Pulpal Heat Changes With Newly Developed Resin Photopolymerisation Systems

Abstract

Composite resin is a widely-used direct tooth coloured restorative material. Photoactivation of the polymerisation reaction can be achieved by visible blue light from a range of light sources, including halogen lamps, metal halide lamps, plasma arc lamps, and Light Emitting Diode (LED) lights. Concerns have been raised that curing lights may induce a temperature rise that could be detrimental to the vitality of the dental pulp during the act of photoactivation. The present study examined heat changes associated with standardised class V restorations on the buccal surface of extracted premolar teeth, using a curing time of 40 seconds. The independent effects of type of light source, resin shade, and remaining tooth thickness were assessed using a matrix experimental design. When a conventional halogen lamp, a metal halide lamp and two different LED lights were compared, it was found that both LED lamps elicited minimal thermal changes at the level of the dental pulp, whereas the halogen lamp induced greater changes, and the metal halide lamp caused the greatest thermal insult of all the light sources. These thermal changes were influenced by resin shade, with different patterns for LED versus halogen or halide sources. Thermal stress reduced as the remaining thickness of tooth structure between the pulp and the cavity floor increased. From these results, it is concluded that LED lights produce the least thermal insult during photopolymerisation of composite resins.

Introduction

Composite resin is a widely used direct tooth coloured restorative material. The material offers the operator adequate manipulation time until the resin is polymerised using a suitable light source. The most common photoinitiator, camphorquinone, is activated by visible blue light between 450 nm and 500 nm in wavelength (1). The photochemical reaction can be initiated by visible blue light from a range of light sources, including halogen lamps, metal halide lamps, plasma arc lamps, and Light Emitting Diodes (LEDs). The spectral bandwidth and conversion efficiency vary considerably between these various light sources. Superluminous blue LEDs are low voltage devices with a narrow spectral bandwidth, with a peak emission at 470 nm (2). The emitting material is indium gallium nitride (InGaN). In terms of conversion efficiency (i.e. the efficiency of converting electrical energy to visible blue light of the correct wavelength for initiation of curing), superluminous blue LEDs have a higher conversion efficiency than halogen or metal halide lamps (14-17% versus < 1%, respectively). This higher efficiency coupled with the lack of a cooling fan allows “cordless” operation of these units via internal rechargeable batteries. In contrast, halogen and metal halide lamps emit light with a wide spectral bandwidth that extends far into the infrared region. While filters remove some of the unwanted long (infrared) wavelength radiation (3-5), heat remains an important clinical concern. Lights with high intensity outputs may induce a substantial temperature rise in hard and soft oral tissues (6).

A landmark study conducted by Zach and Cohen (7) using Macaca Rhesus monkeys established the threshold values for thermal injury to dental pulp. Whilst an increase in temperature of 2.2°C resulted in no adverse effects, an increase of 5.5°C resulted in pulpal necrosis in 15% of cases. However, if the temperature in the pulp rose by 11°C, the pulp routinely succumbed (7). Zach also demonstrated that increased temperature was an extremely traumatic biological event for the dental pulp (8). Subsequent studies of the effects of temperature increases on dental pulp have used 5.5°C as the threshold value for thermal insult (9, 10). Clinically, it is important to ensure that any temperature increases caused by dental procedures remain below this limit, so that irreversible damage to the dental pulp is avoided.

The aim of this study was to investigate the thermal effects of high intensity light sources at the level of the dental pulp, with an emphasis on the most recent curing technologies, i.e. metal halide lamps and LEDs. The study measured the heat generated from the curing lamp alone, which would be additional to the heat released during the exothermic polymerisation reaction of composite resin. Several determinants of thermal insult were examined, including the shade of composite resin, and the remaining insulating thickness of the tooth structure beneath the cavity floor.
Materials And Methods

Four resin light-polymerisation systems were investigated. A conventional halogen lamp (a Demetron light integrated into a Sirona S1 dental unit) served as a control. Two LED lamps were used—the E-Light (GC Corporation), which has 64 miniature (1 mm square) LEDs in a flat array, and the Elisan Free Light from 3M Espe, which has 19 medium-sized (5 mm diameter) LEDs in a conical array. The metal halide unit used was the Optilux 501 from Kerr Demetron.

Thermal changes were assessed in extracted teeth using an established laboratory model. A total of 20 extracted sound human upper first premolars were sectioned mesio-distally and mounted into plaster blocks. The pulpal contents were then removed by direct vision. Conservative standardized class V cavities were cut into the sound enamel on the buccal surface, 1 mm coronal to the cemento-enamel junction. The cavity was 1.5 mm deep, with a meso-distal width of 2 mm and a height of 1.5 mm. All cavities were prepared using a cylindrical diamond bur. The depth of remaining dentine between the cavity floor and the pulp was measured using a micrometer, and the specimens classified into three groups according to this thickness: 1.5, 2.0 or 2.5 mm.

The cavity preparations were then etched with 37% orthophosphoric acid for 30 seconds, washed for 20 seconds, dried for 10 seconds, and a bonding agent placed (Single Bond from 3M Espe). The bond was light cured for 20 seconds, and the cavities restored using a hybrid composite resin (3M Espe Filtek Z-250) with one of three shades (A3, B1 and C4). To achieve polymerisation of the resin, each restoration was cured for 40 seconds using the control (Sirona S1) curing light. The teeth were then left for 24 hours to ensure that the exothermic setting reaction in the composite resin was complete.

To measure the temperature rise caused by each curing light, a K type miniature thermocouple with a diameter of 0.7 mm and an accuracy of 0.1°C was located within the pulp chamber, against the dentine opposing the side of irradiation. The thermocouple was coupled thermally to the dentine using heat-conductive silicone heat sink compound. The thermocouple was connected to a two-channel digital thermometer unit (Clicd Smith Electronics, Sydney, Australia). A separate thermocouple on the second channel of this unit allowed for simultaneous measurement of the ambient temperature 50 mm from the tooth, away from the direct path of irradiation. Automatic subtraction of the ambient temperature allowed the extent of temperature rise in the tooth to be recorded.

Each restored specimen was irradiated by each light source in turn, with the tip at a distance of 1 mm from the surface of the restoration, for a period of 40 seconds. The temperature was recorded every 5 seconds during irradiation, and then for an additional 20 seconds. Each trial was repeated three, and the mean value used. As group data were normally distributed (as demonstrated by Kolmogorov-Smirnov analysis), parametric statistical methods were used. A two-way repeated-measures analysis of variance (ANOVA) was used to assess differences between light sources. Separate analyses examined the influence of dentine thickness and composite resin shade, using a matrix design. Post-hoc tests for individual differences used the Tukey-Kramer test. A P value of <0.05 was considered significant.

Results

Effect of light source on thermal changes

There was a significant effect of light source on temperature increase (P<0.001). The greatest thermal changes were seen with the Demetron Optilux 501 unit, followed by the Sirona halogen unit, and then the two LED lights, in decreasing order. A typical example is shown in Figure 1. Considering all 40 samples used in the study, the maximum value (in any specimen) recorded with the Demetron Optilux 501 was 11°C at 45 seconds, while the Sirona halogen light gave a maximum rise of 5°C. The Free Light and E-Light elicited maximum temperature increases of only 2 and 3°C at 45 seconds, respectively.

![Figure 1: Effect of type of light source on thermal changes, with shade C4 resin and a dentine thickness of 1.5 mm.](image1)

![Figure 2: Effect of shade on thermal changes with the Kerr Demetron Optilux 501 metal halide lamp, with a dentine thickness of 2.5 mm.](image2)

![Figure 3: Effect of shade on thermal changes with the Sirona S1 halogen lamp, with a dentine thickness of 2.5 mm.](image3)
Effect of resin shade on thermal changes

The accumulation of heat varied according to the shade of resin used (A3, B1 or C4), however, the pattern differed according to the light source used. With both the metal halide lamp (Demetron) and the halogen lamp (Sirona), the C4 shade gave a greater temperature rise than either A3 or B1. In contrast, with both LED lights, shade A3 gave the greatest temperature rise (Figs. 2-5).

Effect of tooth thickness

As expected, the greatest temperature increases occurred when the thickness of dentine beneath the cavity floor was least. The greatest impact of reducing depth was seen for the interval of 2.0 to 1.5 mm (Fig. 6).

Discussion

The results of this study indicate that LED lamps elicited minimal thermal changes at the level of the dental pulp, whereas the metal halide lamp caused the greatest thermal insult of all three types of light sources. In addition, the extent of thermal changes were influenced by resin shade and by the thickness of tooth structure.

With regards to maintaining the health of the pulp, the results of this study support the concept that LED-based curing lights are “safe”. The maximum temperature rises as a result of irradiation with these lights, to the teeth, was minimal and was well below the threshold for pulpal injury. This is consistent with the emission properties for LEDs, which emit radiation with a narrow spectral bandwidth in the visible spectrum, but no significant infrared radiation (heat). In contrast, the metal halide and halogen lamps induced temperature increases which peaked at 11°C and 5°C, respectively. Given that the conditions used in the study (40 seconds curing and dentine thickness of 1.5 mm or greater) approximate those which would be encountered in clinical practice, this study raises concerns that thermal injury to the dental pulp is possible. In vital teeth, the cooling effect of pulpal blood flow would reduce these thermal changes, whilst the exothermic resin polymerisation reaction would increase these changes.

The higher temperature increases for halogen and metal halide lamps are consistent with the nature of operation of these light sources, and their higher native power. Both halogen and metal halide bulbs produce large amounts of infrared energy (i.e. heat) (3), and this is not removed completely by the filters in the curing lights. The visible blue light from these units represents approximately 1/6 or less of the emitted radiation (4). In addition, these lights have a higher power than LED lights, and thus for the same spot size deliver more energy per second to the tooth. The production of infrared energy by halogen and halide lamps necessitates a high power consumption and the use of a fan for cooling (6), neither of which are required with LED lights.

An additional point raised by this study is that temperature increases could also occur in the gingival soft tissues, as well as in the dental pulp, during procedures requiring prolonged irradiation, such as power bleaching. Thermal changes during such extended procedures should be investigated.

There is considerable interest in the properties of composite resin when cured using different light sources. The commonly used photoinitiator, camphorquinone, absorbs light of wavelengths between 450 and 500 nm, but absorbs little energy at lower or higher wavelengths (11). Halogen lamps emit light with a peak wavelength of approximately 700nm, whilst the peak wavelength for LEDs is 470nm (5). This difference explains why the effect of resin shade on heat changes varies according to the type of light source used. In terms of curing depth, both conventional
halogen lamps and LED lights cure composite resin deeper than the
requirement of ISO 4049, with no significant differences in
compressive strengths (4).

In conclusion, this study has shown that LED lights elicit minimal
thermal changes when used for resin curing, and can be regarded
as inherently safe when used for photopolymerisation of com-
posite resins.

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