TEMPERATURE CHANGE AND DEGREE OF CONVERSION DURING ARGON LASER INDUCED POLYMERIZATION OF DENTAL RESIN

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Abstract: In the present study the effect of different wavelengths, power densities of argon laser and irradiation times on the degree of conversion and temperature rise of a dental resin based on Bis-GMA monomers was studied .The resin was prepared by mixing of Bis-GMA and TEGDMA with a mass ratio of 75/25. Camphorquinone (CQ) and DMAEMA were added to the monomers as photoinitiator system. The resin was cured by applying the laser beams at wavelengths of 488 and 514 nm and power densities of 1075 mW/cm^2 and 700 mW/cm^2 in different irradiation times. The temperature of specimens at 2mm thickness was recorded with a K type thermocouple. After 8 minutes the specimen was re-irradiated to measure the temperature rise due to irradiation. The degree of conversion (DC %) of the resins was measured using FTIR spectroscopy. The results showed that the specimens cured with 488 nm at 1075 mW/cm^2 exhibited higher temperature rise due to reaction (13.5°C) with a total temperature rise of 24.9°C. The specimens cured with 514 nm at 700 mW/cm^2 showed lower temperature rise due to reaction (3.8°C) with a total temperature of 21.3°C. The maximum degree of conversion was reached in 20 sec, and decreased by decreasing the power density.

Introduction

The primary monomer resin of dental composites was the Bis-GMA developed by Bowen in 1962[1]. However, there are some limitation with the curing of the composite resin ,such as limited polymerization depth (which varies with the penetration of the light beam in the bulk material) and low degree of conversion. Some of these limitation may lead to an incomplete polymerization of the restorations, affecting their physical and biological properties [2].The most important dental resin characteristics are the degree of conversion (DC) and the depth of polymerization. These are of great importance for the clinical longevity of the restorations. The DC is the measurement of the percentage of consumed double bonds .Conversion of the monomer to the polymer in light-activated composites is dependant on several factors, such as the light source, the power density ,the light wavelength ,the resin composition ,the transmission of light through the material and the amount of activator-initiator and inhibitor present[3].

Low DC of dental resin may give inadequate wear resistance and a low bonding stability to tooth surfaces. This clinical problem can result in marginal shrinkage, subsequent loss of anatomic form and fractures in the restorations.

Several methods have been used to investigate the effectiveness of irradiation source on the polymerization of dental resin, such as micro hardness, optimal microscopy and vibration methods including infrared spectroscopy (FTIR) and Raman spectroscopy (RS)[4].

Vibration methods allow precise assessment of the depth of polymerization and DC (i.e., the percentage of vinyl group converted to aliphatic functions)of methacrylate composite resins. This evaluation is carried out by comparing the vibration bands of the residual unpolymerized methacrylate C=C stretching mode at 1638 cm^{-1} to the aromatic C=C stretching mode at 1608 cm^{-1} ,which is used as an internal standard ,since it doesn't change during the polymerization reaction[2].

Decreasing in curing time for dental composites and adhesives is an important aspect of clinical success[5]. Recently, the argon laser has been marked as an alternative to conventional light-curing units for quick, safe, and effective polymerization of dental resins[6]. Laser light has a single, narrow band of wavelength that emits in parallel waves that are in phase spatially and temporally.

The power density, the exposure time and the temperature of the exposed tooth are closely interconnected. The larger the intensity, the larger the heat production and, consequently, higher the

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temperature of the exposed surface. According to Zach et all [7],the temperature of the tooth can induce irreversible pulpal lesion ,when higher than 42.5°C.

This study will focus on the effect of an argon laser on the degree of conversion and temperature rise during photopolymerization of dental resin monomers.

Materials and methods

A mixture of 75% (wt%) Bis-GMA and 25%(wt%) triethylene glycol dimethacrylate (TEGDMA) (Rohm, Degussa Group, Germany) was used as a resin. This composition is similar to that used in most of commercial dental resin formulations. Camphorquinone (CQ, 0.5%wt, Fluka) and N , N'-dimethyl aminoethyl methacrylate (DMAEMA, 0.5%wt, Fluka) were used as photoinitiator system .

To measure the degree of conversion , the uncured paste of resin was placed between two polyethylene films, pressed to form a very thin film and absorbance peaks obtained by transmission mode of FTIR (Brucker, EQUINOX 55, Germany) . The samples were cured by applying the laser beams at wavelengths of 488 and 514 nm and power density of 1075 mW/cm^2 and 700 mW/cm^2 for different irradiation times and the absorbance peaks were recorded for the cured samples. The percentage of unreacted carbon-carbon double bonds was determined from the ratio of absorbance intensities of aliphatic C=C (peak at 1638 cm^{-1})/aromatic C….C (peak at 1609 cm^{-1}) before and after curing of the specimen. The degree of conversion can then be obtained as follows

DC%=100-percentage of unreacted double bond (1)

To measure the temperature rise, five specimens were prepared in 6mm diameter and 2mm thickness between two glass slides and then cured with power densities and wavelengths mentioned above. For all the samples the irradiation time was 40 sec. The temperature rise was recorded with a K type thermocouple. After 8 minutes the specimens were irradiated again to measure the temperature rise due to reaction.

Results

Fig.1 shows the effect of wavelengths on DC% of the resin at power density of 700mW/cm^2. For the specimens cured at 488nm curve reached a plateau in less than 20 sec but for specimens cured at 514 nm the degree conversion of resin reached to the maximum value after 40 sec. It can also be seen that the maximum DC% of the specimens cured at 514 nm is much less than those cured at 488 nm.

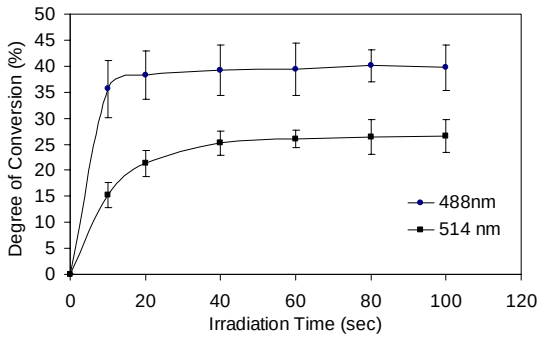

Figure 1: The effect of wavelength on DC% of resin cured at power density of 700 mW/cm^2

Fig.2 shows the effect of power density on DC% of resin at wavelength of 488 nm. For the specimens cured with power density of 1075 mW/cm^2 the degree of conversion is significantly higher than those cured with power density of 700 mW/cm^2.

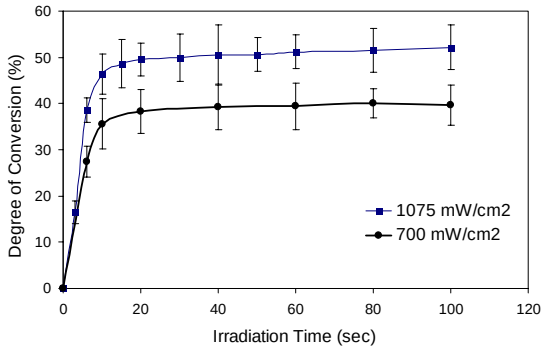

Figure 2: The effect of power density on DC% of resin at the wavelength of 488nm

Table 1 shows the temperature rise due to reaction and total temperature rise of dental resin cured by different power densities and wavelengths.

Table 1: Temperature rise due to reaction and total temperature rise of cured specimens.

PD (mW/cm^2)	Wavelength (nm)	ΔT(reaction (°C)	ΔT(total) (°C)
1075	488	13.5	24.9
700	488	9.8	16.8
700	514	3.5	21.2

Fig.3. is a typical curve of the temperature rise during photo polymerization of dental resin at the wavelength of 488nm with power density of 1075 mW/cm^2. The curve of reaction in this figure can be used to study the curing behaviour (kinetic) of dimethacrilates in a simple way.

Fig.4. is a typical curve of the temperature rise during photo polymerization of dental resin at the wavelength of 514 nm with power density of 700 mW/cm^2.

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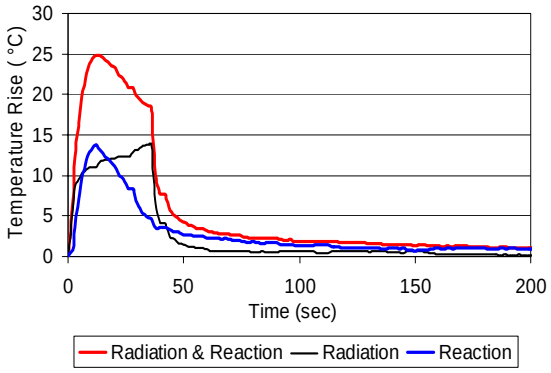

Figure 3: The temperature rise due to reaction and radiation of dental resin cured at 488nm with 1075 mW/cm^2

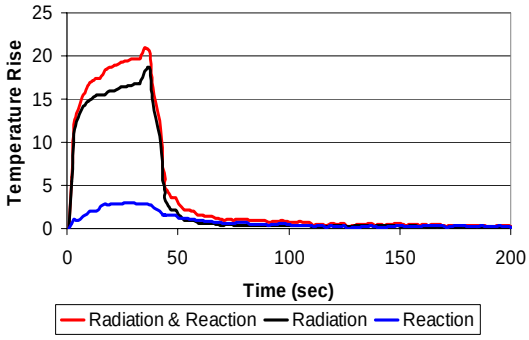

Figure 4: The temperature rise due to reaction and radiation of dental resin cured at 514 nm with 700 mW/cm^2

Discussion

As the results showed, the maximum temperature produced during the curing process was higher for the specimens cured at 488 nm with 1075 mW/cm^2 than specimens cured with 514 nm at 700 mW/cm^2(Table1). As the polymerization is an exothermic reaction, the temperature rise is related to the number of carbon double bonds that react and therefore it is related to DC% of dental resin. The DC% of specimens cured by 488 nm is higher than those cured by wavelength of 514 nm of argon laser.

For argon laser curing the highest degree of conversion was obtained using 488nm emission line. As showed in Fig.5 the 488nm line is closet to the camphorquinone absorption peak. The absorption peak of camphorquinone is about 470nm. The wavelength of the 514 nm line appears at the tail-end of the camphorquinone absorption peak and therefore results in the lowest degree of conversion in camphorquinone-based dental resin. After 20 sec the specimens reached the highest DC% and further increase in the irradiation time did not affect the DC% of the resin. The DC% in the group cured by 514 nm reached a value above 25% after 80 sec which is not a suitable value for dental resin.

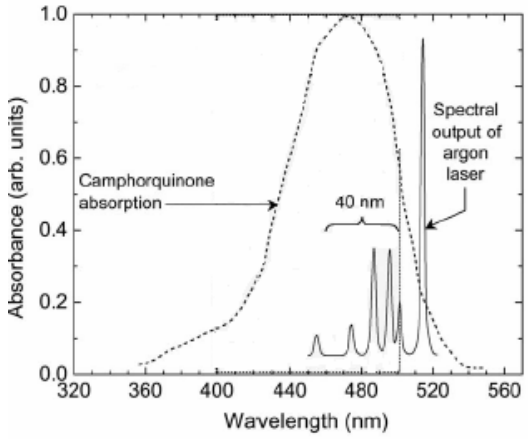

Figure5: Absorption spectrum of camphorquinone [8]

As it can be seen in Fig.2, the higher power density resulted in higher DC% which can be related to the more decomposition of photoinitiator providing more active radicals to initiate and progress the polymerization.

Reaction curves in Fig.3. and Fig.4. also show a typical shape of kinetic curves for the polymerization of methacrylate monomer. The polymerization of methacrylate monomers is a complex process that forms a co-polymeric network [9]. Rising and falling parts of the temperature rise due the reaction curve could be representative of auto-acceleration and –deceleration stages of polymeraization of dimethacrylate monomers. It has been found that the polymerization of multimethacrylates is diffusion-controlled. In the auto-acceleration stage segmental movement of radicals are restricted and termination becomes diffusion-controlled leading to an increase the propagation rate Continuing the reaction , the system becomes more viscous and restricted so that the propagation reaction also become diffusion – controlled leading to the drop off of the polymerization rate. This decline in the rate is called auto-deceleration effect [11].

Conclusion

The effect of argon laser wavelength and power density on DC% and temperature rise during photo polymerization of a dental resin was studied. The results revealed that the maximum DC% in the resin was reached in less than 20 sec for the power density of 1075 mW/cm^2 and wavelength of 488nm which is much less than the required time for the wavelength of 514 nm. The better matching between absorption peak of CQ and emission peak of laser beam resulted in higher DC%. The temperature rise during photo polymerization of the resin was higher for the wavelength of 488nm and power density of 1075 mW/cm^2 which can be related to the higher degree of conversion and more energy of photons

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emitted of higher laser power density. Using argon laser with the wave length of 488 nm and power density of 1075 mW/cm^2 can resulted in reduced curing time.

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