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Comparison of Temperature Changes in the Pulp Chamber Induced by Various Light Curing Units, *In Vitro*

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Clinical Relevance

The thickness of the residual dentin is a critical factor in the reducing thermal transfer to pulp, and this transfer varies with the curing unit used.

SUMMARY

This study compared the temperature increase in a pulp chamber as a result of using various light-curing units during resin composite polymerization, and it determined the effect of remaining dentin thickness on temperature rise. A Class II occlusodistal cavity with a remaining dentin thickness of 2 mm was prepared in an extracted human mandibular molar. A 2-mm layer of fine hybrid resin composite was placed on the floor of the proximal box. A K-type thermocouple was inserted into pulp chambers filled with heat sink compound, and pulp chamber temperature rise (starting temperature: 37.0 ± 0.1°C) during polymerization of the composite was measured. The light-curing units tested included two halogen lights, Spectrum 800 and Elipar Trilight (Standard and Exponential mode); a light-emitting diode (LED, Elipar Freelight) and a plasma arc (Virtuoso, Xenon Power Arc). Irradiation time was 40 seconds for the halogen and LED lights and 3 seconds for the plasma arc light. Five measurements were carried out for every light-curing unit. The same experimental design was conducted after the cavity preparation was modified, leaving a 1-mm thick dentin layer. The Kruskal-Wallis and multiple comparison tests were used to evaluate the differences among the tested curing units. Mann Whitney-U tests were used to compare the mean temperature rise in each curing unit for different remaining dentin thicknesses.

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The increase in pulp chamber temperature ranged between 1.40-3.8°C. The highest temperature rise was observed when using Elipar Trilight Standard mode, and the lowest temperature rise was observed with light emitting diode for both remaining dentin thicknesses. The only significant differences in temperature rise were observed between Elipar Trilight Standard mode and LED. No significant difference (*p*>0.01) existed for the different modes of Elipar Trilight.

A statistically significant higher temperature rise was observed within each curing unit at a depth of 1 mm compared to 2 mm. Although the tested light-curing units caused a temperature rise in the pulp chamber, none exceed the critical value of 5.5°C.

INTRODUCTION

Light curing units (LCU) for dental applications were developed to initiate photopolymerization of resin composites, adhesives, sealants and resin cements. The degree of polymerization of a resin composite is affected by the irradiation time and light intensity (Rueggeberg, Caughman & Curtis, 1994; Unterbrink & Muessner, 1995). Visible LCUs may have several drawbacks, such as degradation of bulbs, reflectors, filters, cracking of light tips, long curing times and inadequate power output (Nomoto, McCabe & Hirano, 2004), resulting in a reduction in curing effectiveness. Thus, inadequate polymerization can lead to gap formation, marginal leakage, recurrent caries, pulpal inflammation and ultimate failure of the restoration (Pearson & Longman, 1989; Rueggeberg & Caughman, 1993; Yap, 2000).

Several new curing units, including lasers and plasma arc curing units, have been introduced to the dental profession within the past few years. Plasma arc curing units with high intensities and short exposure times are marketed by manufacturers as reducing polymerization shrinkage and saving clinicians' time (Manhart, García-Godoy & Hickel, 2002; Hofmann & others, 2000). Recently, light-emitting diode technology (LED) has become available as an alternative energy source for polymerizing dental restorative materials (Mills, 1995). LEDs are solid-state semi-conductor devices that convert electrical energy directly into light (Duke, 2001).

Modifications of curing methods have also been suggested. Soft-start polymerization, which is characterized by an initial low-power density followed by higher power density, is advocated to minimize internal stresses in the composite and is thought to compensate for shrinkage strain (Mehl, Hickel & Kunzelmann, 1997; Burgess & others, 1999; Manhart & others, 2002).

Light units with high outputs are characterized by an increase in temperature during light curing (Lloyd, Joshi & McGlynn, 1986; Hansen & Asmussen, 1993). Since pulp is vulnerable to a rise in temperature as a result of its low-compliance nature, there is the potential for light curing units to cause pulpal damage (Masutani & others, 1988; Goodis & others, 1990; Hussey, Biagioni & Lamey, 1995). Several studies have looked at the physical properties of resin composites polymerized with different LCUs versus a conventional visible light (Asmussen & Peutzfeldt, 2003; Park, Krejci & Lutz, 2002; Deb & Sehmi, 2003). Few, however, have compared the temperature increase for different LCU and curing modes (Goodis & others, 1989; Shortall & Harrington, 1998; Hannig & Bott, 1999; Hofmann, Hugo & Klaiber; 2002). Using a different light technique may reduce the amount of heat generated. The thickness of dentin between the floor of a cavity preparation and the pulp chamber may also influence intrapulpal temperature rise. Therefore, this study compared temperature increases in the pulp chamber by various light-curing units during resin composite polymerization and determined the effects of the remaining dentin thickness on temperature rise.

METHODS AND MATERIALS

A freshly extracted, non-carious mandibular molar stored in a phosphate-buffered saline solution containing 0.2% sodium azide was used for the study. A Class II occlusodistal cavity having a remaining dentin thickness of 2 mm between the pulp chamber and proximal cavity wall was prepared. The mesial root was cut about 2 mm apically to the cementoenamel junction and the apical orifice of the root canal was enlarged. The remaining pulp tissue was removed from the canal and the pulp chamber was filled with heat sink compound (American Oil and Supply Co, Newark, NJ, USA). A thin K-type thermocouple (Pyrometer, The Pyrometer Instrument Company, Northvale, NJ, USA) was inserted into the pulp chamber through the cut area until contact was made with the opposite wall of the pulp chamber. The position of the thermocouple and remaining dentin thickness was checked radiographically from two directions. The root surfaces and lower portion of the crown of the tooth were submerged in a water bath (37° ± 0.1°C) during the testing procedure. This method was preferred, as it minimized the effects of ambient temperature changes and provided a consistent initial body temperature for each data set. All experiments were performed with the same sample tooth.

A 2-mm layer of fine hybrid resin composite (Herculite XRV A2, Kerr Corporation, Orange, CA, USA) was placed on the floor of the proximal box. This was done without acid etching or dentin bonding in order to enable easy removal of the composite after polymerization and, thus, to keep the cavity size constant during repeated removal of the polymerized composite as suggested by Hannig and Bott (1999). The resin was cured with one of the curing units according to the manufacturer's recommended curing times. For each curing period, the temperature increase was measured for 60 seconds. The light guide tip of every curing unit was positioned at the same point of the occlusal surface. The light curing units tested included two halogen lights, Spectrum 800 (Dentsply, Milford DE, USA) and Elipar Trilight (Standard and Exponential mode, 3M ESPE, St Paul, MN, USA); a LED light (Elipar Freelight, 3M ESPE) and a plasma arc (Virtuoso, Xenon Power Arc, Den-Mat Corporation, Santa Maria, CA, USA). Details of the light curing units and curing modes are shown in Table 1. Before beginning the experiments, the light intensity of the curing units (and the different curing modes) were assessed with a radiometer (Demetron, Danbury, CT, USA). The entire procedure was repeated, in turn, with new resin composite placement for each of the different light curing units. Each light curing unit was tested five times. To minimize the effects of heating, the next measurement was started after the tooth had cooled down to the starting temperature of 37°C.

Table 1: *Details of Light Curing Units Used in This Study*

LCU	Manufacturer	Curing Modes	Curing Profile
Spectrum 800 (Halogen)	Dentsply, Milford, DE, USA	Standard	550 mW/cm^2 (40 seconds)
Elipar Trilight (Halogen)	3M ESPE, St Paul, MN, USA	Standard (TL1)	800 mW/cm^2 (40 seconds)
		Exponential (TL2)	100-800mW/cm^2 (15 seconds) → 800mW/cm^2 (25 seconds)
Elipar Freelight (LED)	3M ESPE, St Paul, MN, USA	Standard	400 mW/cm^2 (40 seconds)
Virtuoso (PAC)	Den-Mat, Co Santa Maria, CA, USA	Standard	1980 mW/cm^2 (3 seconds)

Table 2: *Mean Maximum Temperature Rise Observed in Pulp Chamber with Different Light Curing Units and Remaining Dentin Thicknesses (RDT)*

	Mean Temperature Rise (°C)	
Light-Curing Units	**RDT (1 mm)**	**RDT (2 mm)**
Spectrum 800	2.94 (0.31)	2.34 (0.11)
Elipar Trilight Standard	3.8 (0.12)	2.98 (0.45)
Elipar Trilight Eponential	3.0 (0.70)	2.32 (0.13)
Elipar Freelight	2.14 (0.18)	1.4 (0.12)
Virtuoso	2.42 (0.27)	1.56 (0.15)

The cavity preparation was modified in order to evaluate the effect of the remaining dentin thickness on heat transfer to the pulp. After radiographically verifying the thickness of the remaining dentin as 1 mm, the same experimental design was conducted.

The Kruskal-Wallis and multiple comparison tests were used to evaluate the differences among the tested curing units. The Mann Whitney-U test was used to compare the mean temperature rise in each curing unit for different remaining dentin thicknesses.

RESULTS

Table 2 shows the mean maximum temperature rise observed in the pulp chamber with the different light curing units and modes. Significant differences were observed among the tested curing lights for both remaining thicknesses ($p<0.05$). The multiple comparison test demonstrated statistically significant differences between the mean temperature rise for Elipar Trilight Standard mode and LED ($p<0.05$). No significant difference ($p>0.01$) existed for the different modes of Elipar Trilight.

Comparing the temperature rise between 1 mm and 2 mm of the remaining dentin thickness within each curing unit and mode, there was a statistically significant increase of 1 mm thickness ($p<0.0.1$).

DISCUSSION

Heat has been identified as a primary cause of pulpal injury (Roberson, Heymann & Swift, 2000). Dentin has a low thermal conductivity but, in deeper preparations, the potential for pulp damage is greater, as the tubular surface area is increased (Brown, Dewey & Jacobs, 1970). Hussey and others (1995) have reported that the pulp might be endangered by the temperature rise, which occurs during resin composite polymerization *in vivo*. Zach and Cohen (1965) showed that 15% of the teeth undergoing an intrapulpal temperature rise of 5.5°C were irreversibly damaged.

In this study, all light-curing units tested caused a measurable temperature increase within the pulp chambers. However, the average temperature increases that were found with all light-curing units were lower than the critical temperature rise reported by Zach and Cohen (1965), which is thought to cause irreversible changes in the dental pulp. The only mean temperature value (3.80) close to critical values was for the Elipar Trilight Standard mode. This might have occurred because of the *in vitro* test conditions. There was no pulp tissue with an intact blood circulation within the pulp chamber that might help to draw off heat generated from the light curing unit (Chang & Wilder-Smith, 1998).

Statistically significant differences in temperature rise were found only between Elipar Trilight Standard and LED light-curing units, respectively, although there was a tendency toward higher temperature values for the halogen units. The greatest temperature rise observed with the Trilight standard unit can be explained by the greater irradiance produced by this unit. On the other hand, interestingly, with the use of the PAC light, which had the highest output intensity, the temperature did not increase. Knezevic and others (2001) also reported that temperature rise was significantly lower in the case of polymerization of resin composites with the plasma light compared to those with the Elipar Trilight halogen curing unit. Danesh and others (2004) observed no significant differences in temperature rise during composite polymerization when using conventional halogen and plasma arc light-curing units.

These results contradict the results of a study by Hannig and Bott (1999) that showed higher pulpal temperature rises obtained with the plasma curing unit compared to the halogen light. A possible explanation for this difference can be found in the duration of the curing time. In that study, irradiation times of 5 and 10 seconds were chosen for PAC units as recommended by their manufacturer. However, in this study, irradiation time was 3 seconds.

Ozturk and others (2004) also found that the Power PAC unit produced temperature rises greater than conventional halogen (Hilux) and LED (Elipar Freelight) units. However, they measured temperature rise beneath a 1-mm dentin disk and not in the pulp chamber. Moreover, their irradiation time for PAC light was 5, 7 and 10 seconds. According to a study by Loney and Price (2001), the plasma arc curing light used for three seconds produced lower mean temperature changes compared to the quartz tungsten halogen unit.

Some researchers have indicated the possibility of improper cure when composites were light cured with PAC (Peutzfeldt, Sahafi & Asmussen, 2000; Hofmann & others, 2002). In this study, as recommended by the manufacturer of the PAC light, a three-second exposure time for the universal hybrid composite was used. However, to adequately cure resins, longer exposure times may need to be used with PAC units. If used in this way, PAC lights may produce more heat. Prolonged curing times are known to be associated with increased pulpal temperatures (Lloyd & others, 1986; Goodis & others, 1989, 1990; Knezevic & others, 2001).

Because LED units had a lower irradiance than halogen units, it is not surprising that LED units caused the least temperature rise on pulp for both remaining dentin thickness. These results concur with those of Yap and Soh (2003), who compared the thermal emission of different light curing units and found that LED units produce less heat than halogen lights. These findings are in agreement with those of Rueggeberg and others (1994), Hofmann and others (2002) and Ozturk and others (2004).

The thickness of residual dentin with its low thermal conductivity is a critical factor in reducing the thermal transfer to pulp (Tjan & Dunn, 1988). This study supports previous studies that showed there was a better correlation between temperature rise and the remaining dentin thickness (Tjan & Dunn, 1988; Price, Murphy & Derand, 2000; Cobb, Dederich & Gardner, 2000; Loney & Price, 2001). As thickness of remaining dentin decreases, the pulpal insult and response from heat increases (Roberson & others, 2000). For all samples, temperature elevation through 2 mm of dentin was less than for 1 mm of remaining dentin thickness, and all differences were significant.

In this study, the same tooth was used for the entire experiment in order to eliminate any possible structural variables of teeth that might cause differences in thermal conductivity. Two-mm thick A2 shade composite specimens were used to ensure uniform and maximum polymerization (Yap, 2000). This shade was selected to minimize the effects of colorants on light polymerization (Bayne, Heymann & Swift, 1994).

CONCLUSIONS

LED units may reduce the risk of pulp injury, because of the lesser temperature rise compared to halogen units. Although the results of this study suggest that plasma arc and LED curing units cause less temperature increase in the pulp chamber, it is also important to assess the physical and mechanical properties of cured resin composites. Therefore, further studies are necessary to examine the clinical performance of restorations cured by high intensity curing lights.

As the remaining dentin increased, the temperature rise within the pulp chamber decreased. A more conservative cavity preparation, allowing thicker dentin overlying the pulp chamber, would help to prevent increased thermal temperatures in pulp during curing.

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