A FOTOPOLIMERIZAÇÃO DE COMPÓSITOS ODONTOLÓGICOS ALÉM DA POTÊNCIA LUMINOSA

PHOTOPOLIMERIZATION OF DENTAL COMPOSITES BEYOND THE LIGHT POWER

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RESUMO:

O objetivo deste estudo foi mostrar que a potência da luz das unidades de fotopolimerização (LED) não é a única ou a propriedade mais importante para uma polimerização satisfatória de compósitos dentários. A distribuição regular e o ângulo de incidência dos raios de luz também são igualmente responsáveis por uma polimerização mais completa e profunda. Esta revisão de literatura mostra que avançamos o suficiente na potência da luz emitida pelos LEDs, mas no que diz respeito à regularidade e ângulo dos raios emitidos, ainda temos muito a avançar. Novos compósitos com cargas reflexivas e preocupações com a diferença de índice de refração entre as cargas e a matriz são importantes para melhorar essa polimerização, mas os LEDs com vários comprimentos de onda podem complicar ainda mais a distribuição regular dos raios de luz emitidos. Dispositivos com diferentes LEDs emitindo raios de luz com diferentes comprimentos de onda não distribuem essas ondas no modo regular. Portanto, parte da restauração pode estar sub polimerizada, tornando-se menos resistente aos esforços mastigatórios e à infiltração. O estudo também relembra propostas de avaliação científica dessa distribuição regular e conclui que os LEDs modernos emitem raios de luz com grande potência e irradiância, mas ainda são irregulares na distribuição dos raios de luz emitidos.

Palavras-chave: fotopolimerização, conprimento de onda, irradiância, resina composta.

PHOTOPOLIMERIZATION OF DENTAL COMPOSITES BEYOND THE LIGHT POWER EMITED BY LED LIGHT CURING UNITS

ABSTRACT:

The objective of this study was to show that light power of light curing units (LCU) is not the only or the most important property for a satisfactory polymerization of dental composites. Regular distribution and angle of incidence of the light rays are also equally responsible for a fuller and deeper polymerization. This literature review shows that we advanced enough in the power of light emitted by LCUs, but as regards the regularity and angle of the emitted rays, we still have much to advance. New composites with reflective fillers and concerns about the difference of refractive index between the fillers and the matrixare important help to improve this polymerization, but LCUs with several wavelengths can further complicate the regular distribution of emitted light rays. Devices with different LEDs emitting light rays with different wavelengths does not distribute these waves in a regular mode. Therefore, part of the restoration can be under polymerized, becoming less resistant to masticatory efforts and infiltration as well. The study also recalls proposals for scientific evaluation of this regular distribution and concludes that modern LCUs emit light rays with great power and irradiance, but are still irregular in the distribution of emitted light rays.

Keywords: photopolymerization, wavelength, Irradiance, composite.

-INTRODUCTION

Nowadays, photopolymerizable dental resin composites has the preference of dentist for direct dental fillings. This preference is due to the facility of inserting the material into dental cavities, total control of the polymerization set and mainly to the high capacity of the resin composite in mimic the dental tissue. This mimetic capacity is even better than the self-curing resin composites (FERRACANE, 2011). For such, several photocuring devices has arisen in markets since 1970, like those by ultraviolet light sources, this one was already removed from the markets due to its potential to cause damages to dentist and his assistance eyes, limited polymerization depth and low lifespan (JANDT K & MILLS R W, 2013). It was substituted by halogen light source that presented less damages to health and more polymerization efficiency than the ultraviolet source (RUGGEBERG, 2011). Since 2000 years the halogen light source has been gradually replaced by LED light source due to its higher lifespan, less energy consumption and heat generation without less polymerization efficiency.

Recently, the Laser and Plasma Arc light source have emerged, which have much more power, greater cost and difficult maintenance. However, the greater luminous power does not result in greater efficiency. Different light source plays different affect in mechanical properties, mainly due to the composition of the composite (VALENTINO et al, 2011; RESEARCHERS AT DALHOUSIE UNIVERSITY, 2016).

The ideal photopolymerizer for resin composite dental fillings is not yet a reality. Despite all technological advances, the various types of light curing devices have their advantages and disadvantages, and there is not yet a type that meets all the desired characteristics. Some basic requirements would be the ability to completely polymerize the resin composite in the shortest time possible, as well as a greater depth of polymerization, being able to polymerize both the surface and the bottom of the cavity without the need of several layers. Such efficiency would result in an aesthetic dental restoration and high resistance to mechanical stresses and chemical aggressions in oral environments (JANDT K & MILLS R W, 2013).

It would also be desirable for this photopolymerizer to have the same luminous power output over the entire area of its active tip, since incomplete polymerization and mechanical properties less of the ideal may be the consequence of an irregular distribution of this power. Once this irregularity is not considered, the failures could be erroneously related to the material.

-LITERATURE REVIEW:

- Polymerization reaction:

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In order to study the polymerization of the resin composites, it is necessary to consider the initiator of the reaction. Nowadays, in dentistry, the composites used are photopolymerizable due to possibility of sculpture before polymerization. The most commonly used photoinitiator is camphorquinone (STAHL et al, 2000; RUGGEBERG, 2011). It reacts with an activating amine present in the composition and initiates the reaction in the presence of an actinic light with about 400 to 500 nm of wavelength (FERRACANE, 2011). Camphorquinone has a maximum absorption at 470 nm wavelength, blue region in the visible light spectrum (NOVERO et al, 2001). Activation by light is initiated by the transfer of energy to the camphorquinone which, in its excited state, interacts with the activating amine by abstracting protons and producing free radicals that initiate an addition reaction with the monomer (NEUMANN et al, 2005). These free radicals are reactive molecules, with unparalleled electrons, that seek bonding with other monomers. When they encounter the monomers, a breakdown of the carbon double bond (C = C) occurs, forming a radical-monomer complex that seeks to make more bonds with other available monomers or other free radicals. If they bind to the monomers, they will also become reactive and the reaction will spread. This process is continuous and the greater the light power of the photopolymerized apparatus, the greater the free radical formation and the more cross-linked the polymer chain (LEPRINCE et al, 2012; HAENEL et al, 2015). However, this reaction is never complete, because not all monomers are converted. The end of the reaction may be a consequence of the direct coupling between two chains with free radicals or the exchange of one hydrogen atom from one growing chain to the other. Therefore, monomers and free radicals would be impossible to follow with the reaction due to the extreme difficulty of mobilization between the formed chains (LEPRINCE et al, 2012).

Other alternative initiators already on the market, Lucerin TPO, Ivocerin, MAPO and BAPO. Their main advantage is that they have a less yellow color than camphorquinone, but the wavelength range is quite different, in the range of 300-400 nm (LEPRINCE et al, 2013; SIM et al, 2012), thus requiring photopolymerizers that emit light with different wavelengths. Since manufacturers generally mix different types of initiators with camphorquinone to make composite with whiter or less yellow colors keeping the demands of today's aesthetics, the dentist feels obliged to know more about the potency and spectra emitted by the photopolymerizer device (HARLOW et al, 2016), as well as on the wavelengths required by the resin composite used.

- Law of Reciprocity:

Several authors (MIYAZAKIL et al, 1996; FRANCO & LOPES, 2000; HALVORSON etal, 2002; EMAMI et al, 2003) defend the direct relationship of a given energy dose (J/cm2) with the maximum polymerization of a resin composite. If a composite needed 16 J/cm2 for its maximum polymerization, an irradiance of 400 mw/cm2 for 40 s (400 x 40 = 16000 mJ/cm2 = 16 J/cm2) or 800 mw/cm2 for 20 s and so on in the case of more powerful photopolymerizers. This reasoning is based on the Law of Reciprocity. This law was introduced by BUNSEN & ROSCOE in 1854 (FINDLAY, 2015) from a research where the dimming of photographic films had a

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linear relation with the exposure dose to light. Within this reasoning, dentists were encouraged to use photopolymerizers with higher irradiance for a shorter time.

However, several other authors have begun to question the applicability of the Reciprocity Law to the photopolymerization reaction of dental composites (MUSANJE et al, 2003, PEUTZFELDT et al, 2005). They reported that the relationship between energy dose (J/cm2) and degree of conversion is not linear, the higher the irradiance used in the polymerization, the shorter it will be necessary to reach the same level of degree of polymerization, but this relation is no proportional. The authors state that a higher irradiance for a shorter time may result in a lower degree of conversion and influence the mechanical properties (HAENEL et al, 2015). This is due to the inexorable relation between the greater luminous power and the greater generation of free radicals, where this greater generation does not guarantee greater conversion. The polymerization reaction of methacrylate is of high complexity, the free radicals would be rapidly isolated by the cross-linking of the formed chains not being able to proceed with the reaction, resulting in a lower degree of conversion (WYDRA et al, 2014).

For a more complete polymerization in a resinous composite, not only the light intensity, the irradiation time and the distance of the photoactivating tip should be considered, but also the thickness of this composite (TSAI et al, 2004; PRICE et al, 2005), where increasing the thickness causes a decrease in hardness and degree of conversion. This phenomenon occurs due to the lower amount of photons reaching the deepest layers of the composite during photopolymerization (EMAMI et al, 2005; SANTOS et al, 2008).

- PHOTOPOLYMERS

There are several types of light-curing devices in the market, which have several light powers that uses Halogen Light, LEDs (Light Emitting Diodes), Argon Laser and Plasma Arc, these last two equipments were developed more recently and therefore are less widely used. Apparatus such as Argon Laser and Plasma Arc have a high irradiance, around 2400 mW/cm2 against 500 to 1400 mw/cm2 of LEDs and halogen light, which causes, in addition to the problems reported above, high contraction and polymerization voltage that can lead to a post-operative pain, detachment of the tooth-restoration interface or fracture of the tooth structure (MICHAUD et al, 2014).

Halogen light curing and LEDs are more commonly used due to their lower cost and ease of maintenance. Halogen lamps use a quartz and tungsten incandescent lamp and have a wide wavelength spectrum, and it is not necessary to incorporate a light filter that allows the passage of light only in the blue range of 400 to 550 nm (RUGGEBERG, 2011) required to activate camphorquinone.

In LEDs, the so-called "Light Emitting Diodes", light is produced by electroluminescence through semiconductors that generate low heat (JANDT K & MILLS, 2013). However, they have a narrower spectrum as compared to Halogen light, being unable to polymerize the resin composites with wavelength range different from camphorquinone. To solve this problem some LED-based photopolymerizers are

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produced with two or more LEDs each emitting different wavelengths (ISSA et al, 2016).

An efficient light curing apparatus should emit not only a light with a wavelength capable of exciting the initiators of the reaction (SHAWKAT et al, 2009; PRICE, 2013), but must also have uniformity in the luminous power along the guide tip of the photopolymerizer used. Thus, the dentist will only place the active tip attached to the restoration, respecting the maximum thickness, irradiance and time recommended by the manufacturer, and will have the composite well polymerized. However, the reality is that they do not have this uniformity and a dental restoration of resinous composite with approximately 4 mm of mesio-distal width polymerized by an active tip with irregular light power can lead to several problems such as very rapid color change (SHIN & RAWLS, 2009), detachment and microleakage through the tooth-restoration interface or low abrasion resistance (SANTIS et al, 2010). This can be attributed to volumetric contraction and irregular elastic modulus during photopolymerization (WEIR et al, 2012; CALHEIROS et al, 2008). Other problems such as excessive bacterial growth and allergic reactions (SANTINI et al, 2012; MANOJLOVIC et al, 2011) should be considered in an insufficient polymerization of dental resin composites, since the leaching of residual monomers to the dental pulp and to oral environment may cause soft tissue irritation and promote allergic reactions (BORGES et al, 2011). Thus, it is extremely important that a composite be well polymerized throughout its volume and not only under the area of greater intensity of the photoactivating tip.

- WAVELENGTH AND AVERAGE IRRADIANCE

The emission spectrum of each LED has differences between them and present a Gaussian distribution in the range of absorption of camphorquinone, which is the most commonly used photopolymerization initiator in dental composites (MAGALHÃES FILHO et al, 2016). For camphorquinone, 25% absorption occurs at the wavelength of 410 nm, peaking at 93% absorption at 465 nm and then dropping to 36% at 489 nm. The energy emission for the three LEDs is close to zero for wavelengths greater or less than the extremes of the region of the evaluated wavelength spectrum, which means that no cure will occur in these regions, even though the initiator molecule absorbs energy. It is important to know both the composite initiators and the spectrum of the light source used. Most of the time, the dentist only cares about the irradiance.

This measurement technique of the light beam by the optical spectrometer measures the power associated with a specific wavelength and the average irradiance, but does not give any information about the distribution of the power emitted from the area of the tip. To do this, it is necessary to scan the entire area of the active tip of the photopolymerizer, measuring point-to-point not only the light power, but also the wavelength spectrum.

Magalhães Filho et al., 2016, measured the luminous power (nW) in function of the xy measuring point on the surface (mm) from each guide tip of three LEDs. In this

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test a marked irregularity was observed in the power distribution of light emitted by the evaluated guide tips. In addition, the LED with the highest average irradiance was also the most irregular LED.

Price et al., 2010, also evaluated the distribution of power through a much more practical process, where the assessment of regularity is made through a special photograph of all the light emitted by the guide. Thus, it is possible qualitative visual evaluation of the light power distribution, as well as the recording of values of this power for quantitative evaluations.

The fact that the LEDs emit light with irregular distribution, pointed out by several studies (PRICE et al, 2010; MAGALHÃES FILHO et al, 2015, HARLOW et al, 2016), reinforce the need af an homogeneity index to facilitate the choice by researchers and dentists when purchasing an LED or halogen light.

- HOMOGENEITY INDEX

A very effective mode of analyzing the light power distribution along the guide tip is through a homogeneity index (VANDEWALLE et al, 2005) proposed an index based on normalized power values, called "TOP HAT FACTOR (THF)". When the THF is equal to 1 (one), outside the area of irradiation of the guide tip there is no light power and within that area, all power values are the same, describing the shape of a top hat. This situation is considered hypothetical. When the THF value is equal to 0.5, it describes a Gaussian form, and this situation is more real. Arikawa et al., 2008, proposed an index based on the ratio between the highest and the lowest luminous power measured on the surface of the guide, where this ratio varies from zero to one, with zero being the most homogeneous situation.

Magalhães Filho et al., 2015, used a homogeneity index called the TOP PLANE FACTOR (TPF), similar to THF, and based on the M2 index, widely used in the characterization of laser beams (JOHNSTON, 1998). The M2 Index is a qualification factor of the laser beam that uses the ratio of the divergence of the beam in the far field to the divergence of a purely Gaussian beam (M2 = 1) with the same radius at the waist.

Even with the publication of these indices, the literature of the regularity of the distribution of light power along the active tips is very incipient, and many articles are only concerned with the average light intensity measured by the radiometers (BENNETT et al, 2004; FLURY et al, 2012; PEREIRA et al, 2016; KUMAR et al, 2018) or measurements of polymerization efficiency made by test of hardness, degree of conversion and depth of polymerization (FLURY et al, 2012; GHAVAMI-LAHIJI et al, 2018).

Exemplifying, from data collected by Magalhães Filho et al., 2015, from the light power measurements of each LED, the TPF was calculated. It is concluded that not

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always the most powerful light source has the best distribution and consequently the composite polymerized by these light sources, will have equally irregular mechanical properties in the same dental restoration or samples in a research. In this research, none of the LEDs obtained an ideal or near ideal TPF (TPF = 1), the best obtained TPF = 0.55. To minimize the effect of heterogeneity, a mask was proposed over the area of the guide tip, where the lowest values would be truncated, scraping those of the edge and using only the values close to the highest light power, about 4 mm in diameter, resulting in an increase of about 15% in TPF.

- INFLUENCE OF REINFORCEMENT FILLERS

According to Degrazia et al., 2016, light attenuation may also vary according to the size and type of fillers used by the composite and the depth of polymerization is limited to between 2 and 3 mm in thickness, regardless of the light output used by the photopolymerizer.

This diffusion of light can be explained by the difference of the Refractive Index (RI) between the charge and the polymer matrix (TAIRA et al, 1994). In other words, the smaller the difference the lower the opacity, so the greater the light transmission in the composite increasing the depth of polymerization (SHORTALL et al, 2008). According to the same author, it is possible to manufacture a composite where the RI difference of charges and matrix is minimal for both unpolymerized and polymerized, resulting in optimum light transmission, minimal color change after polymerization and a high index of conversion.

The light scattering increases when the volumetric fraction of charge also increases and, since the composites with greater volumetric fraction have higher fillers and the variation of the refractive index of the types of fillers was negligible, the size of the fillers is the major responsible for this light scattering (EMAMI e al, 2005). Within this same reasoning, composites with large fillers are more sensitive to the ideal thickness for photopolymerization, and the dentist should be aware that it will require several thin layers to complete a well polymerized dental restoration. However, when the analysis is between nanoparticulate and nanohybrid composites, the volumetric fraction of the charge is more important in determining the mechanical properties than the size (RASTELLI et al, 2012). However, the fact that light radiation penetrates more into nanoparticulate composites and spreads more in large fillers should not be neglected and is certainly an important factor in the development of mechanical properties.

-DISCUSSION

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Nowadays, dental restorations are mostly made with light-curing resin composites. Knowing the details about the power distribution emitted by the guide tip of the photopolymerizer used is a "sine qua non" condition in order that the resinous composite reach what is expected for its mechanical properties and biocompatibility.

The present review showed that the irregularity of the light power along the LS guiding tip is a fact. Furthermore, in agreement with Michaud et al., 2014, and Haenel et al., 2015, this irregularity is an important influence factor in the mechanical properties of the composites. Therefore, the evaluation of the efficiency of any type of LS must go through the analysis of the distribution of light power along the guiding tip of the LS and not only by the measurement of the average irradiance.

The method of analysis of the distribution of light power along the surface of the LED guide point showed the symmetry but with the lack of homogeneity of the LEDs found in the market. The distribution of the luminous power of the LS guiding tips (PRICE et al, 2010; ARIKAWA et al, 2011) found the same lack of homogeneity with symmetry in the Bluephase 16i LEDs (IvoclarVivadent) and Flashlite Magna (Discus Dental), but Price et al., 2010-b, only found irregularity without symmetry when the spectral range was analyzed in LEDs with more than one wavelength, Bluephase G2 (ivoclarVivadent), Valo (Ultradent) and G-Light (GC).

The average irradiance (AI) of the LEDs found in the market may be higher than the average value recommended by the manufacturers of the composites, however, the higher AI of the LEDs does not guarantee efficiency in the polymerization of the composites. We have to consider the distribution and divergence of the emitted light radiation. According to Leprince et al., 2012, the consequence of the greater divergence can be reflected in the low efficiency for photopolymerizing the composite at the recommended thickness of 2 mm, as well as in situations where it is not possible to position the light guide as close to the composite as possible. The latter situation is extremely common in dentists' daily clinics, due to the inclinations and anatomy of the teeth (BENNETT et al, 2004). According to Vanderwalle et al., 2005, light source with minimally divergent rays are more effective in the polymerization of composites.

However, even in suitable "in vivo" or "in vitro" conditions, that is when it is possible to bring the light source closer to the composite, this inefficient photopolymerization can lead to less wear resistance, infiltration, color change in a short period of time and other problems related to the mechanical properties below to the recommended ones (FLURY et al 2012). According to Arikawa et al., 2008, the greater homogeneity in the distribution of light power, guarantees more durable dental restorations, due to the increase of the mechanical resistance of the resinous composites.

Therefore, if the power seems to be the most important factor in the polymerization process, the mechanical properties must be directly related to it, which was not observed by Flury et al., 2012, and Magalhães Filho et al., 2016. This large difference in mechanical properties over a very short distance suggests the formation of internal tensions, probably of contraction, where the detachment followed by microleakage at the tooth-restoration interface could be formed easily, leading to a

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faster failure of dental restoration. In addition, Price et al., 2010, and Arikawa, 2008, reported a great variation in hardness when the heterogeneity of the light power distribution also increases.

Continuing the light emission analysis subject, despite the difference of the measuring methods, they are valid and have advantages and disadvantages. Indirect methods proposed by Arykawa et al., 2008, Price et al., 2010 , Leprince et al., 2010, Flury et al., 2012, such as the instrumented microhardness test and direct methods with the aid of high technology and precision equipment (OSA), are within the reach of the manufacturers, so they should disseminate tables and graphs that inform dentists and researchers about the power distribution of their light curing device.

Knowing that an irregular polymerization can produce a sample with different microstructures and a fault could be erroneously related to the material, researchers should pay special attention to the distribution of light intensity of the photopolymerizers used in their research in order to avoid errors of evaluation of the properties of the material , as well as dentists in their clinics where restoration durability are related not only by the technique used, but also by the quality of the polymerization devices.

Since a light guide with TPF equal to 1 seems to be utopian and it is known that the average mesiodistal size of posterior dental restorations is 5 mm (TANTBIROJN et al, 2004), a light guide where at least the central part is more regular with an TPF as close as possible to 1, is the most ideal situation of homogeneous light exposure resulting in a more homogeneous polymerization. Another solution to the problem of distribution heterogeneity could be the use of a mask that would exclude the smallest light powers, but in this case, the filling could not be polymerized in one single layer or long layer.

-CONCLUSION

- The distribution of the luminous power emitted by the guiding tips of the LEDs is not homogeneous, concentrating its greater power in the center and less in the edges.

- The irregularity of the light power distribution along the guiding area impairs the mechanical properties of the polymerized composites.

- The average irradiance measured as a single value does not reflect the reality of the power distribution and cannot be used by itself to characterize a particular photopolymerizer.

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