International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-8, Issue-11; Nov, 2021
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.811.28

Polymerization shrinkage of composite resins: consequences and control

Sonielly Passos da Silva[1], Susana Hellen da Costa Lima[1], Raísa Castelo[2,3,*]

[1]Undergraduates at the Dentistry School of Centro Universitário do Norte – Ser Educacional, Brazil
[2]PhD in Dentistry (Oral Rehabilitation) at University of São Paulo – USP, Brazil
[3]Professor of Centro Universitário do Norte – Ser Educacional, Brazil
*Corresponding author: dra.raisacastelo@gmail.com

Received: 19 Sept 2021,

Received in revised form: 03 Nov 2021,

Accepted: 15 Nov 2021,

Available online: 26 Nov 2021

***Keywords*— composite resin, polymerization shrinkage, bonding, biomechanical properties.**

***Abstract* — Bonding strategies associated with the aesthetic and conservative properties of resin materials have increased their popularity in restorative dentistry. Direct composite restorations are one of the most prevalent medical interventions on the human body, with millions of composite restorations placed each year around the world. The optimal performance of these restorations depends on the proper polymerization of the resin component, which is characterized by the transformation of monomers into polymers, accompanied by volumetric reduction of the material. Despite several improvements in new restorative materials in recent years, the disadvantages related to polymerization shrinkage of resin composites remain a clinical problem. The aim of this study is to explore, through an integrative literature review, the causes of polymerization shrinkage of composite resins, as well as their risks and how to control them, in order to obtain long-lasting restorations. A consequence of shrinkage stress can be related to the detachment along the restoration/tooth interface or restoration margins, resulting in internal and marginal gaps, microcracks of one or both restorative material and tooth structure, marginal stain, and cusp deflection.*

***Clinical Relevance* - Clinicians must understand the concept of polymerization shrinkage stress and realize that the quality of composite resin restorations depends on the successful management of these efforts.*

I. INTRODUCTION

The search for highly esthetic treatments, through minimally invasive procedures, resulted in the wide use of direct adhesive restorations with composite resin on anterior and posterior teeth. In order to achieve functional success and a natural appearance for direct restorations, is important to understand the properties of composite resins, how the adhesion process to enamel and dentin works, and use appropriate restorative technique (ALENCAR et al., 2016).

When choosing restorative material, the advantages, disadvantages and characteristics of this material are evaluated, such as aesthetics, mechanical properties, surface finish and cost-effectiveness. With the aesthetic demand in restorative procedures, a gradual replacement of metallic alloys and silver amalgam restorations by resin systems took place. The clinical use of composite resin has expanded in restorative dentistry, with indication for direct and indirect restorations, mainly due to its aesthetic quality and good physical properties (VINAGRE et al., 2016).

Direct composites promote a strengthening of the tooth structure and good clinical performance. However, there are some problems related to the direct restoration technique, such as polymerization shrinkage, which has been one of the most considered issues in restorative dentistry in recent years. Several factors influence the contraction stress, such as the cavity configuration, the speed at which polymerization occurs, in addition to the elastic modulus and the contraction itself, inherent to the resin material (SOARES et al., 2017).

Clinically, the stress resulting from polymerization shrinkage can induce traction forces on the lateral walls and pulp wall of a cavity preparation, promoting the appearance of cracks or fissures, due to the displacement of the restorative material from the tooth margin. These cracks can cause fluid infiltration between the tooth and the restoration, marginal pigmentation, postoperative sensitivity, and secondary caries. (SILVA et al., 2017).

To reduce the stress generated during the polymerization of composite resins, without compromising their mechanical properties, the gradual light curing technique could be considered. It has been experimentally demonstrated that a slow polymerization reaction can cause minor damage to the adhesive interface, increasing the possibility of material flow, prolonging the pre-gel phase of the composite resin and, consequently, reducing shrinkage stress, resulting in less induction, mechanical stress and, therefore, lower rates of cracking and marginal leakage (SCARIOT et al., 2017).

The aim of this study is to explore, through an integrative literature review, the causes of polymerization shrinkage of composite resins, as well as their risks and control, in order to obtain long-lasting restorations.

II. LITERATURE REVIEW

2.1 Composition of composite resins

Composite resins are a complex mixture of monomers (resin matrix) mixed with inorganic filler particles. To bond the filler particles to the resin matrix, the particles are coated with silane, a bonding agent. Other additives are included in the formulation, such as photoinitiator, which initiate polymerization, and compounds that can adjust viscosity and improve radiographic opacity (MARTINS et al., 2017).

The resin matrix is composed of aliphatic or aromatic dimethacrylate monomers. Monomers like Bis-GMA - bisphenol-A-glycidyl methacrylate and triethylene glycol dimethacrylate - TEGDMA play a fundamental role in the potential of polymerization shrinkage of resins. Usually used together, this system presents relatively satisfactory clinical results, but there are still properties that need to be improved, such as resistance to abrasion (PAMPULHA et al., 2015; SOARES; PINTO, 2019).

Filler particles provide dimensional stability to the resin matrix and improve its properties, reducing polymerization shrinkage, water sorption and thermal expansion coefficient, providing an increase in tensile, compression and abrasion resistance, and increasing the elastic modulus of the composite resin (ARAÚJO et al., 2019).

During the initial development of composite resins, material properties were shown to depend on the formation of a strong bond between the inorganic filler and the organic matrix (resin). The union of these two phases is obtained by coating the charge particles with a binding agent, silane (NOBRE; GOMES, 2020).

2.2 Polymerization shrinkage

The shrinkage of a composite resin during polymerization appears as a major problem without an effective solution. This contraction occurs as a result of the rearrangement of the monomers in a smaller space, that is, the monomers bind to form polymers and occupy a smaller space, in volume. Before polymerization, the distance between molecules is 0.3 to 0.4 nm, determined by Van der Waals forces. When the covalent bonds between the monomers are established, the distance between them can reduce to 0.15 nm, resulting in volumetric contraction. This phenomenon happens due to the shortening of the polymer chains, inherent to the polymerization reaction. Clinically, it can favor the formation of a marginal gap in restorations, as the contraction forces can be greater than the bond strength provided by the adhesive system used (SILVA et al., 2017).

The shrinkage of composite resins can be divided into two phases, pre-gel and post-gel, since material shrinkage is the result of both. During the polymerization shrinkage, in the pre-gel phase, the molecules can slide and reach new positions and orientations, neutralizing the polymerization shrinkage stress. The gel point is the transition stage in which the resin changes from a fluid to a viscous state. From this moment, in the so-called post-gel phase, the material obtains a higher elastic modulus, losing its ability to drain and start transferring the tension generated by the material to the tooth-restoration interface (SCARIOT et al., 2017).

According to Silva et al. (2017), there are two types of contraction:

- *Free shrinkage*: When resins do not adhere to any surrounding surface, the shrinkage and shrinkage vectors (direction of shrinkage) will not be affected by any bonding agent. In this way, the composite resin will contract towards the center of the mass. As consequence, there will be no difference between the pre-gel and post-gel phases. As long as the contraction is not limited or hampered, the stress of the contraction will not occur (SILVA et al., 2017).

- *Effective shrinkage:* If the resin is bonded to a single surface, shrinkage will be affected by this adhesive condition. Shrinkage towards the center of mass will not be possible, as the resin is not able to detach from the adhesive surface. Therefore, the lost volume will be compensated by the contraction towards the bonded surface. Again, there will not be a major difference between the contraction vectors of the pre-gel and post-gel phases, nor will contraction stress occur because there will be a bonded surface and a free surface to compensate for the contraction (SILVA et al., 2017).

In most dental cavities, contraction will be limited by the opposing walls of the cavities. Once polymerization starts, shrinkage occurs. However, in the pre-gel phase, the loss of volume can be balanced by the plasticity of the resin from the free surfaces to the bonded surfaces. Due to this compensation, there will be no increase in polymerization shrinkage of the dentin-resin interface. When the gel point is being reached, the resin becomes more rigid, and could prevent shrinkage. At that moment, the contraction tension or the force that pulls the resin from the dentin walls increases at the dentin-resin interface (TORRES et al., 2019).

2.2.1 Clinical consequences

Although polymerization shrinkage is the cause, the shrinkage stress resulting from the reduction in material volume can be considered to be the mechanism responsible for a number of problems encountered with the adhesion of restorations to the tooth. This tension can cause traction forces on the cavity preparation walls and promote the appearance of cracks at the tooth-restoration interface that can cause fluid infiltration, marginal pigmentation, postoperative sensitivity, secondary caries, restoration loss and even fracture of the remaining tooth (VINAGRE et al., 2016).

2.2.2 Clinical control of polymerization shrinkage

In order to control the clinical damage generated by the polymerization contraction, it is important to control the photoactivation process and use incremental technique, aiming to reduce the C-factor (SILVA et al., 2017).

Chemically activated resins have less polymerization shrinkage because their pre-gel phase is longer, unlike photopolymerizable resins, which polymerize faster and gelation occurs seconds after the material is exposed to the light source, making it impossible to handle the reaction of polymerization by the professional. Therefore, there is not enough time for its drainage and, the lower this capacity, the greater the retraction stresses, which can be detrimental to the success of adhesion, favoring the formation of cracks (TORRES et al., 2019).

In 2000, Bouschlicher et al. found that the use of a more intense light source led to more rapid development of shrinkage stresses in the early stages of polymerization, when the bond between the hard tissue and the composite resin is still being established. Luo et al. in 2002, reported a linear relationship between the intensity of the light used and the contraction of polymerization that occurred, that is, the greater the light intensity, the greater the contraction found (SILVA et al., 2017).

Using low intensity or soft onset of light curing can improve edge quality without compromising the composite's physical properties. This effect can be attributed to the elongation of the resin's plasticity and the decrease in post-gel phase contraction (PAMPULHA et al., 2015; SILVA et al., 2017).

In recent years, manufacturers have been producing light curing devices with programs that allow the adjustment of light intensity, enabling the use of different gradual photoactivation techniques: steps, ramps and pulses. Increasing the intensity in the steps means reducing the power and making it available for a certain period. The device then increases the power to maximum levels, which are maintained until the end of the cycle. In the ramp technique, there is a gradual increase in light intensity until reaching the maximum level, which is also maintained for a certain period, until a degree of conversion is reached. Finally, the increase of power in pulses, also called late pulse, implies the reduction of light emission for a few seconds (3-5 seconds), followed by a waiting period (3-5 seconds), to then expose the composite resin at maximum light power, completing the conversion reaction. Thus, it can be seen that there are several options to reduce the polymerization reaction rate, however, it is vital to understand that the basic principle is related to the initial reduction in power density followed by an increase to adequate levels, to achieve an acceptable conversion degree of the composite resin (DAMASCENO et al., 2020; SILVA et al., 2017).

An important factor in reducing polymerization stress is the cavity configuration factor or "C-factor". The shrinkage stress in some chemically activated resins is related to the relationship between the adhesion area and the free area. The amount of free area is directly proportional to the flow (or elastic deformation) of the material, relieving, in part, the stresses generated by volumetric contraction. However, there are still doubts about the real importance of this factor in the shrinkage stresses of a light-curing composite resin, as it has a shorter period to alleviate stresses (ALENCAR et al., 2016).

The horizontal insertion technique uses composite resin layers, each less than 2.0 mm thick. This technique has been reported to increase the C-factor and therefore to increase the shrinkage stresses between opposing cavity walls. The oblique technique is performed by placing a series of wedge-shaped composite increments. Each increment is photoactivated twice, first through the cavity walls and then through the occlusal surface, to direct the polymerization vectors towards the adhesive surface. This technique reduces C-factor and avoids distortion of the cavity walls (BACCHI; PFEIFER, 2016; SOARES et al., 2017).

In the vertical stratification technique, small increments are placed in the vertical pattern starting from one wall, that is, buccal or lingual, and taken to another wall. The polymerization starts behind the wall, that is, if the buccal increment is placed on the lingual wall, it will be cured from outside the lingual wall. This reduces the gap in the gingival wall that is formed due to polymerization shrinkage, therefore, postoperative sensitivity and secondary caries (BARATIERI; MONTEIRO JÚNIOR, 2015; SILVA et al., 2017).

The centripetal accumulation technique offers a number of advantages when posterior composite resin restorations are indicated. This technique employs thin metal matrix bands and wooden wedges, eliminating the need for clear matrix bands, which may not provide firm contact areas and anatomical proximal contours and are difficult to use for many professionals. Furthermore, recent studies do not indicate any impairment of metal matrix bands in the formation of cervical gaps (NUNEZ et al., 2015; LACERDA et al., 2019).

III. METHODOLOGY

Integrative review, with a qualitative approach, whose data collection was carried out from May to September 2021, developed in five stages. In the first two stages, the justification, question and objective of the research were outlined. In the third stage, the Scielo, Pubmed and Lilacs databases were defined as research sources.

In the fourth stage, the inclusion criteria were: articles focused on the causes of polymerization shrinkage of composite resins, as well as their risks and how to control, in order to obtain long-lasting restorations, published from January 2015 to December 2020, containing the words "Contraction", "Polymerization" and "Composite Resin", or in the title, abstract or keywords. In the fifth stage, an evaluation and critical reading of the compiled articles was carried out so that they could support the results, exposed through a flowchart (Figure 1) and enriching the discussion, using content analysis for theoretical evaluation.

IV. RESULTS AND DISCUSSION

In the first stage of the study, 787 articles were found, which were initially related to the proposed theme. After reading the titles of selected articles, 75 articles were selected. After reading the abstracts, only 59 studies were selected to be included in the critical and full reading. Finally, 19 studies met the inclusion criteria, as shown in Figure 1.

The development of adhesive restorative materials is the main feature of current Dentistry. Despite all the technology applied in the development of composites, the presence of a polymer matrix as a basic component of this type of material causes shrinkage during polymerization by photoactivation (ALENCAR et al., 2016). The study by Scariot et al. (2017) show that the shrinkage of a composite resin is a natural molecular phenomenon and a consequence of the approximation of the monomer during the formation of the polymer chain. Contraction forces originating within the material are transmitted, in part, to the adhesive interface between the tooth and the restoration, which can result in cusp deflection and gap formation. These gaps allow oral fluids and bacterial penetration which are the main factors producing clinical problems such as marginal percolation, secondary caries, and postoperative sensitivity. In the meantime, Silva et al. (2017) demonstrates that to minimize the tensions of the contraction forces during and after the polymerization process, it is important to know and use technical resources.

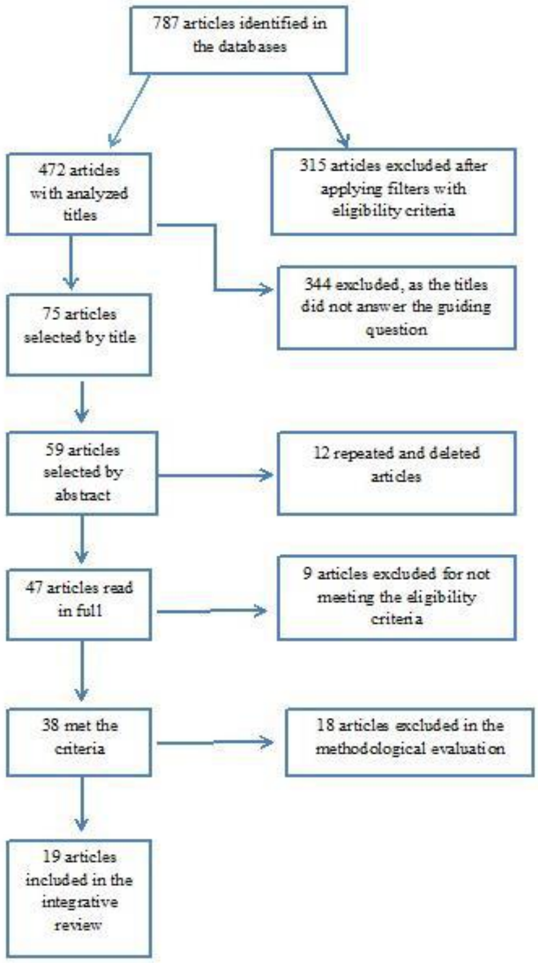

Fig. 1: Selection of articles for review.

An important factor in reducing polymerization stress is the C-factor. Some authors (CARVALHO; PIEROTE, 2020; SOARES et al., 2020) observed that the shrinkage stress in some chemically activated resins is related to the relationship between the adhesion area and the free area (called cavity configuration factor or "Factor Ç"). For these same authors, the amount of free area is directly proportional to the flow (or elastic deformation) of the material, partially relieving the stresses generated by volumetric contraction. However, there are still doubts about the real importance of this factor in the shrinkage stresses of a light-curing composite resin, which has a shorter period to alleviate stresses.

Factor C is related to the flowability of composite resin-based materials, which is an important phenomenon for relieving shrinkage stresses at the tooth/restoration interface. In the studies by Ishikiriama et al. (2017), it was observed that the greater the factor C, the greater the tension at the adhesive interface, regardless of the volume increments in chemically activated resins. To alleviate these stresses, there must be a considerable free area (low Factor C) and a longer pre-gel phase, allowing for better resin flow and stress relief.

In the aforementioned study, a constant volume of composite resin and the delayed pulse technique were used in groups B and D, with 2x2 (Factor C 0.33) and 3x2 (Factor C 0.6) bases, and it was observed that the surfaces free flow allowed the composite resin to flow, relieving some of the polymerization stress with less shrink force. These results are in agreement with other authors (BACCHI; PFEIFER, 2016; SOARES et al., 2017). However, for groups E and F, with higher C Factors (1.5), which means larger areas of adhesive surfaces in relation to free surfaces, the contraction values were greater, regardless of the activation technique used. These results demonstrate the importance of C-Factors and similar observations have been reported, as in the study by Pampulha et al. (2015). It is important to emphasize that composite resin was included in the studies by Ishikiriama et al. (2017) in a single increment, and for cavities with high Factor C, it is recommended to use the incremental technique and modulation by light activation to reduce Factor C.

Another important factor in controlling polymerization shrinkage stresses is light intensity. As highlighted by Lacerda et al. (2019), a low light intensity increases the period in which the resin remains with a low modulus of elasticity (pre-gel phase), allowing molecular accommodation and relieving the contraction stress. Thus, Silva et al. (2017) reinforces that the techniques able to modulate the polymerization process were developed to minimize shrinkage problems. One technique that has been recognized is pulse delay: polymerization starts with a low light intensity for a short period, followed by a light-free interval and then conventional activation allowing for reasonable conversion rates. The light-free interval allows some time for the pre-gel phase to be extended, allowing the material to flow during the initiation of the polymerization reaction and relieving some of the stress generated by the resin's shrinkage. Some authors (PAMPULHA et al. 2015; SCARIOT et al. 2027) emphasize that this technique reduces polymerization shrinkage forces when compared to the single pulse technique, enhancing adhesive forces and not reducing surface hardness.

In the study by Ishikiriama et al. (2017), the combination of the delayed pulse technique and low Factor C resulted in lower contraction forces, probably due to better material flow during the pre-gel phase and a rearrangement of polymer chains. For groups A, B, C and D with reduced C-factor (0.33 and 0.6, respectively), significant differences were found between the two light activation techniques, demonstrating that the polymerization technique is also important to alleviate stresses arising from polymerization shrinkage when sufficient free area is available. Authors who compared the conventional and gradual light activation techniques found similar results that the gradual light activation did not compromise the bond between tooth and restoration (SILVA et al., 2017). However, according to Ishikiriama et al. (2017), for 6x2 bases with superior C-factor (1.5), the activation technique was not significant, demonstrating that the small free area present in this cavity configuration was not able to relief tensions. Therefore, according to the results obtained in this study, the use of the pulse delay technique for composite resin polymerization can result in restorations with less stress at the tooth/adhesive restoration interface. Furthermore, a free surface is necessary to allow the flow of the composite resin and the consequent relief of tension forces arising from polymerization shrinkage. When small amounts of free surfaces are present to relieve these stresses (high C-factor), even the pulse delay technique is not able to decrease the intensity of the contraction forces.

Baratieri and Monteiro Júnior (2015) mention that high shrinkage and/or high shrinkage stress can lead to failure of the bond between the resin composites and the tooth structure. As for Damasceno et al. (2020), the uncured resin content determines the amount of shrinkage and tensile modulus. Therefore, the use of pre-polymerized agglomerates will improve the shrinkage properties as seen in Heliomolar resin, while high polymerization rates and low flow factors have a deteriorating effect on the shrinkage properties.

Aiming to promote stress relief, the reduction of polymerization shrinkage in proximal cavities, guided by adhesive properties and thermal expansion coefficient similar to the tooth, some authors obtained better results with the glass ionomer cement (GIC) used as a base on the cervical wall of these restorations, which characterizes the so-called “sandwich technique” (DAMASCENO et al., 2020; SILVA et al., 2017).

In the study by Veras et al. (2020), the GIC using the same technique showed similar performance in relation to composite resins (GZ250, GSDR and GBFP) as a base material during the evaluations, which corroborates the studies by Haller and Trojanski (2019) and Güngör et al. (2017), who showed no improvement with the use of a base in CIV compared to adhesive systems used with conventional resins.

Consensus in direct comparisons of studies using glass ionomer cements is difficult to obtain, since there is a wide variety of materials available with different formulations and characteristics (VERAS et al., 2020). In addition, for the authors, the use of healthy teeth and younger patients may have reduced the possibility of better sealing of these materials compared to adhesive systems used in association with composite resins due to the lower probability of the presence of dentinal sclerosis induced by stimuli to this substrate, which is more common in senile teeth or teeth affected by caries lesions, where the performance of the material would be optimized.

Thus, it was verified the importance of the present study in the use of new light curing methods to reduce polymerization shrinkage in composite resin restorations; encourages further research to obtain restorative procedures with greater clinical durability. All this aims to ease the contraction of composite resins when light activated, using new resources such as changing their composition or using new photoactivation techniques. Thus, it was demonstrated how photoactivation techniques are able to reduce the contraction stress, which implies a better clinical performance of the restoration. It is always recommended to have a thorough knowledge of the materials and equipment used, for example, due to the great diversity within each type of photo-activator lamp on the market, without neglecting the lamp intensity as well as the exposure time, wavelength required, etc.

V. CONCLUSION

Polymerization shrinkage stress is an undesirable and unavoidable characteristic of restorations found in the dental clinic that can compromise restoration success. Clinicians must understand the concept of polymerization shrinkage stress and realize that the quality of composite resin restorations depends on the successful management of these efforts.

REFERENCES

[1] ALENCAR, A. A. et al. Avaliação da contração de polimerização de duas resinas comerciais: ensaio clínico randomizado. Jornada Odontológica dos Acadêmicos da Católica – JOAC, v. 2, n. 2, 2016.

[2] BACCHI, A.; PFEIFER, C.S. Rheological and mechanical properties and interfacial stress development of composite cements modified with thio-urethane oligomers. Dent Mater. v. 32, n. 8, p. 978-86, 2016.

[3] BARATIERI, L. N.; MONTEIRO JUNIOR, S. Odontologia Restauradora - Fundamentos e Possibilidades. 2 ed. São Paulo: Santos Editora, 2015. v. 1.

[4] CARVALHO, G.; PIEROTE, J. General aspects of bulk fill resins: a literature review. Research, Society and Development. v. 9, n. 7, p. 1- 29, 2020.

[5] DAMASCENO, R. F. et al. Efeito da saturação de cor na profundidade de polimerização de resina composta

nanohíbrida. Revista Eletrônica Acervo Saúde. v. 1, n. 42, p. 1-9, 2020.

[6] ISHIKIRIAMA, S. et al. The influence of "C-factor" and light activation technique on polymerization contraction forces of resin composite. J Appl Oral Sci. v. 20, n. 6, p. 603-6, 2017.

[7] LACERDA, L.R. et al. New generation bulk-fill resin composites: Effects on mechanical strength and fracture reliability. Journal of the Mechanical Behavior of Biomedical Materials, v. 96, n. 1, p. 214-218, 2019.

[8] NOBRE, D. F; GOMES, C. Resina composta tipo bulk fill- um avanço na odontologia restauradora. Cadernos de odontologia do UNIFESO. v. 2, n.1, p.24-33, 2020.

[9] NUNEZ, C.C. et al. State of the art of bulk-fill resin-based composites: a review. Revista Facultad de Odontologia Universidad de Antioquia, v. 27, n. 1, p. 177-196, 2015.

[10] PAMPULHA, I. et al. Inibição da polimerização de resinas compostas por materiais usados como matrizes oclusais. Rev Port. Est. v. 56, n. 1, p. 51-57, 2015.

[11] PRIGOL, J. et al. Avaliação da rugosidade superficial de uma resina composta com uso de diferentes polidores. Journal of Oral Investigations, Passo Fundo, v. 9, n. 1, p. 13-25, 2020.

[12] SCARIOT, R. C. et al. Abordagem dos Cirurgiões Dentistas em Relação a Fotopolimerização de Resinas Compostas. Journal of Oral Investigations, Passo Fundo, v. 6, n. 1, p. 38-49, 2017.

[13] SCHNEIDER, A. C. et al. Influência de três modos de fotopolimerização sobre a microdureza de três resinas compostas. Polímeros. v. 26, n. 3, p. 37-42, 2016.

[14] SILVA, F. J. et al. Técnicas para reduzir os efeitos da contração de polimerização das resinas compostas fotoativadas. SALUSVITA, Bauru, v. 36, n. 1, p. 187-203, 2017.

[15] SILVA, J. D. et al. Forças de contração de polimerização em resinas compostas constituídas com novas matrizes orgânicas e fotoativadas por diferentes técnicas. Rev Odontol Bras Central. v. 26, n. 79, p. 21-25, 2017.

[16] SOARES, A. F.; PINTO, A. C. Taxa de sucesso de restaurações com resina composta bulk-fill: Revisão de literatura. Id on Line Rev. Mult. Psic. v.13, n.47, p. 397-409, 2019.

[17] SOARES, C. J. et al. Polymerization shrinkage stress of composite resins and resin cements – What do we need to know? Braz. Oral Res. v. 31, n. 1, p. 49-63, 2017.

[18] TORRES, L. H. et al. Estudo in vitrodo efeito do tempo de fotopolimerização na pigmentação de resinas compostas. Arch Health Invest. v. 8, n. 8, p. 443-447, 2019.

[19] VINAGRE, A. et al. Cuspal Displacement Induced by Bulk Fill ResinComposite Polymerization: Biomechanical Evaluation UsingFiber Bragg Grating Sensors. International Journal of Biomaterials. v. 16, n. 1, p. 1-8, 2016.