Influence of polymerization device tube width on the degree of conversion of composites: A pilot study

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Abstract

Objectives: The output light intensity of the curing unit used for hardening of composite materials is one of the main factors influencing the quality of composite resin filling. The purpose of this investigation was to determine whether there is a difference in the degree of conversion between polymerization of composite materials with curing units of different tube width. **Methods and Materials:** For the polymerization of four composite materials (Tetric Ceram shade A3, Tetric EvoCeram shade A3.5, Tetric EvoCeram shade A2 and Artemis Enamel shade A2 (all Ivoclar Vivadent, Schaan, Liechtenstein) the LED curing unit, Bluephase (Soft Start mode) (Ivoclar Vivadent, Schaan, Liechtenstein), was used with two tubes of different diameter: 6mm and 13mm. The degree of conversion was determined with Fourier Transform Infrared Spectroscopy (FTIR) immediately after finishing polymerization of the composite sample. **Results:** Results showed no statistically significant difference in the polymerization of composite materials regarding the tube width of the polymerization device ($p=0.531$), regardless of the type of composite material. The average degree of conversion of composite material achieved with the narrow tube was 68.04% and with the wide tube, 69.18%. **Conclusion:** The size of the curing unit tube is more important for clinical adjustability and facilitating work in certain clinical situations, and not for achieving a significantly higher degree of conversion of the composite material. **Clinical Significance:** Proper curing of composite resin is crucial to achieve a long-lasting composite resin restoration. Since light intensity decreases with distance, the diameter of the polymerization device tube is an important factor for adequate curing of composite at the base of a cavity.

Key words: composite material, curing unit, degree of conversion

Introduction

Sufficient polymerization of composite material is of immeasurable importance for physico-mechanical and esthetic characteristics of composite material as well as an entire composite filling. Contemporary technological advancement has introduced new composite materials and new light sources.

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A halogen curing unit is the polymerization device most often used for the setting of composite materials. These curing units produce primarily white light and, with the use of installed filters, transform it into a blue light with a wavelength of 400 to 500 nm. According to the literature, the degree of conversion of composite materials polymerized with halogen devices varies from 43 to 75%.[1,2,3] Halogen units create light by heating tungsten filaments to a high temperature. During the process, a very small percentage (<1%) of usable energy is necessary for polymerization while the rest is reproduced in the form of thermal energy.[4] An adverse consequence of the aforementioned thermal energy is not only the gradual destruction of components of the curing unit, but also a rise in the temperature of the material or filling during setting. All of the above, with improper handling, can very easily compromise the vitality of the pulp tissue. Since these

Table 1
Degree of conversion of composite materials polymerized with Bluephase LED curing unit of different tube width.

Degree of conversion (%)							
Composite material		**N**	**Mean**	**Std. Deviation**	**Std. Error**	**Minimum**	**Maximum**
TCA3	Narrow tube	8	65.05	1.46	.5188	62.1	66.3
	Wide tube	8	71.65	2.17	.7687	67.8	75.0
TECA3.5	Narrow tube	8	61.85	1.60	.5680	59.8	64.3
	Wide tube	8	65.92	.63	.2251	65.2	67.0
TECA1	Narrow tube	8	64.05	1.46	.5181	62.1	66.0
	Wide tube	8	61.44	.50	.1788	60.9	62.0
AA2E	Narrow tube	8	81.18	2.17	.7701	78.1	85.4
	Wide tube	8	77.68	2.52	.8927	74.9	81.7

units produce a very small percentage of usable energy, the last few years has seen the advancement of diode (LED – light emitting diodes) curing units over halogen in everyday clinical use. LED curing units emit blue light with an approximate wavelength of 470 nm (± 20 nm). Experimental LED devices did not exhibit a sufficient degree of conversion (≈ 50 %) although it was not negligible, taking into account power of devices at that time.[5] Contemporary LED units achieve a degree of conversion equal to or even higher than traditional halogen curing units.[6,7]

The degree of conversion measurement is a basic method for determining the quality and acceptability of the clinical use of both composite material and a light source. It is dependant on several factors: composite material composition (type of organic matrix, inorganic filler, size and pattern of filler particles), color of the composite material, layer thickness, intensity of the light source, width of outgoing beam of the curing unit, time of illumination and the distance of the light source from the surface of the composite material or filling.[8,9] Contemporary polymerization devices, diode as well as halogen, possess the ability to replace the tube and apply various tube widths for different clinical scenarios. The purpose of this investigation was to determine the influence of the curing unit tube width and the width of the outgoing beam of light in the same intensity curing unit on the degree of conversion of the composite material.

Materials and Methods

In this study, Tetric Ceram (shade A3 – exp. 2008-03, lot. G06853) (TCA3), Tetric EvoCeram (A3.5 - exp. 2009-09, lot. H28536) (TECA3.5), Tetric EvoCeram (shade A1 – exp. 2009-09, lot. H28235) (TECA1) and Artemis (shade A2-Enamel; exp. 2009-05, lot. H19896) (AA2E) composite materials were used (all Ivoclar vivadent, Schaan, Liechtenstein). The Bluephase LED curing unit (Soft Start mode) (Ivoclar vivadent, Schaan, Liechtenstein) was used as a light source for the setting of composite materials (650 mW/cm^2 for first 5 seconds, then 1100 mW/cm^2 for the next 15 seconds). The intensity of the lamp was measured with a light intensity gauge situated at the base of the device. All composite samples were polymerized for 20 seconds according to manufacturer's instructions for the mentioned LED device and material. Two tubes of different diameters – narrow ø6mm and wide ø13mm - were used to measure the degree of conversion

A total of 64 samples were prepared - 16 for each material - out of which 8 were polymerized with a narrow tube of the Bluephase device and the remaining 8 with a wide tube. TCA3 composite material was chosen as a control group since it has been available on the market for some time and A3 shade is used for most measurements of the properties of composite materials .

The composite resin samples for the degree of conversion measurement were prepared as follows: a sample of unpolymerized composite material, 40 mg in

Table 2
Levene`s Test of Homogeneity of Variances.

Composite material	F	df1	df2	Sig.
TCA3	.817	1	14	.381
TECA3.5	6.613	1	14	.022
TECA1	11.123	1	14	.005
AA2E	.591	1	14	.455

weight, was placed on a Mylar sheet 3x3 cm in size, and covered with another Mylar sheet of the same size. The sample was then placed between two round Inox plates, 2 cm in diameter, and pressed in a hand press at 10^7 Pa to 0.3mm thickness. The Inox plates were used to keep the sample in the same position. After pressure was applied in the hand press, the Inox plate was removed. Prior to the polymerization of the prepared composite samples, overlays (1cm diameter, 1mm thick) of the same composite material, similar to the unpolymerized sample, were prepared and polymerized. The overlays simulated a depth of 1mm. The overlay was placed on the unpolymerized sample, which was still covered with Mylar sheet on both sides, and cured with the curing light. The samples were measured after polymerization and separated from the Mylar sheet.

The degree of conversion of the composites used in this study was measured using a FT-IR spectrometer (Perkin-Elmer, model 2000, Beaconsfield, Buckinghamshire, UK) operating in transmittance mode immediately after the end of the polymerization of the resin sample with the curing device. The FT-IR spectra were taken at room temperature (RT) in the IR range 4000 - 400 cm^{-1}, with a resolution of 4 cm^{-1} and 20 scans per sample. Cured samples were recorded in the form of thin films. Approximatelly 2 mg of uncured samples were diluted in ~100 mg of spectroscopically pure KBr matrix in agate mortar and then pressed into small discs, using a standard press with a pressure of 5 t/cm^2. The IRDM (IR Data Manager) program supplied by the manufacturer of the FT-IR spectrometer was used to process the obtained spectra. The spectra were converted into absorbance mode and the degree of conversion was then determined using the standard method described by Rueggeberg.[10] This method records the change in the aliphatic carbon-to-carbon (C=C) (13) double bond absorbance at 1636 cm-1 related to (with regard to) the aromatic C=C absorption peak at 1608 cm^{-1} as internal standard. The ratio of the peaks area of cured and uncured samples was used to calculate the degree of conversion according to Rueggeberg's[10] formula:

%conversion=(1-(polymerized sample/unpolymerized sample)) x100%.

For the statistical data analysis descriptive statistics, the T-test, Levene's Test of Homogeneity of Variances and Pearson's correlation were used.

Results

Results of the experiment are represented in Tables 1-3. In Table 1 descriptive statistical analysis is presented forthe tested composite materials and various tube widths of the LED curing unit. The greatest degree of conversion exhibited was the AA2E composite material when polymerized with wide tube light source (81.18%), while the lowest degree of conversion was recorded in the TECA1 composite material polymerization with a wide tube (61.44%).

The Independent samples T-test showed a significant difference in the setting of each individual composite material, depending on the polymerization device tube width (for TCA3, TECA3.5 and TECA1 composite material $p<0.001$, and for AA2E $p=0.01$). However, TCA3 and TECA3.5 composite material set better using a wide tube, while TECA1 and AA2E were better using a narrow tube width.

Levene's Test of Homogeneity of Variances (Table 2) showed that TCA3 and AA2E composite materials do not have homogeneity of variance, while the other two composite materials do. However, the T-test performed on the same samples, with the supposition that they do not have homogeneity of variance, gave the same data on the significant differences within samples TCA3 and AA2E depending on the tube width.

When comparing the total setting of the different composite materials, regardless of the tube width (Paired samples T-test) (Table 3), there is a significant difference between all pairs of composite materials. The exception was between TECA1 and TECA3.5, where there is no

Table 3
Paired Samples Test.

	Composite material	Paired Differences	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
		Mean			Lower	Upper			
Pair 1	TCA3 - TECA3.5	4.46	2.42	.60	3.17	5.75	7.36	15	.000
Pair 2	TCA3 - TECA1	5.60	5.15	1.28	2.86	8.35	4.35	15	.001
Pair 3	TCA3 - AA2E	-11.08	6.25	1.56	-14.41	-7.74	-7.08	15	.000
Pair 4	TECA3.5 - TECA1	1.14	3.66	.91	-.81	3.09	1.24	15	.232
Pair 5	TECA3.5 - AA2E	-15.54	4.96	1.24	-18.18	-12.90	-12.52	15	.000
Pair 6	TECA1 - AA2E	-16.68	2.64	.66	-18.09	-15.28	-25.27	15	.000

significant difference. They have a similar average setting of 63.89 and 62.75%.

Pearson's correlation points to a significant linear correlation between all combinations of pairs, except TCA1 and AA2E. TCA3 and TECA3.5 composite materials have positive correlation, in other words, they both set better with the wide tube, than with the narrow tube, while in other combinations the correlation is negative. Pearson's correlation also reveals the existence of a linear correlation between tube width within composite samples – it is positive for TCA3 and TECA3.5 composite material, and negative for TECA1 and AA2E.

When analyzing the total distribution of setting of all composite materials (regardless of the type) the Independent samples T-test showed no significant difference in setting, depending on the polymerization device tube width (p=0.531). The average setting with the narrow tube was 68.04% and with the wide tube, 69.18%. Levene's Test of Homogeneity of Variances proves that samples which set at wide and narrow tube do not have homogeneity of variance.

Discussion

It was mentioned in the Introduction that many factors influence the degree of conversion of the composite material and filling. Even though the goal is to achieve maximal monomer conversion, unfortunately maximal conversion has, as a consequence, greater polymerization shrinkage and polymerization stress. [11] On the other hand, insufficient conversion leads to greater portion of residual monomer that will compromise composite filling biocompatibility. [12]

This study deals with only one of the clinically important parameters for achieving a sufficient degree of conversion, which is tube width or width of outgoing intensity of the beam of light. Ideally the light source should be in direct contact with each layer of composite material placed in cavity. However, in many cases that is not possible. Many published articles have dealt with the subject of the influence of the distance of the light source from the composite sample on the degree of conversion. Results of these studies show that the degree of conversion decreases with an increase in distance from the light source.[13,14,15,16] The mentioned problems in clinical conditions can be compensated with the use of tubes of varying widths. Wider tubes would be used for the illumination of the surface layer and deeper layers in wider cavities if the tube is not too wide to reach the bottom of the cavity. Narrow tubes, on the other hand, would be appropriate for proximal and deep cavities.

Corciolani et al. [17] investigated the influence of the light guide shape on the polymerization efficacy of a light-activated composite cured with LED units as a function of the distance between the tip and the restoration. They used two different LED units, each with different light guides and shapes, and evaluated the efficacy of the light-curing system by measuring the depth of cure using the Acetone Shake test. They concluded that the tip geometry of the tested light guide had a significant influence on the depth of cure of the tested resin composites. Kramer et al. 18 found in their study that the curing depth is fundamentally dependent on the distance of the resin composite from the light source, but is decisive only when exceeding 6mm. Therefore, depending on the distance, the more suitable light guide should be selected based on the clinical situation.

In their study, Vandewalle et al. 19 examined the influence of the light guide type on the distribution of irradiant emission from a light-emitting diode curing light and measured the effect of light dispersion on surface microhardness. The standard guide had a significantly more uniform light distribution than did the turbo tip. They did not find any difference between the two types of tested light guides. However, they found significant differences between the hardness at the specimen center and at various lateral distances, depending on composite type, surface, and light guide type.

This study shows there is no statistically significant difference in the degree of conversion when using a wide or narrow tube (p=0.531). The average setting with a narrow tube was around 68.04%, and with a wide tube, 69.18%. However, since there is always a certain temperature rise during illumination of the composite material, (even though it is significantly lower in the case of diode curing units than halogen devices, 20) care should be taken when using narrow tubes in deeper cavities where there is only a thin remaining dentin layer and the energy of the outgoing beam is concentrated on the small area.

Furthermore, for the degree of conversion, as well as the before-mentioned temperature rise, not only is the intensity important, but also the amount of energy calculated from the product of multiplication of total light intensity and the time of illumination. The greater the amount of total applied energy, the greater the degree of conversion. 21,22,23

Taking into account the results of this study, as well as the size and shape of the composite material samples, it can be supposed that the narrow tube will produce a greater degree of conversion because the same amount of energy is concentrated on the smaller area. A narrower concentration of light will cause better polymerization of a smaller part of the sample while marginal parts will remain poorly polymerized. Conversely, a wider tube will enable uniform sample polymerization due to the wider beam surface. Taking into account that the FTIR s pectroscopy beam targets the surface of the sample, it is not always possible to determine exactly, possibility of error arises in interpretation of results in a way that in samples polymerized with narrow beam one time it can pass through most polymerized section and other time through less polymerized. The explanation can be found in less uniform distribution of individual results and standard deviation with regard to results obtained with the degree of conversion measurements using wide tube. Froom the given results it can be concluded that darker composite shades obtain better polymerization with a wide tube, while lighter shades obtain better polymerization with a narrow tube. Since it is well known that lighter shades polymerize better than darker, better polymerization of lighter shades with a wide tube was expected. 9,24 The differences between the degree of conversion results using wide and narrow tubes are not statistically significant. And error that occurs can be attributed to movement of laser beam during scanning of samples in the FTIR device.

More samples should be done to confirm clinical significance of data presented in this study.

Conclusion

The application of both wide and narrow tubes can significantly ease handling in certain clinical situations. The average degree of conversion of composite material achieved with narrow polymerization curing tube was 68.04% and with wide 69.18%. No statistically significant difference was found in polymerization of tested coted c ted composite materials regarding curing tube width.

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