteration of the composite material itself such as the monomer formulation, the amount of fillers, initiator level, inhibitor level and addition of additives, while other approaches include incremental placement, alternative light curing methods and sandwich restoration with flow able composites, low viscosity liners or glass ionomer cements (GIC's).

Alteration of dental composites

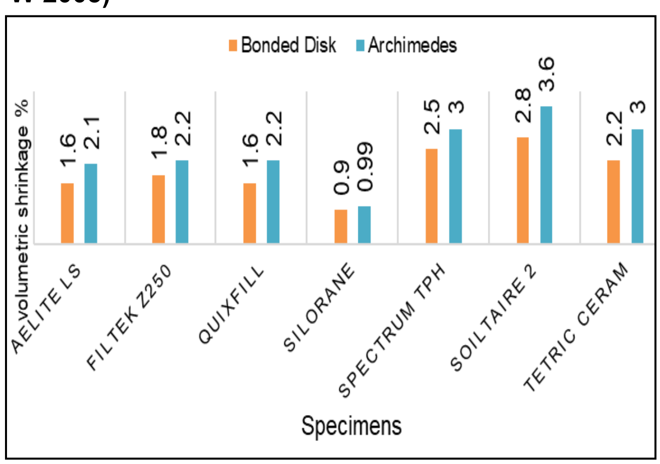
The size of the monomer and its type plays a role in generating polymerization stress. Anseth KS et al[23] performed an *in vitro* study in which he reported decreased shrinkage stress when monomers with a bigger size were used, compared to the stress generated by materials with smaller monomer size. The probable reason could be that there are lesser number of monomers present to form polymers, thereby shrinkage is reduced[22].

Camphorquinone (CQ) is a commonly used initiator in light cured composites that helps in initiating the polymerization reaction when visible light is shown. However, Emami N 2005[24] performed an *in vitro* study in which he used another initiator named 1-phenyl-1, 2 -propanedione (PPD) and compared it with CQ and reported that PPD caused slower rate of reaction, thus allowing for increased time duration for the material to flow without altering the final degree of conversion, as compared to CQ.

Incorporation of inhibitors in composite materials has been advocated by some studies which have shown reduced shrinkage stress and strain with varying concentrations of inhibitors[23,24]. Inhibitors help in slowing the polymerization reaction by reacting with free radicals that are produced during photo-activation[11]. Braga and Ferracane showed in an *in vitro* study that increasing the inhibitor (Butylated hydroxytoluene) concentration from 0.5% to 1.0% resulted in slower rate of polymerization and reduced polymerization stress[25].

Silorane based composites are available which can be used as alternatives of methacrylates. It is reported that the silorane based composites undergo volumetric shrinkage as low as 0.99% (Figure II)[26], while methacrylates show 1.9% to 4.05% shrinkage[27].

FIGURE II: SHOWING COMPARISON OF SHRINKAGE OF SILORANE WITH METHACRYLATES (ADAPTED FROM WEINMANN W 2005)[26]



However, a study performed by Boaro LC et al. in 2010 showed that low shrinkage of the material does not always result in low shrinkage stress[28]. Another approach to minimize shrinkage stress and strain involves the development of new liquid crystal monomers having low-polymerization shrinkage. The liquid crystal monomers are fluids at room temperature with compact molecular arrangement which transforms into isotropic amorphous state during polymerization resulting in an expansion which helps in reducing shrinkage[29]. Moreover, shrinkage of such type of dental composite was found to be around 2%[30].

Layering technique

Incremental placement of composite filling materials might reduce shrinkage stress and strain, but it is debatable. The main reason behind incremental placement is to reduce the C-factor and allow the material to flow[29]. This in turn leads to minimized stress on the prepared cavity and increases the effectiveness of curing light[31].

Park J 2008[31] reported decreased polymerization stress and less cuspal deflection by restorations placed with the incremental technique when compared with bulk filling technique[31]. This was reconfirmed in a study conducted in 2013 which concluded that that use of any variation of the layering technique reduced cuspal deflection and polymerization shrinkage in composite[32].

However, this is still a point of debate among researchers. Kuijs RH 2003[33] in a study conducted in 2003 concluded that the reduction in polymerization shrinkage was minimal as compared to conventional methods. Similar results were reported by other studies which showed the decrease in shrinkage of composite as being non-significant[34,35]. Therefore this requires further research to be considered a valid strategy for reduction in polymerisation shrinkage.

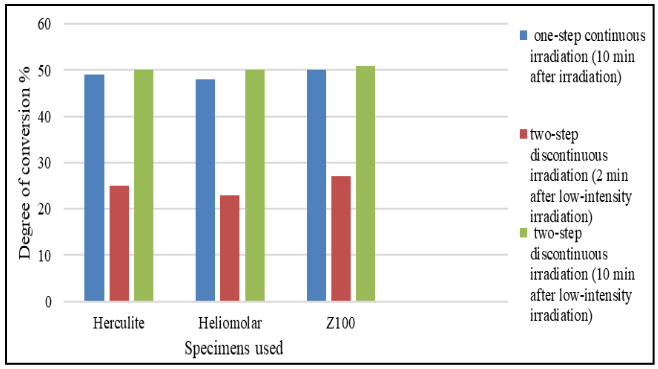
Bulk fill resin-based composites

Recently, to overcome the complex and time-consuming procedure of placing large resin based composite restorations, the manufacturers have developed materials that can be placed in a single increment with depth ranging between 4-10mm. These materials are known as Bulk-fill resin-based composites. It has been claimed by the manufacturers that the polymerization shrinkage of bulk-fill resin based composited is lower or at least similar to conventional resin-based composites when placed in increment of higher thickness. An *in vitro* study by El-Damanhoury HM 2014[36] and Platt in 2014 reported that the polymerization shrinkage stress of bulk-fill resin-based composites was significantly lower than conventional resin-based composites when placed in increments of 4mm thickness. However, another study did not show any significant reduction in the polymerization shrinkage stress of bulk-fill and conventional resin-based composites[37].

Intensity of light curing units

Various curing methods have been recommended to reduce polymerization stress and strain which include pulsed exposure, delay between exposures, low initial irradiance, and ramped light application. An *in vitro* study performed by Lim BS 2002[38] showed reduced polymerization shrinkage stress with low initial irradiance (exposure to 60 mW/cm^2 of light for 5 seconds after which an interval of 2 min was done and then exposed to 330 mW/cm^2 for 60 seconds), when compared with single continuous irradiance (radiation of 330 mW/cm^2 for 60 seconds) (Figure III).

FIGURE III: SHOWING DEGREE OF CONVERSION OF COMPOSITES WITH THREE IRRADIATION SCHEMES (ADAPTED FROM LIM BS 2002)[38]



Another study conducted in 2000 working under the hypothesis that the reduction in intensity of the curing light will reduce the shrinkage in composite also yeilded positive results[39]. The comparison was done between exposure for 40 seconds at 750 mW/cm^2 and 40 seconds at 200 mW/cm^2.[40] This hypothesis was reinforced by a study conducted in 2005 by Tarle Z et.al[41]. There fore use of different protocols for curing of the composite material will effect the amount of shrinkage.

Viscosity of the material

Utilization of a low viscosity liner between the restoration and the tooth allows some freedom of movement of the material during polymerization and might help in distributing stress evenly throughout the adhesive interface. Moreover, thicker layer of unfilled resins allows more chances of stress relief[42]. On the other hand, this technique might interfere with the radiographic diagnosis, as the unfilled resins are radiolucent, while due to fluid nature, adequate placement may be problematic[25]. Alternatively, low viscosity flowable composites between the tooth and conventional composite can be used as it can act as a shock absorbing layer[43], and could help in reducing microleakage[3]. Multiple studies have shown reduced amount of shrinkage stress of composite filling materials when GIC or resin modified GIC has been placed as a base or liner, compared to composite restorations placed without GIC[3,44]. A change of polymer matrix inside the composition of dental composite could also reduce the stress produced by cross-linking composite resin[45].

Another suggested method of reducing polymerization shrinkage is to use preheated resin composites as heating will decrease the viscosity of the material and enhance the movement of the radicals which might result in higher degree of conversion and lower stresses[46].

CONCLUSION

It can be summarized that the final setting reaction of dental composite material is followed by polymerization shrinkage of the material which leads to shrinkage stress and strain. This shrinkage stress and strain could result in debonding of the material, cuspal flexure, fracture of the tooth, microleakage and poor mechanical properties. It can be proposed that the formulation of a composite material with large monomers, lower filler contents, suitable inhibitors and alternative initiators may help in producing a material which undergoes less shrinkage and consequently induce low stress and strain. Some clinical techniques such as placement of a small layer of flowable composite, glass ionomer or low viscosity liner, incremental placement (oblique, horizontal or vertical) of composite and soft or slow start light curing have been advocated which may also help in reducing shrinkage stress and strain.

AUTHOR CONTRIBUTIONS

Khabeer A:	All authors have contributed equally towards the MS
Faridi MA:	
Farooq I:	
Ali S:	

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AUTHOR AFFILIATION:

Abdul Khabeer
Department of Restorative Dental Sciences
College of Dentistry, Imam Abdulrahman Bin Faisal University
Dammam, Saudi Arabia.

Muhammad Ali Faridi
Department of Restorative Dental Sciences
College of Dentistry, Imam Abdulrahman Bin Faisal University
Dammam, Saudi Arabia.

Imran Farooq
Department of Biomedical Dental Sciences
College of Dentistry, Imam Abdulrahman Bin Faisal University
Dammam, Saudi Arabia.

Saqib Ali *(Corresponding Author)*
Department of Biomedical Dental Sciences
College of Dentistry, Imam Abdulrahman Bin Faisal University
Dammam, Saudi Arabia.
E-mail: drsaqiibali@gmail.com