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Abstract

Objectives

The use of LED light-curing units (LED LCUs) for polymerising resin-based composite restorations has become widespread throughout dentistry. Unfortunately, there is a paucity of clinical longitudinal studies that evaluate the comparative efficacy of LED-based polymerisation in direct posterior composite restorations. The aim of the present study was to investigate the performance of class I and II resin composite restorations for two successful composite restorative materials cured with LED versus halogen LCUs.

Methods

One hundred restorations were placed using the nano-filled composites Grandio® or Filtek™ Supremé. The following test groups were established: LED-Grandio® *n* = 23 (LG), LED-Filtek™ Supremé *n* = 21 (LS). As controls were used: Halogen-Grandio® *n* = 28 (HG), Halogen-Filtek™ Supremé *n* = 28 (HS). All restorations were evaluated according to the clinical criteria of the CPM index (C-criteria) at baseline and after 6, 12 and 36 months.

Results

After 12 and 36 months, there were no significant differences between restorations polymerised with LED or halogen light. At the end of the study, 97% of the restorations showed sufficient results regardless of the employed LCU or composite. Globally, after 36 months, 56% of all restorations were assessed with code 0 (excellent) and 41% with code 1 (acceptable). In detail, excellent results (code 0) among the criteria surface quality; marginal integrity and marginal discoloration were assigned in 72, 70 and 69%.

Conclusions

For the current limitations in the clinical trial design, the results showed that LED-polymerisation is appropriate to ensure clinical success of direct posterior resin composite restorations in a range of 3 years.

Clinical significance

The choice of LCU has no significant influence on the clinical performance of posterior direct resin composite restorations within 3 years of wear.

Keywords

Composite Grandio Filtek Supremé Clinical evaluation LED Halogen Posterior resin restorations

Introduction

Composite materials are often used in modern dentistry to restore carious lesions. These distinguish themselves by their outstanding aesthetic appeal, while also increasingly providing satisfactory results in both class I and II cavities [1, 2, 3, 4, 5, 6]. In general, posterior composite restorations show a high survival proportion if the composite materials and adhesive systems are applied as intended [7, 8, 9]. The vast majority of such composites are cured by a complex photochemical process which is clinically controlled by means of light-curing units (LCUs) [10].

The widespread use of the composite technology in aesthetic dentistry also influenced the evolution and improvement of the light-curing devices. In addition to the established quartz-tungsten-halogen (QTH) LCUs, other curing units with plasma or laser light sources were developed as well [11]. However, none of these rather expensive technologies were clinically used for a prolonged period of time. This changed in the late 1990s with the introduction of the LED technology [12]. The new developed LED LCUs ensured a much faster and more

convenient way of photo-polymerisation and caused a rapid replacement of the halogen-driven devices which have dominated the market up to this time [10].

Compared to QTH LCUs which deliver a constant flux of light for only 100 h, modern LED LCUs are able to operate without any loss in flux for up to 100,000 h [13, 14, 15]. In addition, the light which is emitted by LED LCUs matches the absorption of the most common photoinitiators more precisely [13, 10, 14, 16, 17, 18]. Another big disadvantage of QTH LCUs results in the heat which is generated during operation. Because of the strong heating, the built-in reflectors and filters are worn down quickly [13, 14]. Besides their unwieldy size, QTH light-curing units therefore need a more frequent maintenance and repair, which results in inconvenience and increased costs. Finally, an LCU with an insufficient output of light causes a lower degree of conversion which may result in unfavourable mechanical properties and an increased cytotoxicity [14, 19]. In contrast, LED-based LCUs are of a more convenient design and combine lower power consumption with much greater durability (advantages and disadvantages of each LCU are shown in Table 1).

Table 1. Advantages and disadvantages of the applied LCU types

	Halogen LCU	**LED LCU**
Advantage	polymerisation of all composites	light matches the absorption of the most common photoinitiators more precisely
	higher range in wavelength	convenient design
	considered the “gold standard” in composite polymerisation	high durability
		low power consumption
Disadvantage	constant flux of light for only 100 h	big variety
	Intense heat generation	older models do not polymerise all co polymers
	bulky	intense heat development at light guide opening
	quick wear of filters and reflectors	
	cost intensive	

The efficiency of LED LCUs in curing resin-based composites has already been investigated in several different in vitro studies [20, 13, 21, 22, 14, 23, 24, 15, 18, 25, 26, 27]. Results of the present study have shown, in addition, that the type of LCU employed and the shade of the composite used have a direct influence on the cytotoxicity of the material [28]. It was found that composites of brighter shades and polymerised by means of LED light presented a significant lower toxic behaviour compared to materials cured with halogen LCUs and of darker shades [28, 17, 29]. Besides the type of LCU used for polymerisation and the shade of the composite material, there are several other important factors such as the thickness of the composite increment, the depth of cure, the angulation of the light guide, the time of the light application and the fluence rate as well as the irradiation pattern of the used device which have a significant impact on the conversion rate and thus the cytotoxicity of the material. In placing composite restorations, there are three major categories of polymerisation variables—(1) manipulation (e.g. angle, distance, time), (2) type of light (e.g. LED, halogen, others) and (3) material compositions (e.g. initiator, accelerator, monomer type and distribution) that impact the result percent conversion. The present study primarily focuses on the influence of the applied LCU type on the long-term performance of composite restorations (number 2).

Up to now, clinical studies are missing that favour LED polymerisation in posterior composite restorations. In addition, to our best knowledge, there are no clinical long-term studies available which compare the performance of posterior resin-based composite restorations cured either by LED or halogen light.

Because of the high efficiency of modern day LED LCUs, it was therefore hypothesise that posterior resin composite fillings polymerised by LED light show a significant better clinical long-term performance compared to restorations polymerised by halogen light. The study is therefore aimed at investigating the influence of LED and halogen photopolymerisation on the clinical long-term behaviour of the nano-hybrid composites Grandio® and Filtek™ Supremé in class I and II cavities over a time period of 36 months.

Methods

A standardised clinical trial for adult patient was designed using two different composite materials which were cured by two different LCUs (halogen, LED). The long-term performance was observed in class I and II cavities after 6, 12 and 36 months.

Patients

Following ethics committee approval (1148–06/03; date of approval 07/10/2003), patients with carious lesions or insufficient restorations were recruited that joined the dental clinic for treatment. Prior to evaluation, all participants signed an informed consent.

Within the scope of this clinical study, a total of 100 class I and II restorations were placed in 57 patients (31 female/26 male) with a mean age of 43.3 years. Assignment to the various groups is shown in Fig. 1. Randomisation was performed by a two-step procedure of drawing lots (1st lot: polymerisation instrument, 2nd lot: restoration material). The test groups were arranged as follows: LED-Grandio® *n* = 23 (LG) and LED-Filtek™ Supremé *n* = 21 (LS). As controls were used: Halogen-Grandio® *n* = 28 (HG) and Halogen-Filtek™ Supremé *n* = 28 (HS).

Distribution of restorations by location and cavity type

Study groups		Number of restorations
Halogen / Grandio® n = 28	*Cavity class I*	n = 6
	Cavity class II	n = 22
LED / Grandio® n = 23	*Cavity class I*	n = 6
	Cavity class II	n = 17
Halogen / Filtek™ Supremé n = 28	*Cavity class I*	n = 10
	Cavity class II	n = 18
LED / Filtek™ Supremé n = 21	*Cavity class I*	n = 6
	Cavity class II	n = 15

Fig. 1. Distribution of restorations by location and cavity type

Study groups		**Number of restorations**
Halogen / Grandio® n = 28	*Cavity class I*	n=6
	Cavity class II	n =22
LED / Grandio® n = 23	*Cavity class I*	n=6
	Cavity class II	n = 17
Halogen / Filtek™ Supreme n = 28	*Cavity class I*	n = 10
	Cavity class II	n = 18
LED / Filtek™ Supreme n = 21	*Cavity class I*	n=6
	Cavity class II	n = 15

Polymerisation instruments

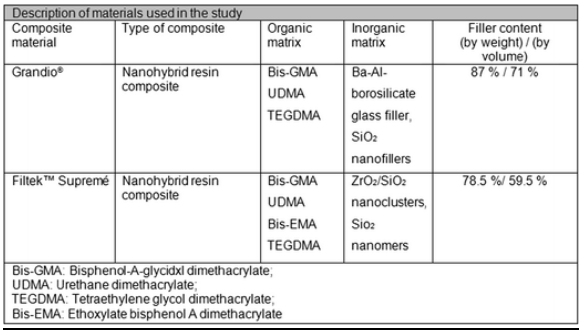
Polymerisation of the restorations was performed with two different light-curing units: an LED prototype designed by the Institute of Materials Science and Technology (IMT, Jena, Germany) and the Polofil Lux, a commercial QTH LCU manufactured by VOCO (Cuxhaven, Germany).

The LED prototype is equipped with a 5-W LED and delivers an emission spectrum of 425–500 nm with an irradiance of 600 mW/cm^2.

The Polofil Lux is a conventional halogen-based LCU with a 75-W halogen light source and an emission spectrum of 400–520 nm which delivers an irradiance of 500 mW/cm^2. The LED LCU used in the present study is a prototype designed by the Chair of Material Science Institute of Materials Science and Technology of the Friedrich Schiller University Jena, Germany. As representative for a QTH LCU, the PoloFil Lux was chosen. The LED prototype enabled a more standardised approach. In order to observe the long-term performance of the composite materials, it was very important to apply curing parameters which were comparable. Both LCUs deliver almost the same output power (halogen 500 mW/cm^2; LED prototype 600 mW/cm^2) as well as emission spectrum (halogen 400–520 nm; LED prototype 425–500 nm). In addition, the tip-diameters of both devices were also of similar size (halogen 7.3 mm; LED prototype 8 mm).

Restoration materials and adhesive systems

In the present study, the nanohybrid composites, Grandio® (VOCO, Cuxhaven, Germany) and Filtek™ Supremé (3M/Espe, Seefeld, Germany), were applied. The composition of the materials is summarised in Fig. 2. Both composites were used in combination with an adhesive system of the respective manufacturer. Grandio® was applied with Solobond M (VOCO, Cuxhaven, Germany) and Filtek™ Supremé with Scotchbond I (3M/Espe, Seefeld, Germany). Total etching was performed for 30 s using Ultra-Etch (Ultradent, Köln, Germany). Afterwards, gentle drying was ensured and the cavities treated by the respective adhesive. Light was applied for 20 s. The cavities were filled by composite increments, each light-cured for 20 s.



Description of materials used in the study

Composite material	Type of composite	Organic matrix	Inorganic matrix	Filler content (by weight) / (by volume)
Grandio®	Nanohybrid resin composite	Bis-GMA UDMA TEGDMA	Ba-Al-borosilicate glass filler, SiO_2 nanofillers	87 % / 71 %
Filtek™ Supremé	Nanohybrid resin composite	Bis-GMA UDMA Bis-EMA TEGDMA	ZrO_2/SiO_2 nanoclusters, Sio_2 nanomers	78.5 %/ 59.5 %

Bis-GMA: Bisphenol-A-glycidxl dimethacrylate;
UDMA: Urethane dimethacrylate;
TEGDMA: Tetraethylene glycol dimethacrylate;
Bis-EMA: Ethoxylate bisphenol A dimethacrylate

Fig. 2. Description of materials used in the study

Composite material	Type of composite	Organic matrix	Inorganic matrix	Filler content (by weight) / (by volume)
Grandio®	Nanohybrid resin composite	Bis-GMA UDMA TEGDMA	Ba-Al-borosilicate glass filler, SiO, nanofillers	87 % / 71 %
Filtek "' Supreme	Nanohybrid resin composite	Bis-GMA UDMA Bis-EMA TEGDMA	ZrO,/SiO, nanoclusters , Sio, nanomers	78.5 %/ 59.5 %

Bis-GMA: Bisphen ol-A-glycidxldimethacrylate ;

UDMA: Urethane dimethacrylate;
TEGDMA: Tetraethylene glycol dimethacrylate;
Bis-EMA: Ethoxylate bisphenol A dimethacrylate

Clinical performance

Patients that showed carious lesions as well as insufficient restorations were selected. Participants who were heavy smokers (> 10 cigarettes/ day) and those who reported highly consumption of dark coloured beverages, wines and teas were excluded. Also, patients with signs of bruxisms as well as teeth that were tender to percussion and/or were determined as non-vital after application of Omnident cryesthesia spray were excluded from the study. If necessary, bite-wings were taken. Before treatment, the tooth underwent prophylaxis with a polishing paste and a brush to remove any surface contaminants such as plaque. The shade of the tooth was identified in daylight using VITA colour samples. If necessary, local anaesthesia was applied and cavities were prepared removing decay and insufficient restorations with 8830.314.010 and 8830RL.314.016 diamonded burs (Komet Dental, Lemgo, Germany) without placement of bevels on the occlusal surface. For isolation, a rubber dam was placed. In case of class II cavities, a Garrison matrix was placed (Composi-Tight Gold, Spring Lake, USA). The cavities were disinfected using a 2% chlorexidine antibacterial solution (Consepsis, Ultradent Products, Inc., South Jordan, UT, USA). Before applying the adhesives, the enamel and dentin surfaces were conditioned by the total-etch technique (Vococid etching gel–orthophosphoric acid 35%), with the appropriate etching times of 30 s for enamel and 15 s for dentin. Vococid was obtained from VOCO GmbH (Cuxhaven, Germany). The adhesive system (Solobond M or Scotchbond I) was applied according to the manufacturers' instructions. The restoration material was put into the cavity using horizontal and oblique increments and carefully adapted to the cavity walls. Each increment had a maximum thickness of 2 mm and was light-cured for 40 s. After curing, the restoration was checked for integrity and adjusted if necessary using diamond burs. After occlusion was checked, the restorations were finished and polished using impregnated silicon rubber cups and points, while final polishing was performed using diamond and silicon carbide impregnated cups, points and brushes (Komet Dental, Lemgo, Germany).

All restorations were placed by one experienced dentist employed at the Department of Conservative Dentistry and Periodontology, Jena, Germany. The restorations were evaluated at baseline and after 6, 12 and 36 months, following the clinical criteria of the CPM Index by only one blinded and trained professional (part C—Table 2) [30, 31]. The number of restorations recalled is summarised for each time point in Fig. 3. The rating scale (code 0–4⁄5) used corresponds to the USPHS index which includes four categories (Alfa, Bravo, Charlie, Delta; Table 2). The USPHS index is based on the rating scale developed by Ryge and can therefore be considered an international accepted system [32, 31]. Overall, the main focus of the study was to observe the long-term performance of composite restorations cured by either halogen or LED light.

Table 2. CPM-Index with C-Clinical criteria, P-photographic criteria, M-micromorphologic criteria in relation to the USPHS-Index (adopted from [31])

CPM-index		
Part C—clinical criteria		
Part P—photographic criteria		
Anatomic form		
0	Correct anatomic form	Alfa
1	Incorrect cavity design	Bravo
2	Incorrect restoration form	Bravo
3	Cavity design and restoration incorrect	Bravo
4	Restoration fracture or restoration loss (partial or total)	Charlie
5	Restoration fracture or restoration loss in combination with incorrect cavity design and/or restoration form	Charlie

Colour match		
0	Matched to adjacent enamel, glossy	Alfa
1	Matched to adjacent enamel, not glossy	Bravo
2	Very bright	Charlie
3	Very dark	Charlie
Surface quality (at least 2/3 of the entire surface)		
0	Smooth, homogenous surface	Alfa
1	Smooth, inhomogenous surface	Bravo
2	Rough, homogenous surface	Bravo
3	Rough, inhomogenous surface	Charlie
Wear		
0	No loss of restoration material according to individual patterns	
1	Local loss of restoration material according to individual patterns	
2	Heavy loss of restoration material	
Marginal integrity		
0	Margin non-detectable by probing	Alfa
1	Margin detectable in fissure ramifications	Bravo
2	Margin detectable in areas with no fissure up to 1/3 of the circumference	Bravo
3	Margin detectable in more than 1/3 of the circumference	Charlie
4	Marginal leakage/gap	Charlie
Marginal ledge		
0	No marginal ledge	
1	Excess of restoration material	
2	Negative ledge	
3	Excess of restoration material and negative ledge	
Marginal discolouration		
0	No discolouration	Alfa
1	Visible discolouration in fissure ramifications	Bravo
2	Visible discolouration up to 1/3 of the circumference	Bravo
3	Discolouration at more than 1/3 of the circumference	Charlie
4	Secondary caries with detectable cavition	Delta
Clinical acceptance		
0	Excellent	
1	Satisfactory	
2	Acceptable after correction	
3	Replacement for prevention	
4	Not acceptable	
Part M—micromorphologic criteria		
Surface roughness		
0	Smooth surface	
1	Local roughness, at least 2/3 of the surface are smooth	
2	1/3 to 2/3 of the surface are smooth	
3	Less than 1/3 of the surface is smooth	
Surface texture		
0	Homogenous surface with no regularly distributed substructures	
1	Local inhomogeneities, at least 2/3 of the surface are homogeneous with no or regularly distributed substructures	

2	1/3 to 2/3 are homogeneous with no or regularly distributed substructures	
3	Less than 1/3 of the surface is homogeneous	
Marginal integrity		
0	Perfect margin	
1	Local marginal irregularities, at least 2/3 of the margin are perfect	
2	1/3 to 2/3 of the margin are perfect	
3	Less than 1/3 of the margin is perfect	
Excess of material		
0	No excess of material	
1	Excess of material up to 1/3 of the circumference	
2	Excess of material from 1/3 to 2.3 of the circumference	
3	More than 2/3 of the circumference with excess of material	
Marginal fracture		
0	No marginal fractures	
1	Marginal fractures less than 1/3 of the circumference	
2	Marginal fractures from 1/3 to 2/3 of the circumference	
3	More than 2/3 of the circumference with marginal fractures	
Negative marginal ledge		
0	No leakage	
1	Leakage less than 1/3 of the circumference	
2	Leakage from 1/3 to 2/3 of the circumference	
3	More than 2/3 of the circumference leakage	
Other restoration imperfections (enamel fracture, bulk fracture etc.)		
0	No imperfections	
1	Imperfections less than 1/3 of the circumference	
2	Imperfections from 1/3 to 2/3 of the circumference	
3	More than 2/3 of the circumference with imperfections	

	C-criteria		Anatomic Form						Colour match				Surface quality				Wear			
	Code		0	1	2	3	4	5	0	1	2	3	0	1	2	3	0	1	2	3
	USPHS criteria		Alpha	Bravo	Bravo	Bravo	Charlie	Charlie	Alpha	Bravo	Charlie	Charlie	Alpha	Bravo	Bravo	Charlie				
time of investigation	test group	n																		
Baseline	LG	23	100	0	0	0	0	0	100	0	0	0	99	1	0	0	100	0	0	0
	LS	21	100	0	0	0	0	0	100	0	0	0	100	0	0	0	100	0	0	0
	HG	28	100	0	0	0	0	0	100	0	0	0	100	0	0	0	100	0	0	0
	HS	28	100	0	0	0	0	0	100	0	0	0	100	0	0	0	100	0	0	0
6 months	LG	20	100	0	0	0	0	0	100	0	0	0	95	5	0	0	100	0	0	0
	LS	20	100	0	0	0	0	0	90	10	0	0	95	5	0	0	100	0	0	0
	HG	26	100	0	0	0	0	0	100	0	0	0	100	0	0	0	100	0	0	0
	HS	25	100	0	0	0	0	0	100	0	0	0	100	0	0	0	96	4	0	0
12 months	LG	20	100	0	0	0	0	0	100	0	0	0	95	5	0	0	100	0	0	0
	LS	21	100	0	0	0	0	0	71	24	5	0	95	5	0	0	100	0	0	0
	HG	24	100	0	0	0	0	0	83	17	0	0	92	0	8	0	100	0	0	0
	HS	25	100	0	0	0	0	0	84	16	0	0	100	0	0	0	100	0	0	0
36 months	LG	15	100	0	0	0	0	0	53	47	0	0	67	0	27	6	73	27	0	0
	LS	15	80	0	7	0	13	0	86	7	7	0	86	7	7	0	87	13	0	0
	HG	18	94	6	0	0	0	0	67	33	0	0	56	6	17	21	78	22	0	0
	HS	18	100	0	0	0	0	0	79	16	5	0	79	16	0	5	89	11	0	0

	C-criteria		Margin integrity					Marginal ledge				Marginal discoloration					Clinical acceptance				
	Code		0	1	2	3	4	0	1	2	3	0	1	2	3	4	0	1	2	3	4
	USPHS criteria		Alpha	Bravo	Bravo	Charlie	Charlie					Alpha	Bravo	Bravo	Charlie	Delta					
time of investigation	test group	n																			
Baseline	LG	23	100	0	0	0	0	100	0	0	0	100	0	0	0	0	100	0	0	0	0
	LS	21	100	0	0	0	0	100	0	0	0	100	0	0	0	0	100	0	0	0	0
	HG	28	100	0	0	0	0	100	0	0	0	100	0	0	0	0	100	0	0	0	0
	HS	28	100	0	0	0	0	100	0	0	0	100	0	0	0	0	100	0	0	0	0
6 months	LG	20	95	5	0	0	0	100	0	0	0	100	0	0	0	0	100	0	0	0	0
	LS	20	100	0	0	0	0	95	5	0	0	80	20	0	0	0	95	5	0	0	0
	HG	26	100	0	0	0	0	100	0	0	0	100	0	0	0	0	100	0	0	0	0
	HS	25	88	12	0	0	0	96	4	0	0	92	8	0	0	0	96	4	0	0	0
12 months	LG	20	100	0	0	0	0	100	0	0	0	100	0	0	0	0	100	0	0	0	0
	LS	21	95	0	5	0	0	100	0	0	0	95	5	0	0	0	95	5	0	0	0
	HG	24	96	4	0	0	0	96	4	0	0	96	4	0	0	0	92	8	0	0	0
	HS	25	100	0	0	0	0	100	0	0	0	92	8	0	0	0	100	0	0	0	0
36 months	LG	15	73	20	7	0	0	80	7	13	0	73	27	0	0	0	53	47	0	0	0
	LS	15	60	40	0	0	0	80	13	7	0	67	33	0	0	0	53	34	13	0	0
	HG	18	83	11	6	0	0	94	6	0	0	61	33	6	0	0	61	39	0	0	0
	HS	18	63	37	0	0	0	89	0	11	0	74	26	0	0	0	58	42	0	0	0

LG = LED / Grandio
LS = LED / Filtek Supremé
HG = Halogen / Grandio
HS = Halogen / Filtek Supremé

Fig. 3. Overview of recalled restorations

Statistics

The data was analysed using the SPSS 19.0 statistics program for Windows. Statistical analysis (multivariable) was performed by the Mann-Whitney *U*and Wilcoxon tests. The significance level was set to $p < 0.05$.

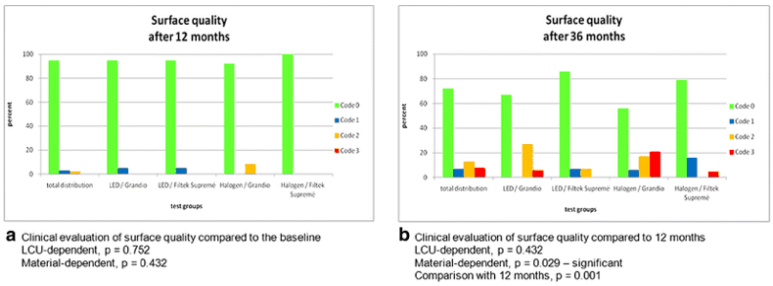
Results

After 36 months, a total of 70% ($n = 70$) of the restorations placed at baseline were evaluated, while 30% ($n = 30$) of the patients did not show up to the final recall appointment.

The overall success rate of the restorations available for evaluation after 36 months was 94% ($n = 66$). Six percent of the restorations could not be evaluated, due either to loss of the restoration (2%, $n = 1$) or because of secondary caries (4%, $n = 3$).

After 12 and 36 months, no significant differences were found between the test groups (LED-Grandio®, LED-Filtek™ Supremé) and controls (Halogen-Grandio®, Halogen-Filtek™ Supremé).

After 12 months, the clinical parameters of colour match, surface quality and marginal discoloration were evaluated with respect to the restoration materials employed and revealed initial changes (code 1 and code 2), regardless of the LCU used (Figs. 4a, 5a, 6a).



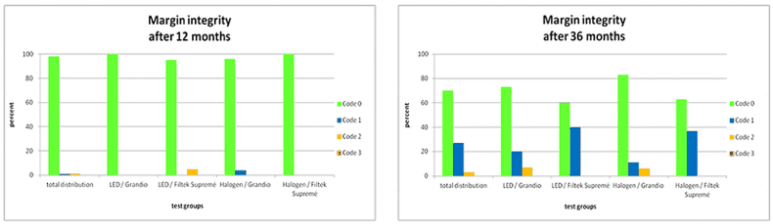
a Clinical evaluation of surface quality compared to the baseline
LCU-dependent, p = 0.752
Material-dependent, p = 0.432

b Clinical evaluation of surface quality compared to 12 months
LCU-dependent, p = 0.432
Material-dependent, p = 0.029 – significant
Comparison with 12 months, p = 0.001

Fig. 4. Criterion "surface quality" after 12 and 36 months

When compared to baseline, significant changes among all evaluated parameters were observed after 36 months (Figs. 4b, 5b, 6b, 7b) within the groups. Throughout the investigation period, no statistically significant influence of the employed LCU on the surface quality was detected. After 36 months, the surface quality of the restorations within the groups was significantly inferior compared to the 12-month examination (Figs. 4a, b). The criterion of surface quality was the quality with the most distinct changes. A total of 8% of the restorations were rated with code 3 (Fig. 4b). In regard to the kind of restoration material, Grandio® showed significant less surface quality compared to Filtek™ Supremé.

With regard to the marginal integrity parameter, no statistical influence of the applied LCU type on the examination results was detected. After 36 months, the codes assessed predominantly were 0 (70%) and 1 (27%) (Fig. 5b), i.e., a significant change compared to the examination after 12 months (code 0 = 98%) was evident. The higher number in code 1, which represents a restoration ledge that can be probed for up to 1/3 of its length, indicates a decrease in margin quality during the observation period.

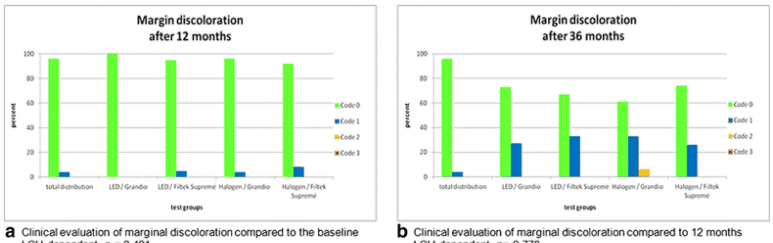


a Marginal integrity compared to the baseline
LCU-dependent, p = 0.886
Material-dependent, p = 0.574

b Marginal integrity compared to 12 months
LCU-dependent, p = 0.574
Material-dependent, p = 0.194
Comparison with 12 months, p = 0.00

Fig. 5. Criterion "marginal ledge" after 12 and 36 months

With regard to the marginal discoloration criterion, too, the type of LCU employed had no significant influence on the examination result throughout the observed period. Overall, a distinct increase in the rate of code 1 assessments was observed between 12 and 36 months after baseline (12 months = 4%, 36 months = 30%) (Figs. 6a, b). No significant changes in regard to the criteria colour match were found during the study period.

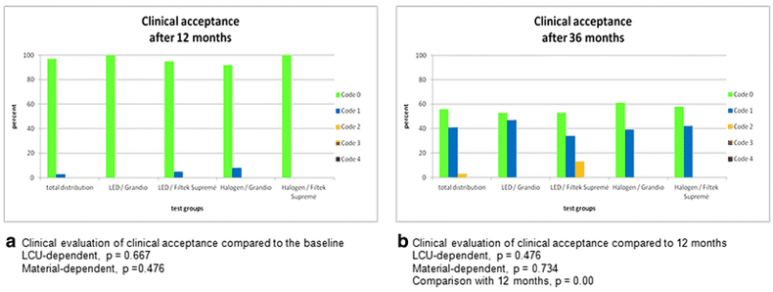


a Clinical evaluation of marginal discoloration compared to the baseline
LCU-dependent, p = 0.401
Material-dependent, p = 0.778

b Clinical evaluation of marginal discoloration compared to 12 months
LCU-dependent, p= 0.778
Material-dependent, p = 0.674
Comparison with 12 months, p = 0.00

Fig. 6. Criterion "marginal discolouration" after 12 and 36 months

For the global criterion of clinical acceptance, again, no statistical difference between the used LCUs was detected. After 36 months, almost all restorations were assessed as acceptable (code 0 = 56%) or acceptable with minor restrictions (code 1 = 41%) (Fig. 7b).



a Clinical evaluation of clinical acceptance compared to the baseline
LCU-dependent, p = 0.667
Material-dependent, p = 0.476

b Clinical evaluation of clinical acceptance compared to 12 months
LCU-dependent, p = 0.476
Material-dependent, p = 0.734
Comparison with 12 months, p = 0.00

Fig. 7. Criterion "clinical acceptance" after 12 and 36 months. Information concerning the clinical acceptance is also presented in Table 2

Overall, the present study showed that after 12 as well as after 36 months, the clinical success of the restorations was uninfluenced by the type of LCU that was applied for polymerisation. No significant results after 6 months of wear were found among the observed criteria.

Discussion

Clinical studies are the ultimate proving ground for testing the durability of composite restoration materials as well as technical innovations inducing the photo-polymerisation process in dentistry. In vitro studies can yield valuable information on diverse material properties and their behaviour under laboratory conditions, but eventually, it is the clinical application alone that decides whether the polymerisation technique and the respective composite are suitable [33, 34].

Apart from the physical properties, the adhesives and composites and the care taken in their application, it is adequate photo-polymerisation that plays the decisive role in ensuring the long-time stability of composite restorations in posterior teeth [19].

The clinical introduction of LED LCUs and their fast establishment in the market strongly promoted a technology that made ever new and more efficient light-curing devices evolved within a very short time. LED LCUs, for example, distinguish themselves by their very stable light emission.

Several in vitro studies on the polymerisation of composites with LED- and halogen-based units have already been reported [21, 14, 15, 18, 35, 25, 26, 36]. It was shown that under laboratory conditions, LED LCUs are just as capable as, or even exceed the capability of QTH LCUs, at polymerising composites [37, 38, 21, 24, 18, 35, 39]. Contrary, Choudhary et al. showed that curing nanocomposites with QTH LCUs results in better micro hardness compared to polymerisation with LED LCUs [40]. To our best knowledge, only one clinical study has so far addressed the question if the type of the LCU (LED or halogen) has any significant influence on the clinical long-term success of resin composite restorations [41]. The mentioned study, however, only compared the clinical performance of composite restorations in cervical lesions. By contrast, the present study was conducted to investigate if posterior resin composite restorations polymerised by LED light are more resistant to wear compared to those cured with halogen light. Other studies have so far only addressed the bonding of orthodontic brackets by means of LED and halogen polymerisation [42, 43, 44]. While these studies suggest clinical reliability of LED LCUs, they do not provide sufficient data to permit any evidence-based statement on the clinical efficiency of LED LCUs for restorations, especially in the posterior teeth. This prompted us to conduct this 3-year study which clinically compares LED-based polymerisation with the long standing gold standard of halogen light curing.

The LED LCU used in the present study is a prototype designed by the Chair of Material Science Institute of Materials Science and Technology of the Friedrich Schiller University Jena, Germany. As representative for a QTH LCU, the PoloFil Lux was chosen [45]. It was shown that both devices are able to sufficiently polymerise resin composites [17, 25]. Because of the rapid progress in the field of light-curing technology, the LED prototype that was used in this study can unfortunately not be compared to the present day high standard LED-curing devices. At the time of the clinical study, the prototype LED LCU was very well studied and ensured a sufficient polymerisation of the applied composites [25, 46, 47, 48]. Furthermore, the LED prototype enabled a more standardised approach. In order to observe the long-term performance of the composite materials, it was very important to apply curing parameters which were comparable. Both LCUs deliver almost the same output power (halogen 500 mW/cm^2; LED prototype 600 mW/cm^2) as well as emission spectrum (halogen 400–520 nm; LED prototype 425–500 nm). In addition, the tip-diameters of both devices were also of similar size (halogen 7.3 mm; LED prototype 8 mm).

To date, several in vitro and in vivo studies have shown that halogen-driven LCUs are able to sufficiently polymerise all contemporary resin composites too. This polymerisation technique, though, has the major disadvantage that the full range of light is delivered for less than 100 h only. In addition, those devices show a high consumption in reflectors and output filters. If not checked regularly, the efficiency of photo-polymerisation declines continuously by time, leading to deterioration in the quality of light curing [49, 13, 22]. However, this was no cause of concern in the present study, because a brand new QTH (PoloFil Lux, VOCO), which was also checked on a daily basis, was used.

The major advantage of an LED LCU is that its projected light output expectancy remains stable for a long period of time, i.e. about 100,000 h, which amounts to about 9,000,000 polymerisation procedures of 40 s each. As the LEDs can be optimally matched to the light spectrum of the composites' photoinitiators, the light output can be utilised for their activation with a high efficiency [50, 13, 22, 14, 16, 18]. This makes it possible to shorten polymerisation times compared to halogen LCUs [26].

In the present study, Grandio® and Filtek™ Supremé were selected as restoration materials because they have proven to resist wear and are of outstanding aesthetic appeal. The clinical performance of both materials as used with the LED and the halogen LCU showed only insignificant differences at the times of clinical evaluation (12 and 36 months after baseline). A comparison between these two time points, however, showed that the clinical parameters had significantly changed. For both composites, regardless of the LCU employed, a distinct increase in colour changes and in margin discolorations as well as a deterioration of surface quality with time was observed. As known from other clinical studies too, the quality of the composite restoration can deteriorate in the course of time [33, 51, 52, 15, 53, 2, 54]. The present study showed, however, that the type of LCU employed (LED or halogen) had no significant influence on the clinically measurable criteria.

The colour changes and the loss of surface lustre, detected in both restoration materials irrespective of the LCU used, can be interpreted as a normal alteration of the composites over an extended period [33, 52, 53, 2, 54]. The more frequent occurrence of a lacklustre surface of the Grandio® composite, regardless of which LCU was used, can be explained by the surface morphology of this material. Its material property, together with the filler size, influences the surface texture and, thus, roughness and lustre [55, 56, 57]. In vitro investigations into surface roughness have shown that, in case of Grandio®, a greater share of the filler can be torn out of the surface during polishing so that its roughness increases [57]. As Filtek™ Supremé's material structure is more homogeneous, its surface is very smooth, and the wear is less visible [57].

With increasing wear and tear, the particular structural properties of Grandio® can cause the surfaces to appear rougher and more inhomogeneous as time progresses, irrespective of the LCU used. Whereas such surface

changes were observed after 36 months with both composites, they were more frequent with Grandio® than with Filtek™ Supremé.

In all groups, discolourations on the margin and a deterioration of the marginal integrity were found among some of the restorations after 36 months. Here again, no influence of the LCU type (LED or halogen) was detected. Margin discolourations are a first sign of a decrease in the marginal integrity of composite restorations; with increasing wearing time, they lead to marginal ledges and marginal gaps detectable by probing [52, 53, 41]. The marginal discolourations found in the present study have, to a similar extent, also been observed in other clinical studies that only used a halogen LCU. Various clinical studies also found that marginal discolourations markedly increased with the length of observation time [33, 52, 53, 41, 2, 54].

The results of the present study do not differ between LED and halogen polymerisation. These results also agree with the result of the only clinical study conducted so far to compare LED and halogen photopolymerisation in cervical lesions [41].

The comprehensive criterion of clinical acceptance provides an overall assessment of the respective restoration evaluated [58, 30, 31, 41]. Regardless of the LCU employed, Grandio® and Filtek™ Supremé feature a high clinical reliability with a total of 97% clinically acceptable restorations after 36 months. With both restoration materials, results similar to those obtained in other clinical studies were obtained [59, 33, 60, 2, 54].

Conclusions

Within the limitations of the present design, the following could be concluded. The analysis of the present clinical data did not reveal any influence of the LCU type on the clinical acceptance of the restorations; this means that LED polymerisation, too, can produce excellent clinical results.

The present clinical study shows that the LED LCU is on a par with conventional halogen-based curing units in clinical use, and especially so in the posterior teeth region.

Notes

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Compliance with ethical standards

Following ethics committee approval (1148–06/03; date of approval 07/10/2003), patients with carious lesions or insufficient restorations were recruited that joined the dental clinic for treatment. Prior to evaluation, all participants signed an informed consent.

Conflict of interest

Mr. Torsten Pflaum declares that he has no conflict of interest. Mr. Stefan Kranz declares that he has no conflict of interest. Mrs. Regina Montag declares that she has no conflict of interest. Mr. Arndt Güntsch declares that he has no conflict of interest. Mrs. Andrea Völpel declares that she has no conflict of interest. Mr. Robin Mills declares that he has no conflict of interest. Mr. Klaus Jandt declares that he has no conflict of interest. Mr. Bernd Sigusch declares that he has no conflict of interest.

Ethical approval

This article does contain studies with human participants. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Submission declaration and verification

The results of the manuscript have not been published elsewhere. The publication was approved by all authors and will not be published in the same form anywhere else.

Informed consent

Informed consent was obtained from all individual participants included in the study.

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