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Evaluation of different light-curing lamps

Halogen versus new-diode lamp

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Abstract The aim of this study has been to evaluate light-curing composites polymerization quality carried out by halogen and new-diode lamps through the thermal analysis (TG–DTA). Samples have been polymerized at 3–20–40–60 s by halogen lamp and 1–3–6–9 s by new-diode lamp. The TG/DTA analysis shows that different light-curing times affect the degree of conversion of the composite, since by increasing the curing time the quantity of the monomer that has not reacted (residual) decreases. The new-diode lamp, according to the manufacturer, can cure composite restorations in few seconds; but at the conditions used in this study, the samples cured by the halogen lamp at the standard times of exposure, compared to the samples cured in few seconds by the new-diode lamp, show a lower mass loss.

Keywords Thermal analysis · TG–DTA · Polymerization · Composite

Introduction

The curing efficiency of light-cured resin composites affects the clinical integrity of resin composite restorations. It is important to investigate the factors that control the composite photopolymerization reaction [1].

When the composite resins are irradiated, the radicals generated attack the double bonds of the monomers, creating cross-linked three-dimensional network polymers [2]. These materials are composed basically by two phases: a resinous matrix (organic phase), comprising dimethacrylate monomers and/or oligomers, photoinitiator and an inorganic phase, known as filler, generally composed by particulate glass [3]. The main monomers/oligomers used in the resinous matrix phase are bisphenylglycidyl dimethacrylate (BisGMA), triethylene glycol dimethacrylate (TEGDMA) and urethane dimethacrylate (UDMA). The photoinitiator system is commonly camphorquinone associated with a tertiary amine. Silicate-based glasses, zirconia, alumina, quartz and barium aluminium silicate are used as fillers which normally are surface modified by a coupling agent aiming to improve mechanical properties [4, 5]. Nevertheless, several problems concerning the lack of mechanical resistance mainly associated with restoration in posterior teeth and heterogeneity in the polymerization frequently are mentioned as drawbacks for the use of polymer restoration dental composites as repairing materials. Both problems are related to the curing process responsible for the formation of the crosslinking network that provides mechanical resistance and hardness to the final composite [6, 7].

The knowledge of polymerization mechanisms offers the possibility to check the properties of the material set in cavity. The degree of conversion (DC) of conventional dental composites depends on several factors: power and intensity of the bright source, time and distance of irradiation, dimensions of the particles of the filler, etc. [8–11]. Therefore, a lower DC value is expected to cause a premature failure of the restoration because of increasing wear, precocious staining and marginal microleakage [12–16].

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Besides, in a wet environment, as the oral cavity, the residual unpolymerized monomer pours out from the polymerized material [17–19] and it is well-known that this can cause several problems, such as toxic effects in the pulpal cells [20–24].

Studies have demonstrated that the distance from the top of the highest cusp to the cavity floor can reach 8 mm at deep cavities [25–27], so the light intensity reaching the deepest region can be strongly attenuated. As a consequence, lower degree of conversion is expected from resin cements when the energy is lower than that required for a proper resin cement polymerization, leading to post-operative sensitivity, staining, marginal breaking, poor adhesion between the tooth and the indirect restoration [28], microleakage, secondary caries and changes in some cement mechanical properties. The degree of conversion depends on the energy supplied during light activation, and can be characterized as the product of light intensity and exposure time [29].

Many experimental techniques have been used to study the degree of conversion (DC) or the number of ethylene double carbon which are converted into single bonds [30–32].

It has been demonstrated the validity of the thermal analysis to evaluate the dental materials and light-curing composites conversion degree [33–35]; differential thermal analysis (DTA) and thermogravimetry analysis (TG) are thermal analysis techniques. DTA is used to gather information on transitions, heats and kinetic of reaction, and others. TG has been used to quantify the inorganic part of dental composites and the rate of mass change, respectively [36–39].

The new-diode lamp uses a 15 W diode. This LED has an optical output well above 4,000 mW cm^{-2}, which is 10 times stronger than a traditional halogen curing light. This is why, according to the manufacturer, FlashMax2 can cure composite restorations in few seconds. The aim of this study has been to evaluate light-curing composites polymerization quality carried out by halogen and new-diode lamps through the thermal analysis (TG–DTA).

Materials and methods

The materials used were: Axia Fill N.F. (Dentalica, Italy), Gradia Direct (GC, USA), X Duo Ceram (Dentsply, UK); resins composite composition has been showed in Table 1.

Samples have been prepared with 2 mm thickness and a 4 mm diameter by a stainless steel matrix to obtain an equivalent mass of about 50 mg. The light intensity was 600 mW cm^{-2} (Bisco's VIP, USA) and 4,000 mW cm^{-2} (FlashMax2, CMS Dental ApS, Denmark). Before proceeding with the TG/DTA analysis, a double weighing with a Gibertini electronic (mod. E42 Milano, Italy) and a TG/DTA scale is made, through which the following thermogravimetric analyses have been carried out. 8 samples of each material (number of materials = 3) for each group (number of groups = 8) have been cured (Bisco's VIP 3–20–40–60 s; FlashMax2 1–3–6–9 s).

Moreover, five samples of each material (controls) underwent TG–DTA cycles without light-curing procedures (15 controls total analysis).

Simultaneous thermal analyzer was used to measure the mass change and heat effects (TG–DTA) of dental composites performed by TG/DTA 6300 (Model TG/DTA 6300, Seiko Instruments Inc. Torrance, CA, USA) The samples were heated at a constant rate of 10 °C min^{-1}, from 25 to 600 °C under nitrogen atmosphere (100 mL min^{-1}).

In our figures values are represented up to 500 °C in order to remark peaks, as we did not observed other significant differences between all materials while reaching 600 °C.

In the figures we also used the curves of a single composite because all samples showed a similar behaviour.

Statistical analysis

Fisher's PLSD, Scheffe and Bonferroni/Dunn were used to evaluate the presence of statistically significant differences. We did not insert the standard deviation because curves are often overlapped.

Table 1 The resin composite composition

Materials	Manufactures	Inorganic filler/wt%
Axia Fill N.F.	Dentalica	Barium glass (silan.) 74.2%, pyrog. silica (silan.) 2.8% in a matrix of Bis-GMA, TEDMA and UDDMA Inorganic filler content: 77 wt%
Gradia Direct	GC	Methacrylate monomers 27%, silica 38%, prepolymerized filler 35%, pigments, catalysts Inorganic filler: n.d.
X Duo Ceram	Dentsply	Methacrylate modified polysiloxane, dimethacrylate resin, fluorescence pigment, UV stabilizer, stabilizer, Camphorquinone, ethyl-4(dimethylamino)benzoate, barium–aluminium–borosilicate glass, methacrylate functionalized silicon dioxide nano filler, iron oxide pigments and titanium oxide pigments and aluminium sulfo silicate pigments according to shade Inorganic filler: n.d

Results and discussion

An adequate polymerization is essential to ensure the best performance of light-curing composites, which is directly associated with the clinical success of materials.

It is well-known that during the preparation of the light-curing composite resins, the laboratories work first the inorganic part by making it react with the silane (silanization process) and second, in the clinical phase, through the photopolymerization, the reaction of the organic and inorganic part is fulfilled [3, 19]. The final product of these chemical interactions between silane and filler is affected by the silanization that brings to the creation of reactive molecules on the filler–silane interface; the subsequent photopolymerization of the matrix with the silane–filler reactive molecules gives a more stable final product that improves the composite physical capacities. The TG/DTA analysis allows to highlight the points where the resinous parts (silane and matrix) deabsorb [10, 38, 39].

Figure 1 shows the representatives TG–DTA curves obtained by heating uncured and cured composite resins. Non-cured composite (a) showed a mass loss of 5.7% at 270 °C and 14.9% at 350 °C, whereas cured composite (b) showed a mass loss of 0.4% at 270 °C and 7.4% at 350 °C. At about 270 °C mass loss is most probably caused by the weak bonds (hydrogen bonds or Van der Waals strengths) break-up between monomer and silane, and by the loss of the same molecules that have not reacted. At about 350 °C mass loss is due to the break-up of the strong (covalent) silane–silane, silane–filler and silane–resin bonds [40, 41].

Thermal stability and dental composite resins degradation were monitored by measuring their TG curves. Table 2 gather properties of the composites taken from the TG curves: 5% mass loss temperature (thermal stability) [37], and (Table 3) residues at 600 °C (filler content after burning the polymeric matrix). Mass loss percentage differences were also due to different materials compositions in organic/inorganic components ratio.

These results have to be attributed to the visible light-cure that creates the cross-linked network polymers and due to the interaction between the polymer chains and

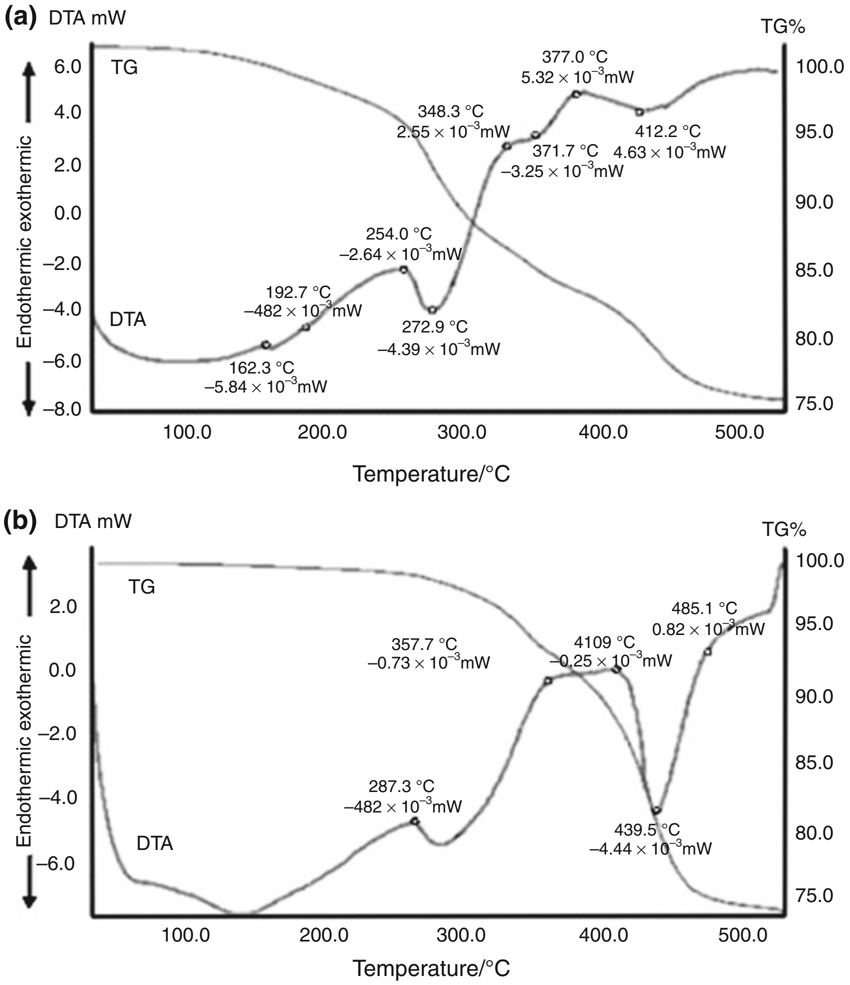

Fig. 1 TG–DTA curves for uncured (**a**) and cured (**b**) composite resins

Table 2 Thermogravimetric (TG) results: temperature of 5% mass loss/±2 °C

Bisco's VIP	Temperature of 5% mass loss/±2 °C			
	Time of irradiation			
	3 s	20 s	40 s	60 s
Axia Fill N.F. Dentalica	354.4	370.5	371.5	373.1
Gradia Direct GC	303.4	314.7	321.5	322.6
X DUO Ceram Dentsply	360.5	381.9	385.8	386.8
FlashMax2	Time of irradiation			
	1 s	3 s	6 s	9 s
Axia Fill N.F. Dentalica	348.9	351.1	352.1	360.8
Gradia Direct GC	301.8	307.9	318.1	323.4
X DUO Ceram Dentsply	371.6	377.7	380.5	384.4

Table 3 Thermogravimetric (TG) results (%): mass loss at 600 °C/%

	Mass loss at 600 °C/%
Axia Fill N.F. Dentalica	17.95 ± 0.57
Gradia Direct GC	49.62 ± 0.57
X DUO Ceram Dentsply	19.45 ± 0.23

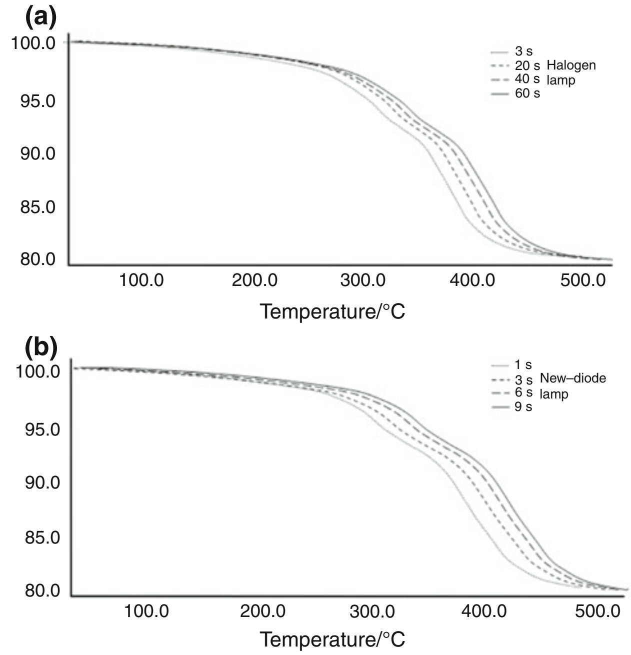

Fig. 2 Comparative TG curves of dental composite cured by halogen lamp (**a**) at 3, 20, 40, 60 s and new-diode lamp (**b**) at 1, 3, 6, 9 s

inorganic particles. Cross-linked network consequently prevents the dental composite resins from thermal decomposition by enhancement their thermal stability.

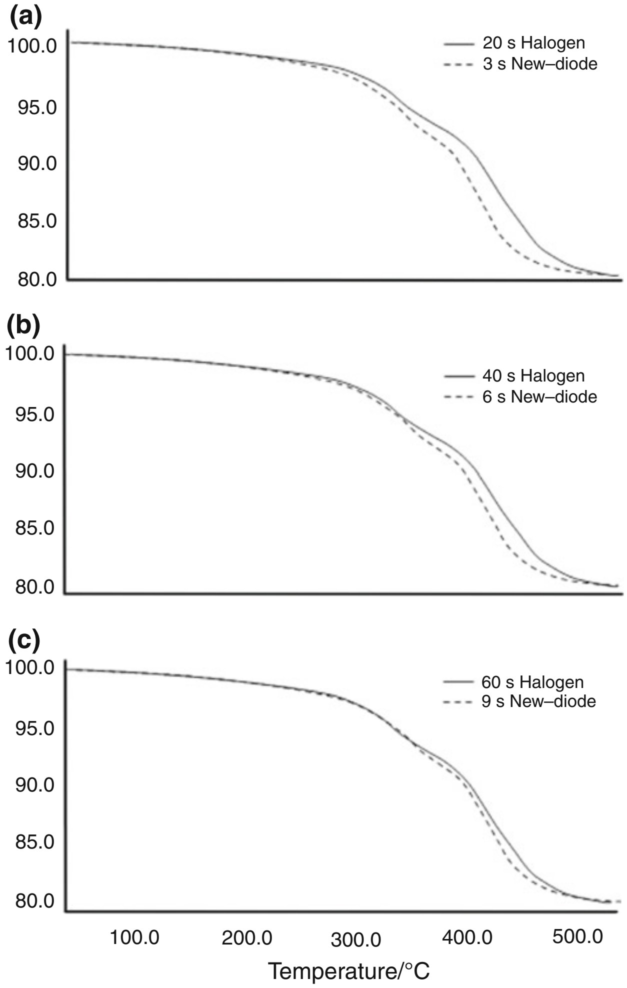

Fig. 3 Comparative TG curves for samples cured in **a** 20 s (halogen lamp) and 3 s (new-diode lamp); **b** 40 s (halogen lamp) and 6 s (new-diode lamp); **c** 60 s (halogen lamp) and 9 s (new-diode lamp)

Figure 2a shows TG curves samples cured, respectively, in 3, 20, 40 and 60 s by halogen lamp; Fig. 2b shows TG curves samples cured, respectively, in 1, 3, 6 and 9 s by new diodes lamp.

Figure 3a shows TG analysis curves expressing composites thermal behaviour, cured, respectively, in 3 s by new-diode lamp and 20 s by halogen lamp; Fig. 3b shows TG curves samples cured, respectively, in 6 s by new-diode lamp and 40 s by halogen lamp; Fig. 3c shows TG curves samples cured, respectively, in 9 s by new-diode lamp and 60 s by halogen lamp.

At the conditions used in this study; it is possible to observe a higher thermal stability of samples cured by halogen lamp at 20, 40 and 60 s, but this does not mean that is clinically better because many factors can interfere with the efficient functioning of halogen units including: fluctuations in the line voltage; the condition of the bulb and filter; contamination of the light guide; damage to the fibre-optic bundle; and heat buildup within the unit [33]. Moreover, it is possible to observe a higher thermal stability of samples cured increasing the curing time. So it is evident the importance of a correct curing time in clinical procedure needs, in order to avoid the release of the monomer; to improve the physical–chemical characteristics of the material and, so to make the restoration more lasting.

It is important to emphasize that in this study a quality comparison between the materials has not been made.

Conclusions

The thermal behaviour of all samples was investigated using simultaneous TG/DTA methods. The TG/DTA analysis shows different thermal behaviour between samples. The new-diode lamp, according to the manufacturer, can cure composite restorations in few seconds; but at the conditions used in this study, the samples cured by the halogen lamp at the standard times of exposure, compared to the samples cured in few seconds by the new-diode lamp, show a lower mass loss.

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