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Thermographic Analysis of Thermal Distribution in Human Teeth Based on Composite Fillings

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ABSTRACT

Composite materials are used in dentistry to rebuild hard tissues of teeth, destroyed by caries disease. Composites intended for dental direct fillings are polymerized with visible light generated by polymerization lamps. The temperature changes during polymerization can be measured within method like thermography. The study used 20 molars without caries, removed from orthodontic indications. A thermal imaging camera was used to test the temperature distribution of composite materials during the polymerization process. The work was taken up about the possibility of imaging the temperature distribution during the polymerization process of composite fillings in human teeth tissues. Temperature distribution was analyzed at specific locations of tooth tissues, particularly in terms of heat migration towards pulp. At the sites of separation of tooth materials and tissues, an attempt was made to assess the hardness of fillings and tissues. It can be concluded that the temperature during test did not exceed 42°C, at which the tooth pulp is damaged. During cooling, heat spreads through the filling, not through the tooth tissues. Bulk fill did not show a difference in fill hardness regardless of the distance of the light source but GC composite hardness depends on the distance of the light source.

Keywords: thermovision, temperature, teeth, hardness test

INTRODUCTION

Composites are materials used in dentistry to rebuild the hard tissues of teeth, destroyed by caries. Currently, about 70% of fillings are made of them. Until now, these products have been manufactured from degradation-resistant artificial polymers, which break down in the natural environment for a very long time [1]. Most of the composites intended for direct dental fillings are polymerized with visible light generated by curing lamps. The currently used devices for polymerizing materials can be divided into the following groups: halogen lamps, xenon lamps (Plasma Arc Curing Lights PAC), semiconductor lamps (Light Emitting Diode LED), and argon lamps [2]. Each of these groups of devices differs from each other in many features, including the light source, the effectiveness of polymerization, as well as the amount of heat emitted. Halogen lamps used for the polymerization of complex materials emit light radiation 360–560 nm in length. [3]. Conventional halogen lamps allow selection of the exposure time that is signalled by a sound, without the possibility of changing the power. The disadvantages of halogen lamps are the wear of the bulb and filter, the gradual degradation of the optical system and the release of heat during

polymerization. Despite using various light curing modes, the temperature of the composite resin increases during photopolymerization [4]. LED lamps were used in dentistry for curing composite materials first one the 1990 s. They are characterized by a narrow emission spectrum, use a small amount of energy, do not significantly increase the temperature of tooth tissues during polymerization and allow shorter irradiation times [4, 5]. The advantages of LED lamps include their practical features. Compared to halogen lamps, they have a longer service life (6 months vs. 5 years), a significant greater depth of cure in three differently filled, medium-shade composite. They have a spectrum better suited to the photoinitiators currently used in composites.

The heat release that always occurs during the polymerization of composite materials is absorbed by the mineralized tissues of the tooth and is transmitted to the pulp. Plant and Jones observed that there is a correlation between the histological changes in the tooth pulp and the increase in tissue temperature during curing [6]. Qudach in an in vitro model observed smaller intrapulpal temperature rises, which was expected with dentine thicknesses. This is the result of heat reduction by dentine fluid odontoblast processes and collagen fibers contained in the dentine tubules [6]. In turn, Dąbrowski et al. observed that a temperature spike of 5.5°C during the absorption of heat energy by the pulp may cause damage to it [7]. Zach and Cohen investigated an animal model and found that pulp damage occurs when temperatures rise by 12°C [8]. According to [7], the maximum temperature rise occurs within three seconds. Irreparable damage to the pulp occurs at 42.5°C [9].

The temperature changes during polymerization can be measured with various methods, for example thermography. The temperature measurement is non-contact and allows observation of heat distribution in the hard tissues of the tooth.

Graphical representation of the thermal image is achieved during the temperature distribution in the object. A thermovision camera clearly and accurately demonstrates the clinical reality of the exothermic polymerization of a resin composite [8]. Therefore, the paper discusses the possibility of visualizing the temperature distribution during the polymerization process of composite fillings in human tooth tissues. The temperature distribution was analysed at specific locations of tooth tissues, particularly in terms of heat migration towards the pulp. At the sites where the materials and tissues of the tooth are separated, an attempt was made to assess the hardness of the fillings and tissues.

During the polymerization of composite fillings, the temperature increases both in the tooth's tissues and in the filling. From a clinical point of view, it is important because the critical temperature for maintaining a healthy and vital pulp is 42°C. Therefore, it is important for dentists to study the propagation of heat in the tooth tissues and to increase the temperature. At the same time, a poorly polymerized filling may be a defective filling in terms of its physico- mechanical properties, and may also lead to the formation of a marginal fissure, bacterial microleakage, which, similarly to thermal damage to the tooth pulp, has important clinical implications, as it may lead to secondary caries, fired states of the tooth pulp and periapical tissues. Good filling out not only shows excellent mechanical properties, e. g. hardness, but also does not adversely affect the tooth tissue. The distribution of temperature in teeth and composite fillings are analyzed in dentistry not only in the aspect of clinical treatment but also i.e. alloys generally nickel alloys in laboratory process [10]. The aim of the paper were analysis and visualization of distribution of temperature in teeth and composite fillings. Moreover, the analysis influence of the polymerization lamp distance from the teeth with comparison with microhardness test was done.

MATERIALS AND METHODS

The study used 20 molars without caries, removed for orthodontic indications, in which Black class I defects with a depth of 4 mm were removed. The material was applied and the composite fillings were polymerized according to the accepted principles of dental art. Two types of composites, Admira Fusion x-tra (VOCO, Germany) and Essentia (GC, Japan), were used to make the fillings. G-Premio BOND (GC, Japan) (Table 1) was used as the binding system for all the teeth after etching the cavities with 37 % orthophosphoric acid using the total etch technique. The fillings were hardened with Cromalux 75 halogen lamp (Megadenta, Germany). The research material was divided into four groups depending on the type of composite and the polymerisation parameters as shown in Table 1.

Table 1. Division of research material according to distance of polymerization and composite material.

Group	1	2	3		4	
Annotation	$AFXB_{min}$	$AFXB_{3mm}$	EGC_{min-1}	EGC_{mm-2}	EGC_{3mm-1}	EGC_{3mm-2}
Material	Admira Fusion x-tra VOCO	Admira Fusion x-tra VOCO	Essentia GC		Essentia GC	
Lamp	Cromalux 75	Cromalux 75	Cromalux 75		Cromalux 75	
Distance	Minimum	3 mm	Minimum		3 mm	

The research material was divided into several groups. The first group consisted of fillings made of the Admira Fusion x-tra material, polymerised with the Cromalux 75 lamp with 30s at a minimum distance, and the second group at a distance of 3 mm from the filling surface. The third group consisted of restorations in the Essentia GC composite material polymerized with the Cromalux 75 lamp at a minimum distance, and the fourth group was 3 mm from the filling surface.

A thermal imaging camera was used to investigate the temperature distribution in the composite materials during the polymerization process. A thermographic test stand consisting of an OPTRIS PI450 thermal imaging camera (USA). with 0.01°C, an insulating cover and a sample holder were used.

The temperature distribution analysis from the thermal imaging camera lasted 60 s. The results obtained immediately after the end of irradiation with the polymerization lamp for 1, 8, 16 s were isolated, where the influence of temperature and cooling was most clearly visible. The measured value was the temperature during cool down. Three areas were analysed:

- Area I – the external surface of the filling,
- Area II – the border between the filling and the tooth in the vicinity of the pulp chamber,
- Area III – root dentine halfway along the tooth root.

For the microhardness studies, metallographic specimens were made, which were incorporated into chemically hardened resin. The samples were grinded using discs of increasing grit (150, 400, 600, 1200) and were polished with a silica active oxide polishing suspension (OPS) using a Buehler Beta Grinder-Polisher (Phoenix Beta, USA).

The test of microhardness was performed using the Vickers hardness method. The apparatus was performed on an FM-700 microhardness tester (FUTURE-TECH CORP., Japan). The test parameters were: load 0.098 N in 10 s. The microhardness of the composite fillings was measured 5 times in different places. The imprints were analysed during the tests using a Nikon Eclipse MA200 light microscope.

RESULTS

Thermographic analysis

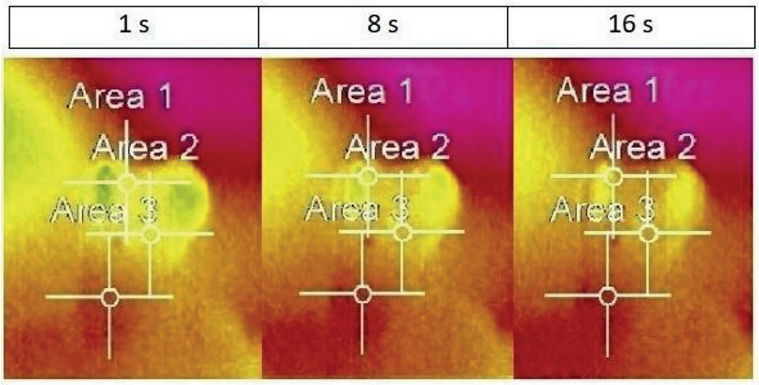
Figures 1- 6 show the results of investigations with a thermal imaging camera of teeth with a filling in place after the polymerization process, during heat propagation in the tissues and fillings. The results shown in the figures are at 1 s, 8 s and 16 s. Three characteristic places were selected on each sample, where at the time of cooling the temperatures were the highest and at the same time showed boundary places such as – Area I – the external surface of the filling, Area II – the border between the filling and tooth in the vicinity of the pulp chamber and Area III – root dentine halfway along the tooth root.

On the Figure 1 is shown similar temperature values can be observed, which decrease over time. At 8 s temperatures in Area 1 and Area 3 are higher compared to Area 2. This may be due to spread of heat to other tooth tissues more susceptible to temperature, i.e. pulp.

Over time on Figure 1, temperature decreases in Areas 1 and 2, while heat dissipation to tooth root and accumulation after 16 s is clearly visible. Temperature in Area 1 is highest 1 s after lamp is turned off, and at 8 s it is reduced by as much as 2°C.

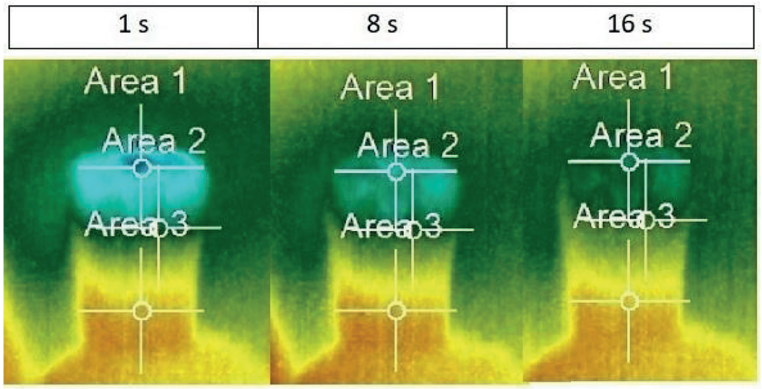
Temperature distribution on Figure 2 is shown during polymerization of first layer of material at minimum distance from polymerization lamp. According to thermographic analysis in Area 2, temperature decreases over time, while in Area 1 it remains at similar level.

During polymerization of second layer of material at minimum distance (Fig.3), it was observed that in Area 1 temperature drops significantly over time, in Area 2 and Area 3 it remains at similar level.



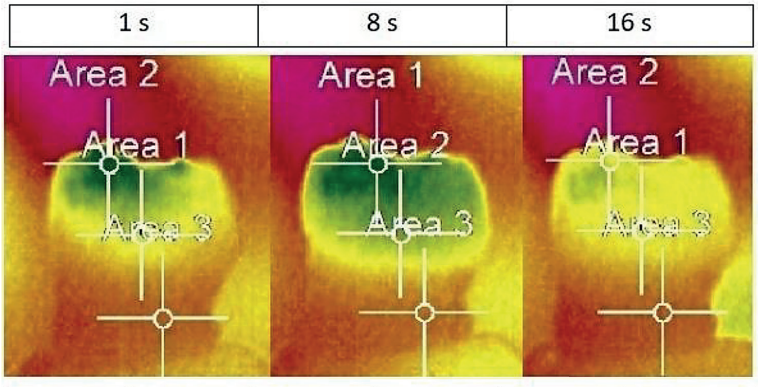
Area 1	30.57 °C	Area 1	30.63 °C	Area 1	30.42 °C
Area 2	30.45 °C	Area 2	30.31 °C	Area 2	30.10 °C
Area 3	29.38 °C	Area 3	29.44 °C	Area 3	29.35 °C

Fig. 1. Thermal images showing changes temperature in $AFXB_{min}$ tooth



Area 1	33.25 °C	Area 1	31.98 °C	Area 1	31.37°C
Area 2	31.16 °C	Area 2	30.84 °C	Area 2	30.66 °C
Area 3	28.96 °C	Area 3	29.02 °C	Area 3	29.20 °C

Fig. 2. Thermal images showing changes temperature in $AFXB_{3mm}$ tooth



Area 1	30.60 °C	Area 1	31.98 °C	Area 1	30.37 °C
Area 2	31.92 °C	Area 2	30.84 °C	Area 2	30.48 °C
Area 3	29.44 °C	Area 3	29.02 °C	Area 3	29.00 °C

Fig. 3. Thermal images showing changes temperature in $EGC_{min\text{-}1}$ tooth

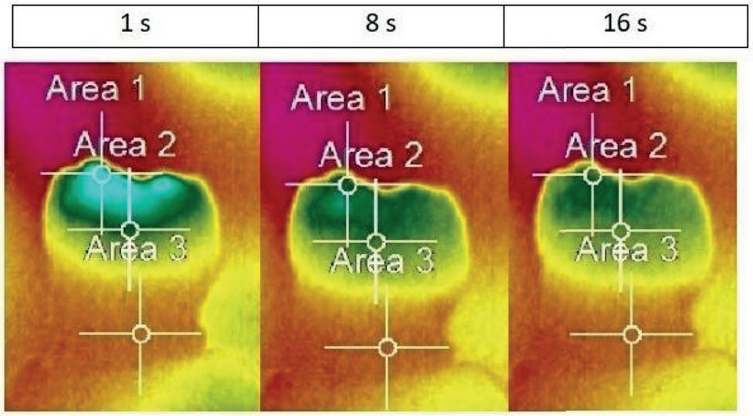
A second layer during polymerization of material at minimum distance (Fig. 4), drop in temperature was observed in each examined area.

At each analysed second (1, 8, 16) in all the investigated areas even on Fig 5 and 6, it can be seen that there is a decrease in the temperature as the distance from the polymerization lamp increases.

According to Table 2, the largest difference in the average temperatures between Areas I and II was observed at 1s of polymerization of the second layer of the EGC_{3mm-2} material, and between Area II and III at 1s of polymerization of the second layer of the EGC_{3mm-2} material. There are two cooling phases: one between the peak temperature and the end of the irradiation, which is free and gradual; the second one is the rapid cooling phase between the end of the irradiation and the end of the temperature observation, which is in line with the observations made in the current study.

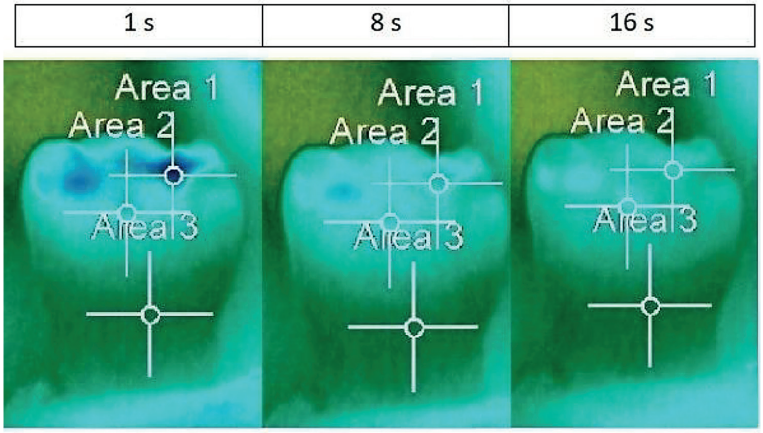
Microhardness Test

The results of the microhardness test of 20 composite fillings placed in human molar teeth were examined and compared in this study. The results obtained from the microhardness test depends on the distance between the composite filling and the tip of polymerization lamp.



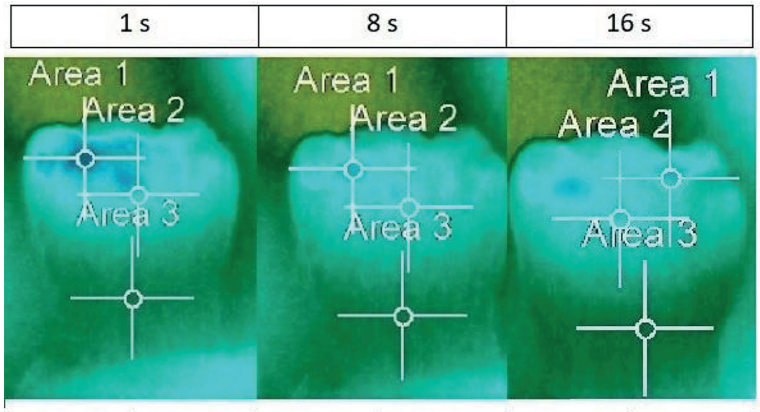
Area 1	33.57 °C	Area 1	32.13 °C	Area 1	31.66 °C
Area 2	31.92 °C	Area 2	31.48 °C	Area 2	31.45 °C
Area 3	29.56 °C	Area 3	29.44 °C	Area 3	29.50 °C

Fig. 4. Thermal images showing changes temperature in EGC_{mm-2} tooth



Area 1	33.05 °C	Area 1	31.75 °C	Area 1	31.07 °C
Area 2	31.69 °C	Area 2	31.57 °C	Area 2	31.19 °C
Area 3	29.77 °C	Area 3	29.71 °C	Area 3	29.65 °C

Fig. 5. Thermal images showing changes temperature in EGC_{mm-2} tooth



Area 1	32.53 °C	Area 1	31.78 °C	Area 1	31.75°C
Area 2	31.48 °C	Area 2	31.16 °C	Area 2	31.00 °C
Area 3	29.92 °C	Area 3	29.98 °C	Area 3	29.71 °C

Fig. 6. Thermal images showing changes temperature in EGC_{3mm-2} tooth

Researchers studying resin-based composites researchers assess the hardness of the structure.

In Tabel 3 are shown the values of microhardness test of fillings.

The mechanical properties of composite fillings can be assessed using the microhardness test. Statistical analysis with the Shapiro-Wilk test of the the hardness coefficient measurement indicated that the obtained results have a normal distribution of $p>0.05$ (assuming $\alpha=0.05$). Thus, $p>\alpha$ and there is no basis for rejecting the hypothesis of a normal distribution of the examined characteristic. This may prove the high structural homogeneity of the investigated materials (uniform distribution of filler particles in the polymer matrix). On the other hand, Student's t-test (for $\alpha=0.05$) showed that only between fills 1 and 2 were the differences in the hardness of the studied produced fillings statistically insignificant ($p>0.05$), whereas for the other groups statistically significant differences ($p<0.05$) were observed.

The indirect microhardness test verifies the degree of polymerization of the resin in the composite. Few studies address the issue that the

Table 2. Difference in average temperatures over test time between zones.

Annotation	Measurement moment [s]	Area I [°C]	Temperature difference AI vs AII [°C]	Area II [°C]	Temperature difference AII vs AIII [°C]	Area III [°C]	Temperature difference AI vs AIII [°C]
$AFXB_{min}$	1	30.57	0.12	30.45	1.07	29.38	1.19
	8	30.63	0.32	30.31	0.87	29.44	1.19
	16	30.42	0.32	30.10	0.75	29.35	1.07
$AFXB_{3mm}$	1	33.25	0.09	31.16	2.2	28.96	4.29
	8	31.98	0.14	30.84	1.82	29.02	2.94
	16	31.37	0.29	30.66	1.46	29.20	2.17
EGC_{min-1}	1	30.60	0.32	31.92	2.48	29.44	2.48
	8	30.98	0.54	30.84	1.82	29.02	1.66
	16	30.37	0.11	30.48	1.48	29.00	0.90
EGC_{min-2}	1	33.57	0.35	31.92	2.36	29.56	4.01
	8	32.13	0.35	31.48	2.04	29.44	2.69
	16	31.66	0.21	31.45	1.95	29.50	2.16
EGC_{3mm-1}	1	33.05	0.64	31.69	1.92	29.77	3.28
	8	31.75	0.18	31.57	1.86	29.71	2.04
	16	31.07	0.12	31.19	1.54	29.65	1.42
EGC_{3mm-2}	1	32.53	1.05	31.48	1.56	29.92	2.61
	8	31.78	0.62	31.16	1.18	29.98	1.80
	16	31.75	0.75	31.00	1.29	29.71	1.51

Table 3. Microhardness test in fillings after thermal exposition

Annotation	Average microhardness [HV]	Std. dev.
$AFXB_{min}$	137.24	2.02
$AFXB_{3mm}$	135.6	1.32
EGC_{min-1}	96.88	0.45
EGC_{min-2}	80.96	0.61
EGC_{3mm-1}	78.02	0.38
EGC_{3mm-2}	82.6	0.72

distance between the tip of the curing unit influences the property of resin composite materials [10]. Some authors found that halogen light did not affect the microhardness results [11]. Others presented different results [12, 13].

In clinical settings, this has an impact on the hardness of the filling, especially in Black class I and class II deep cavities, where the light source of the polymerization lamp is far from the bottom of the cavity. The microstructural analyzis based on metallographic microscopy was shown that every imprints possess the same shape and dimension.

DISCUSSION

The technique of infrared thermography allows non-invasive monitoring of temperature changes during polymerization by measuring the infrared emission from the surface of the resin composite. This is unaffected by the blue light of the curing lamp, which is in the range of 470 nm. The blue light acts on the initiator system, usually a mixture of a diketone and an amine with the diketone forming free radicals in the presence of the amine when subjected to the correct wavelength of light [8]. Infrared thermography is a viable means of quantifying the change in temperature during the polymerization of a restorative resin composite in vivo [8, 9].

Real-time thermographic analysis showed that the type of composite and the application method did not increase the temperature to 42°C, which is critical for pulp [9]. The tolerance threshold for the temperature increase for pulp was not exceeded either. According to the current studies, the largest increase was observed in Area 1, which is closest to the light source in all the examined teeth. The radiation of the light curing device had the greatest effect on the initial size and rate of temperature rise. A higher intensity curing light may induce a relatively large heat transfer in a Cromalux lamp, which may increase the risk of pulp damage. In contrast, in the presented thermographic studies the temperature increase did not exceed the tolerance threshold value. The range of temperature rise measured in the study by Hussey et al. [8] (mean 5.4±2.5°C) would suggest that the pulp may be endangered by the temperature rise, which occurs during composite polymerization. The study would support the practice of protecting the pulp by adequate thermal insulation such as a cavity liner, or by maintaining, if possible, a sufficient thickness of dentine.

In the present research results, the polymerization peak temperature in Area 1 was observed on the filling surface.

The polymerization peak temperature measured in the middle of the cavity was significantly high. This can also be explained by the fewer monomers available adjacent to the cavity wall than in the middle of the cavity for further polymerization.

The results of the present study indicate that the temperature increase in both the investigated materials occurs almost immediately after the start of polymerization, reaching its peak 1–8 seconds. Similar results were obtained by Qudach [5]. Many authors noted, as in our studies, the highest temperature increase during 8- 10 seconds [6, 9].

The temperature increase during photopolymerization of the composite resin is the result of the rate and degree of transformation of the carbon=carbon double bonds [6].

Loney and Price [10] noted that the thickness of the dentine and the fluids and cells contained in it influence heat conduction. The depth of the defect, and the distance of its bottom from the pulp may affect the amount of heat reaching the pulp cells. According to Meredith et al. [11], the flow of blood and fluids in the dentine tubules has a significant impact on heat conduction. The present studies were conducted in vitro; hence this factor was not taken into account.

The microhardness of composite fillings in the teeth depends on many factors: which is confirmed by Walczak's et. al. research [12].

This work focuses on the analysis of microhardness in the range of the distance of the polymerization lamp during the curing of fillings. The indentation method for assessing the mechanical properties of the material surfaces is relatively easy to conduct. The development of an apparatus for indentation tests makes it a useful

tool for various measuring systems of different scale (from macro to nano) [13–16].

Mechanical strength depends on the filler chemical content and the sizes. It has been found that the increase in the content of ceramic filler particles results in improved strength and this relationship is exponential [17–19]. In this case, the smaller the particle sizes of the filler, the better the polishability and smoothness. The bigger and larger ceramic particles can provide higher mechanical resistance but the lower material shrinkage. Also, the level of shrinkage depends of the volume content of the filler in the composite structure [20].

The indirect microhardness test verifies the degree of polymerization of the resin in the composite. Study addresses the issue that the distance between the tip of the curing unit influences the property of resin composite materials [11]. Some authors found that halogen light did not affect the microhardness results [21]. Others presented different results [22–24].

In clinical settings, this has an impact on the hardness of the filling, especially in Black class I and class II deep cavities, where the light source of the polymerization lamp is far from the bottom of the cavity.

Both in the case of polymerization of conventional and bulk-fill composites, the distance of polymerization lamp from the filling surface affects the properties (hardness) of the composite.

From the studies assessing the light intensity of photoactivators and the distance from the tip of the device to the refill, which also interferes with the intensity of light reaching the material, it can be concluded that higher intensity light devices improved the microhardness and the degree of conversion [25]. In addition, the shortest distances between the device and the composite also favored better results regardless of the type of light source [26]. The obtained results show that greater distances between the tips reduce the microhardness values and the degree of conversion, while increasing the resin thickness reduces the microhardness values. This study suggests that current light curing devices promote a similar degree of conversion and microhardness, provided the light source is at the maximum distance as well as Rode et. al. 3mm from the resin surface [27,28]. Pryliński [29] investigated the thermal effects depending on the polymerization lamp used. They obtained similar results to their own research in the case of halogen lamp irradiation. At the same time, noting that the type of lamp is only one of the factors influencing the generated thermal effects and other parameters should be considered, such as the length of the exposure time, distance, thickness of the layer, type of composite, etc.

Cacciafestaa et al. [30] irradiated the samples at a distance of 2 and 9 mm from the tip of the fiber and measured the Knoop hardness values. They found that when the distance between the composite and the light guide was increased, the impact on the hardness of the composite was not the same for all light / tip combinations.

CONCLUSIONS

Based on the results it can be concluded that the temperature during the studies did not exceed 42°C, at which tooth pulp is damaged. The temperature changes did not exceed the tolerance threshold for pulp.

During cooling, heat spreads through the filling, not through the tooth tissue. The Admira Fusion x-tra filling did not show a difference in fill hardness regardless of the distance of the light source. The Essentia composite fillings exhibited a difference in the hardness of the filling depending on the distance of the light source.

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