bluephase®

Scientific Documentation

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passion vision innovation

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The new generation of the bluephase family from Ivoclar Vivadent AG now features the polywave LED. What does polywave mean?

So far, only composites containing camphor quinone as photoinitiator could be cured with conventional LED curing lights. All other initiator systems, such as Lucirin TPO, were contraindicated. Compared with halogen lights, this was a drawback. Given the success of LED lights, many manufacturers of dental products had to take this fact into account and modify the composition of their composites, which resulted in compromises in terms of aesthetics and the shelf life of certain products.

polywave now allows users to cure without restrictions in the wavelength range between 380 and 515 nm. The emission spectrum of the new bluephase is therefore comparable to the effective range of halogen lights. Bluephase family featuring polywave can therefore be used to cure composites with all current dental photoinitiator systems without restrictions.

1. Introduction

1.1 Light curing of dental materials

Photopolymerization, i.e. light initiated polymerization, has become an integral part of modern dentistry. Composites, composite-based luting materials and adhesives are all cured with the help of light. The following properties in particular have to be considered in the development of light-curing materials:

- shade and optical translucency of the composite
- shrinkage properties
- initiator system

These features in turn set certain standards for curing lights or polymerization lamps.

1.2 The effect of the colour and translucency on the curing depth

Ideally, a light-curing composite is optically transparent and consequently features a high curing depth. The depth of cure is measured according to ISO 4049. For this purpose, a 6-mm thick test sample is illuminated with light for 40 seconds under defined conditions. Subsequently, the soft uncured portion of the composite sample is scraped off and the remaining sample thickness is measured with a sliding caliper. In addition to the degree of translucency, the depth of cure depends on the exposure time, the shade (i.e. the amount of pigments contained in the composite) and the light intensity of the curing light. The first UV curing lights achieved a limited depth of cure due to poor UV transparency. In addition, they were harmful to the eyes and soft tissue. The power of halogen curing lights, which emit light almost entirely in the visual spectral range, steadily increased as they were further developed:

Astralis 5	approx. 500 mW/cm^2
Astralis 7	approx. 750 mW/cm^2
Astralis 10	approx. 1200 mW/cm^2

As the curing depth increased, the exposure times were significantly shortened.

Plasma-arc and laser curing lights, which achieve a high light intensity, failed to capture the market because they build up too much heat and are very expensive.

Blue light emitting diodes (LEDs) are now used as the most recent light source in polymerization units. LEDs are characterized by the following advantages:

- Light output at room temperature
- High mechanical stability
- Long service life
- Narrow emission spectrum

While the spectral output of early dental LED curing lights tended to be fairly low (approx. 400 mW/cm^2), current lights may attain light intensities of up to 1000 mW/cm^2 and more if they are operated at higher currents.

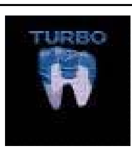
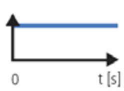
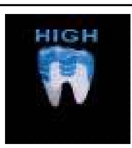
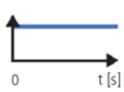
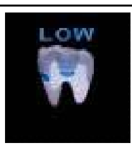
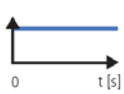
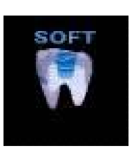
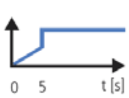
The first product family of bluephase from Ivoclar Vivadent AG was able to meet the exacting demands of LED curing light technology. bluephase, which was launched in 2004, was a curing light with a light intensity of 1100 mW/cm^2. A lot of composites can already be polymerized in 10 seconds. In addition, it is possible to achieve adequate polymerization of luting composites under ceramic restorations. The highlight of the bluephase series is the bluephase 16i with a light intensity of 1600 mW/cm^2, which helps to achieve unmatched short curing times.

1.3 The effects of the light curing method on the polymerization shrinkage

Methacrylate-based monomers constitute the light-curing component in composites and adhesives. As the resin matrix polymerizes, its organized polymer needs less space than its disorganized constituent monomers do. Therefore, the composite shrinks in volume. On the one hand, the volumetric change can be used for controlling the polymerization process via dilatometry. On the other hand, the resulting shrinkage forces may cause stresses and cracks within the composite or separation and detachment at the composite-tooth interface. This may lead to secondary caries and eventual failure of the restoration.

Designing new composites that show less shrinkage is one way of solving this problem. The other method is to reduce the shrinkage stresses by using an appropriate polymerization technique. In the incremental layering technique, the composite is applied in layers and each layer is polymerized individually. As the material is polymerized in smaller quantities, less shrinkage stress develops. A possible decrease in volume may be compensated by the layer that is applied subsequently. Additionally, the gel point may be extended by delayed polymerization initiation. This measure also helps reduce shrinkage-related stresses.

bluephase family features the following curing programs:

			bluephase C8	bluephase	bluephase 20i
			800mW/cm² ± 10% 	1200mW/cm² ± 10% 	2000 – 2200 mW/cm² 
		for maximum performance	---	---	2000 mW/cm²
		for rapid curing	800 mW/cm²	1200 mW/cm²	1200 mW/cm²
		for curing near the pulp	650 mW/cm²	650 mW/cm²	650 mW/cm²
		for stress-reduced polymerization	650/800 mW/cm²	650/1200 mW/cm²	650/1200 mW/cm²

1.4 The effect of the initiator system on the light curing method

Light-curing composite materials set via radical polymerization. Incoming photons are absorbed by molecules (photoinitiator). The energy absorbed excites the molecules. In their active state, these molecules enable the formation of radicals if one or several activators are present. The free radicals then trigger the polymerization reaction. The initiator molecules are able to absorb only the photons of a specific spectral range.

Camphor quinone is typically used as an initiator molecule.

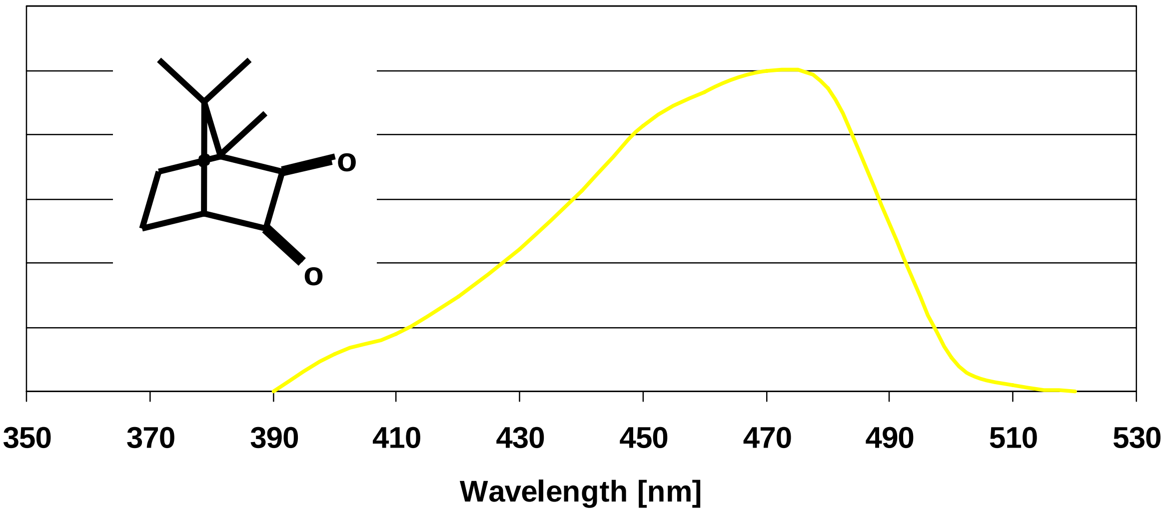


Fig 1: Absorption spectrum of camphor quinone

The peak sensitivity of camphor quinone is near 470 nm in the blue wavelength range. As camphor quinone has an intense yellow colour due to its absorption properties, other initiators have been and are used in dentistry. Alternative initiators are for instance employed in the formulations of composites in bleach shades and colourless protective varnishes.

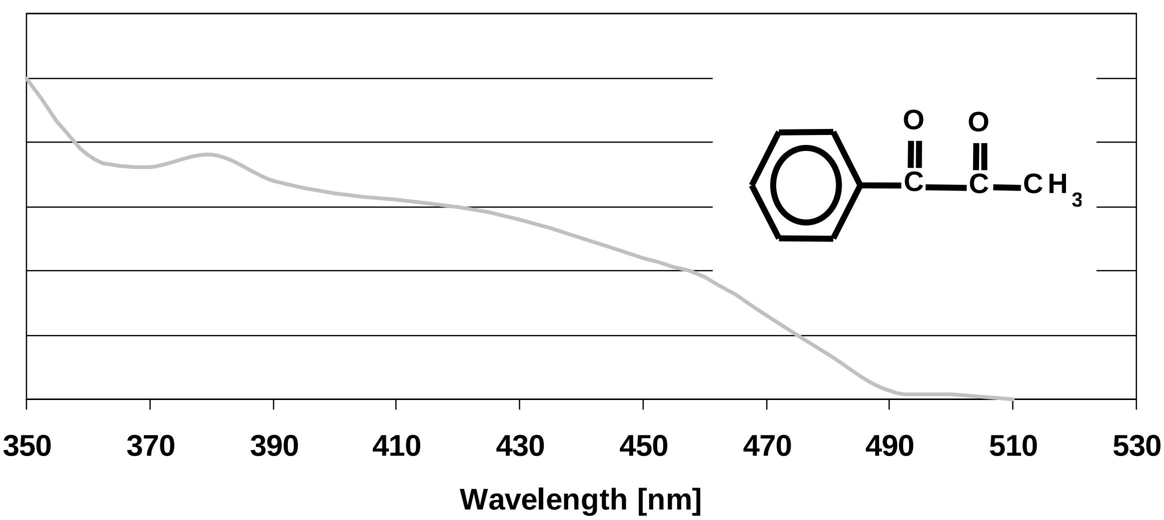


Fig. 2: Absorption spectrum of phenylpropanedione (PPD)

PPD (phenylpropanedione): The absorption spectrum of PPD extends from the UV wavelength range to approx. 490 nm.

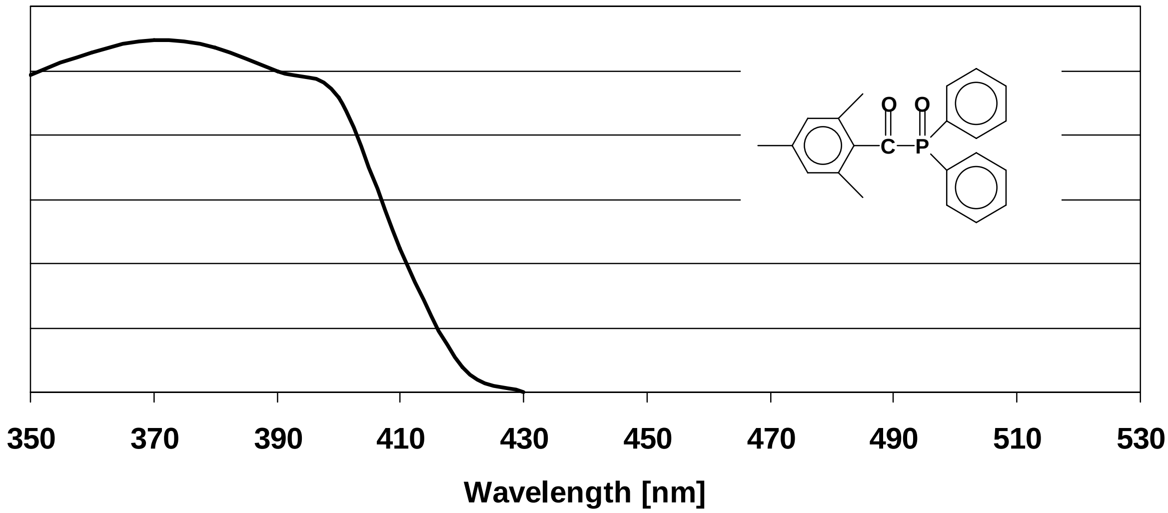


Fig 3: Absorption spectrum of Lucirin TPO

Lucirin TPO is an acyl phosphine oxide. This photoinitiator has gained in popularity because it completely bleaches out after the light reaction is finished. Its sensitivity peak has been shifted to a considerably lower wavelength range.

Lucirin TPO and PPD can be cured with conventional LED lights of the first and second generation only to a limited extent, since their narrow spectral output hardly covers the absorption spectra of these initiators. The objective in the development of new LED lights was therefore to emit light in lower wavelength ranges, which excites Lucirin TPO and PPD similar to halogen lights. The new bluephase has a second spectral peak at approx. 410 nm (see Fig. 5), which allows curing of materials with all photoinitiator systems. A new LED developed by Ivoclar Vivadent AG achieves a spectral peak at approx. 410 nm and 470 nm.

Fig. 4: polywave LED (light emitting diode) which covers the wavelength range of 380 to 515 nm.

The light emitted from the light guide is measured by means of an integrating sphere to accurately determine the light intensity in mW. Appropriate filters ensure that only light in the adequate wavelength range is measured. The light intensity in mW/cm² is calculated on the basis of the cross-section of the light guide.

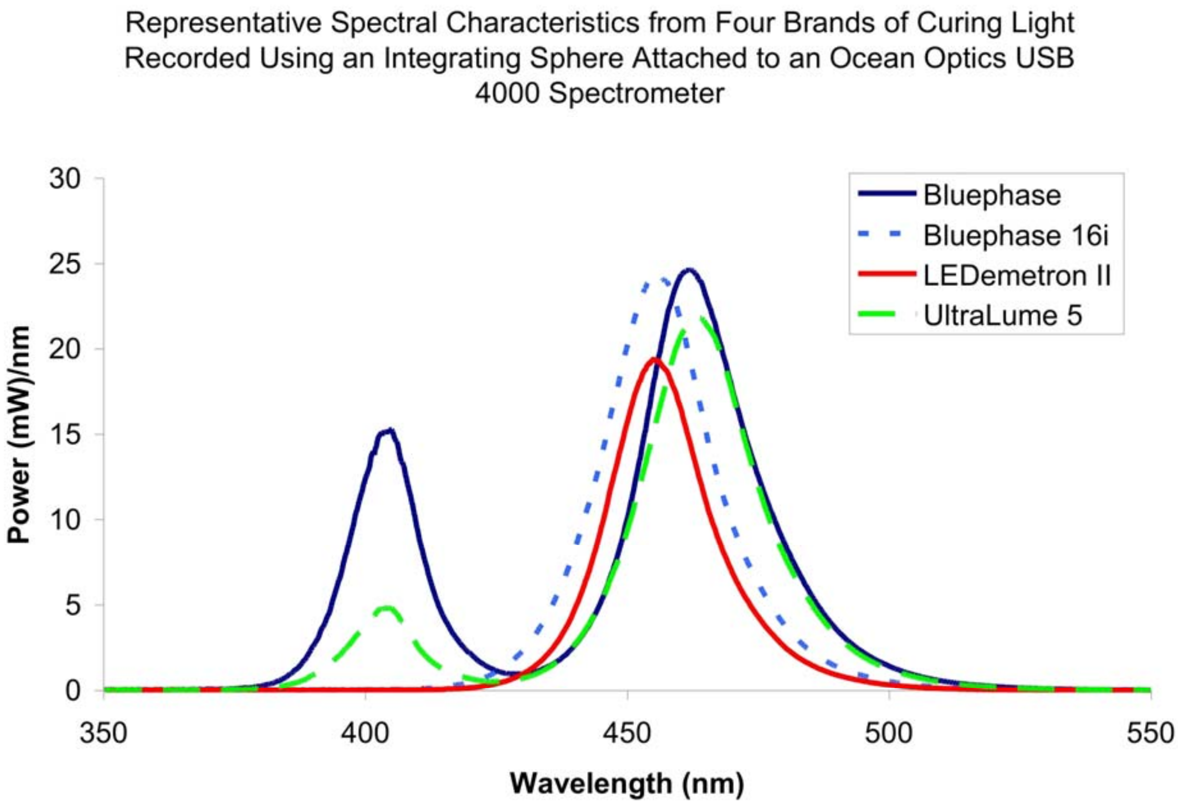


Fig. 5: Wavelength range and light output of bluephase compared to three other LED lights measured with an integrating sphere (Price, Halifax, 2007)

Due to the halogen-like light spectrum, limitations are a thing of the past in the wavelength range of 400 to 500 nm. In general, it is possible to ExciTE all popular dental photoinitiators. This means that light-curing adhesives, bonding agents, luting composites, fissure sealants and other materials can be polymerized in addition to composites.

1.5 The "Total Energy" concept

The “Total Energy” concept states that the process of light-induced polymerization is energy-dependent and basically a product of light intensity and time. Therefore, an irradiation of 20 s with a light intensity of 600 mW/cm^2 results in a dose of 16000 mWs/cm^2.

As a rule of thumb, a dose between 4000 and 16000 mWs/cm^2 is recommended to sufficiently cure a composite increment of 2 mm (depending on the shade and translucency). The higher doses are typically required for darker and less translucent composites. Therefore, depending on the intensity of the curing light used, specific maximum curing times required for curing also more problematic shades can be indicated for curing an increment of 2 mm. This is how the various curing recommendations for curing lights with various intensities are calculated. The curing time to achieve the same degree of curing can therefore be reduced for lights with a high intensity, which helps to save time during the treatment.

Required dose (mWs/cm^2)	16000	16000	16000
Intensity of the light (mW/cm^2)	400	800	1600
Recommended curing time (s)	40	20	10

Table 1: Maximum curing time recommendations according to the “Total Energy” concept

According to studies and measurements, LED lights and halogen lights with identical intensities and curing times achieve comparable depths of curing or hardness profiles (see Table 2)

Intensity (mW / cm^2)	Depth of curing (LED) (mm)	Depth of curing (halogen) (mm)
400	2.40	2.43
600	2.54	2.55
700	2.65	2.67
800	2.73	2.69

Table 2: Depth of curing of Tetric Ceram (according to P. Burtscher, V. Rheinberger; R&D, Ivoclar Vivadent AG)

1.6 Light guide

The light guide too has an influence on the efficiency of polymerization lights. In order to achieve a high power density, i.e. light intensity per surface area, many curing lights are equipped with a light guide that features an emission window of a smaller diameter. For example, the diameter of the “Turbo” light guide of the bluephase 16i decreases from 13 mm to 8 mm. This feature, however, has an adverse effect on the light scattering characteristic. The scattering angle becomes wider and the light intensity decreases more rapidly as the distance grows larger. However, a larger distance cannot be prevented in daily working routines, for example, when curing in deep cavities or curing luting composites through the restoration.

bluephase and bluephase C8 are equipped with a parallel light guide with a correspondingly lower intensity loss if the distance of the light guide to the radiated surface becomes larger. Bluephase 20i is equipped with a 10>8 mm light guide.

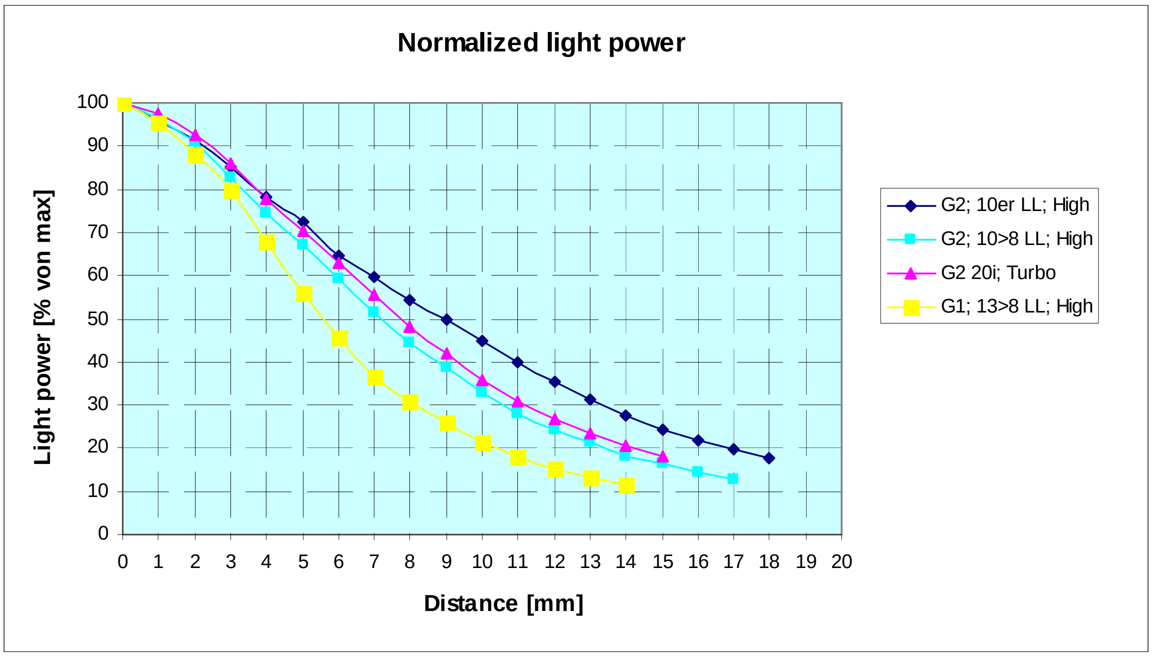


Fig. 6: Decrease of the light intensity in percent with a growing distance to the material to be cured if different light guides are used

		
Homogeneous light scattering of the parallel light guide in bluephase	Light scattering of a Turbo light guide (13>8 mm)	Diffuse light scattering if the LED is mounted in the front

Fig. 7: Light scattering characteristics of different light guides

1.7 Radiometer

Adequate polymerization is a decisive factor when it comes to the clinical success of a composite restoration. For this purpose, it is essential that the polymerization lights in use offer a sufficient light power.

Insufficient polymerization of composites is a common reason for failures in the placement of direct or indirect restorations. Incompletely cured restoratives may cause postoperative sensitivities and even necessitate endodontic treatment.

Therefore, it is required to regularly check the light power of the polymerization lights. This is all the more important, since the light power of the units may drop over time.

A comprehensive study conducted by the University of Mainz (Prof. Ernst) in dental practices in the Rhein-Main area showed that many polymerization lights do not feature the specified light intensities provided by the supplier. In extreme cases, they did not even achieve half of the stipulated power.

Device	**Manufacturer**	**Light intensity [mW/cm^2]**		**Share of light curing units with an intensity of less than 70% compared to the manufacturer's specifications**
		Manufacturer's specifications	Measured mean value	
bluephase*	Ivoclar Vivadent	1100 (± 10%)	1066	0%
Smartlite PS	Dentsply	950	927	0%
Mini L.E.D.	Satelec	1250	872	50%
FlashLite 1401	Discus dental	1400	859	88%
Radii	SDI	1400	825	86%
L.E.Demetron 1	KerrHawe	1000	699	67%
Elipar Freelight 2	3M Espe	1000	602	58%
Translux Power Blue	Heraeus Kulzer	1000	513	100%
Elipar Freelight 1	3M Espe	400	231	88%

Table 3: Light intensities of polymerization lights in the dental practice (C. P. Ernst et al., 2006)

Only inaccurate measurements are carried out with conventional commercial radiometers. Radiometers cannot be calibrated and therefore do not provide precise results. They are only suitable for taking approximate measurements of light intensity. Radiometers are primarily used to observe the drop in power of a curing light, so that the customer may react if the required light intensity can no longer be achieved. However, the diameter of the diffuser cap has to correspond to that of the light guide. The values measured in small light guides tend to be erroneously low, because the radiometer calculates the incoming light according to the diameter of the diffuser cap. In contrast, the intensities measured in large light guides tend to be too high, since the light power is not evenly distributed over the emission window but decreases from the centre to the peripheral. In addition, the different scattering characteristics of various light guides have an adverse effect on the measured value, since there is a distance between the light guide and the sensor.

Fig. 8: Different commercial radiometers

Radiometers are useful for quick routine tests to check the light output of a curing light in the dental office. Only if the above restrictions are borne in mind, radiometers are also suitable for comparing the light output of different curing lights with each other. Due to the different dimensions of light guides, which may vary between 5 and 13 mm in current polymerization units, radiometers available to date are not generally suitable for determining the absolute light intensity.

Integrating sphere

The integrating sphere is used to determine the absolute light intensity of curing lights.

Fig. 9: Measurement with the integrating sphere

The integrating sphere measures the light output in Watt independent of the diameter of the light guide used and the light scattering characteristic. If it is regularly calibrated, it is possible to achieve an accuracy of 5 %. For determining the light intensity, the measured value has to be compared with the actual diameter of the light guide. The light intensity is measured in mW/cm^2.

The integrating sphere is an approved physical measurement device for achieving accurate measuring results of about ± 5 %. However, it is comparatively expensive.

Since the integrating sphere measures the light emission power as an absolute value in mW, the spectral output in mW/cm^2 has to be determined by defining the light emission area and the respective diameter of the light guide. This area, however, has to be measured individually for each polymerization light. The reference value is the actually luminiferous internal diameter of the light guide, which can be measured by means of a commercial calliper. This measurement, however, is error-prone and may result in significant deviations in the determination of the light intensity due to the exponential influence.

bluephase meter

The bluephase meter is a small handy device for measuring the absolute light intensity of all LED curing lights with a circular light emission. The line sensor determines the cross-section of the light guide. The bluephase meter is suitable for all types of LED curing lights. It determines the emitted light power and radiating surface. Based on these data, an integrated micro-processor then calculates the available light intensity.

In the wavelength range of 380 to 520 nm, the sensor determines linearly standardized measuring values. The measuring tolerances are ± 20 % in general. A multiple coating of the sensor offers protection against wear and decrease of the measuring accuracy.

Measuring devices	Customer benefit	Properties
Integrating sphere	Accurate measuring results (particularly for study purposes)	Large, expensive, not suitable for regular measurements in the dental practice
Radiometers and integrated radiometers in curing lights (e.g. bluephase)	Measurement of the light intensity over a defined period of time (during practical use)	Small, handy, easy operation, relatively inexpensive, no accurate absolute values, no comparative values, not suitable for all curing lights
bluephase meter	Reliable measurement of absolute values of the light intensity (during practical use)	Radiometer for measuring the absolute light intensity, universally suitable for all LED light guides with a circular emission window, comparative values possible, small, handy, easy operation, relatively inexpensive

Table 4: Comparison of the measuring devices for determining the light intensity in dental curing lights

Fig. 10: bluephase meter

In contrast, bluephase meter is suitable for all types of LED lights, as long as the light emission window is circular. The measuring tolerances are ± 20 %.

2. The new bluephase® - LED for every use

Advantages and special features
The second generation of the bluephase family sets new standards in the dental praxis with the *"in house"* development of the polywave LED.

Every material due to polywave LED
The ability to polymerize all dental materials depends on the generated light. To date, conventional LED lights have not been suitable for universal use due to the narrow emission spectrum. Like halogen lights, the innovative bluephase achieves a broad light spectrum of 380 to 515 nm. With the specially developed polywave LED, the bluephase light is suitable for all light initiators and thus its use is unrestricted.

Every indication due to continuous cooling
Due to the virtually noiseless built-in fan, the bluephase light can be used for an unlimited period of time to cure all indications. It allows you to avoid unpleasant breaks or having to wait for minutes at a time. bluephase can be used for extensive cementation procedures involving multi-unit restorations, including the consecutive placement of up to 10 veneers.

Every time due to Click & Cure
A cordless design based on state-of-the-art lithium polymer batteries offers the ultimate in mobility. The light can be used wherever it is needed due to the smart Click & Cure function. The handpiece can be connected with the power cord of the charging base to enable continuous operation – no matter if the battery is discharged.

The products
Compared to the classical **bluephase (1200 mW/cm^2)** the mains-operated **bluephase C8 (800 mW/cm^2)** possesses minimally constricted features, which positively effect the price. The battery-operated **bluephase 20i** combines a maximum light intensity of **2000 mW/cm^2** in the Turbo mode with extremely short curing times of minimally 5 s for clear and dark composites.

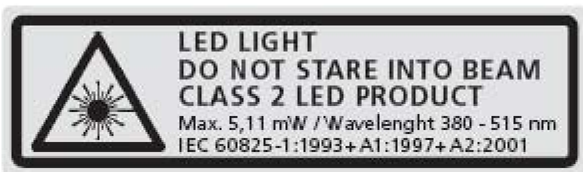
The innovative **bluephase meter** with its unique measuring principle serves for the determination of the light intensity of LED units with a circular emission window.

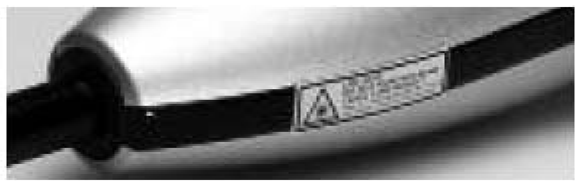
3. bluephase 20i

With the introduction of the bluephase 20i, Ivoclar Vivadent AG offers its customers an unrivalled high power LED unit. In the TURBO programme, the bluephase 20i reaches a light intensity of 2000 mW/cm^2. This allows composite increments to be cured in 5 s.

Particularly for full ceramic restorations and the luting of orthodontic brackets, when continuous maximum power output is required, the high light intensity of bluephase 20i in TURBO mode plays a crucial role.

The high light intensity requires a high light power and this means the bluephase 20i comes under the LED Standard DIN EN 60825-1.





The units have special labels, according to the Standard, and related information is also contained in the Instructions for Use.

For this reason the possibility of clinical risks when using the bluephase and bluephase 20i were also investigated in detail. The studies for temperature rise in the pulp cavity, tissue reactions and the clinical use of bluephase 20i can be found in Sections 5.5 - 5.7. However, even though the study results show there are no increased risks when the bluephase 20i is used according to the manufacturer's recommendations, the user should always take particular care and in case of doubt, use the HIP modus as an alternative.

4. Technical data

Technical data	new bluephase® C8 800 mW/cm² ±10%	bluephase® 1,200 mW/cm² ±10%	new bluephase® 20i 2,000 mW/cm² - 2,200 mW/cm² LED Class 2	bluephase® meter 300 - 2,500 mW/cm² ±20%
Every material (wavelength range)	✓ 380 - 515 nm	✓ 380 - 515 nm	✓ 380 - 515 nm	✓ 380 - 515 nm
Every indication (continuous operation for at least 10 min)	✓	✓	✓	
Every time Click&Cure (optional mains operation)	✓ (mains operation)	✓	✓	
Maximum curing time for composites	20 sec	15 sec	10 sec	
Maximum curing time for Tetric EvoCeram	15 sec	10 sec	5 sec	
Curing programs				Measuring the light intensity of LED curing lights
TURBO	–	–	2,000 mW/cm²	
HIGH Power	800 mW/cm²	1,200 mW/cm²	1,200 mW/cm²	
LOW Power	650 mW/cm²	650 mW/cm²	650 mW/cm²	
SOFT Start	650 / 800 mW/cm²	650 / 1,200 mW/cm²	650 / 1,200 mW/cm²	
Light probe	10 mm black	10 mm black	10>8 mm black	
Power supply	Mains operation (upgrade to battery operation possible)	Lithium-polymer battery capacity: approx. 60 min/ charging time: approx. 2h	Lithium-polymer battery capacity: approx. 45 min/ charging time: approx. 2h	3 x LR6 AA 1,5 VDC
Display	OLED colour display	OLED colour display	OLED colour display	Digital LCD display
Warranty	3 years	3 years (battery 1 year)	3 years (battery 1 year)	3 years

5. Results from external and internal studies

5.1 Composite curing

The efficiency of the light curing of composites can be verified by examining various properties of the polymerized material. Composites change their hardness, flexural strength or modulus of elasticity during polymerization. Spectroscopic methods (e.g. infrared spectroscopy) can be used to determine the chemical conversion of the monomers used.

5.1.1 Surface hardness

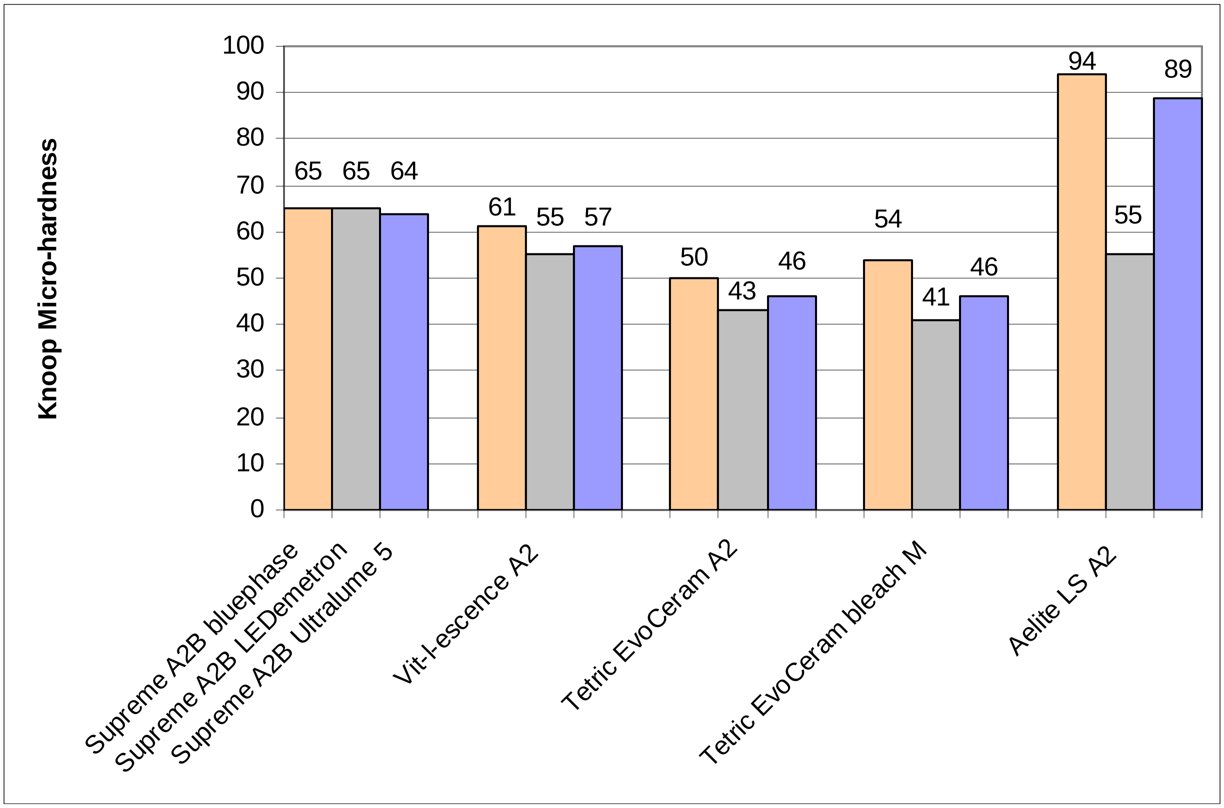


Fig. 11: Surface hardness of five different composites after having been exposed to the light of bluephase (orange), LEDemetron II (grey) and Ultralume 5 (blue) for 10 seconds at a distance of 4 mm from the light guide (Price, Halifax, 2007)

Competitor products: Filtek Supreme (3M ESPE), Vit-l-essence, UltraLume 5 (Ultradent), Aelite (Bisco), LEDemetron II (Kerr Hawe)

The surface hardness provides a measure of the polymerization on the top surface, which is directly exposed to the light of the curing unit and is consequently directly dependent on the intensity of the light applied. The final hardness of the individual composites differs due to their different compositions. In general, the surface hardness reflects a direct connection of the light intensity with the curing light used. The large differences observed with Aelite indicate that an initiator has been used which absorbs light at a low wavelength.

A standard test for composites determines the curing depth which relies on the absorption properties of the composite and its constituents in addition to the light output of the curing light.

In the present study, samples with a thickness of 2 mm were light cured. Besides the surface hardness, the micro-hardness on the bottom surface is determined.

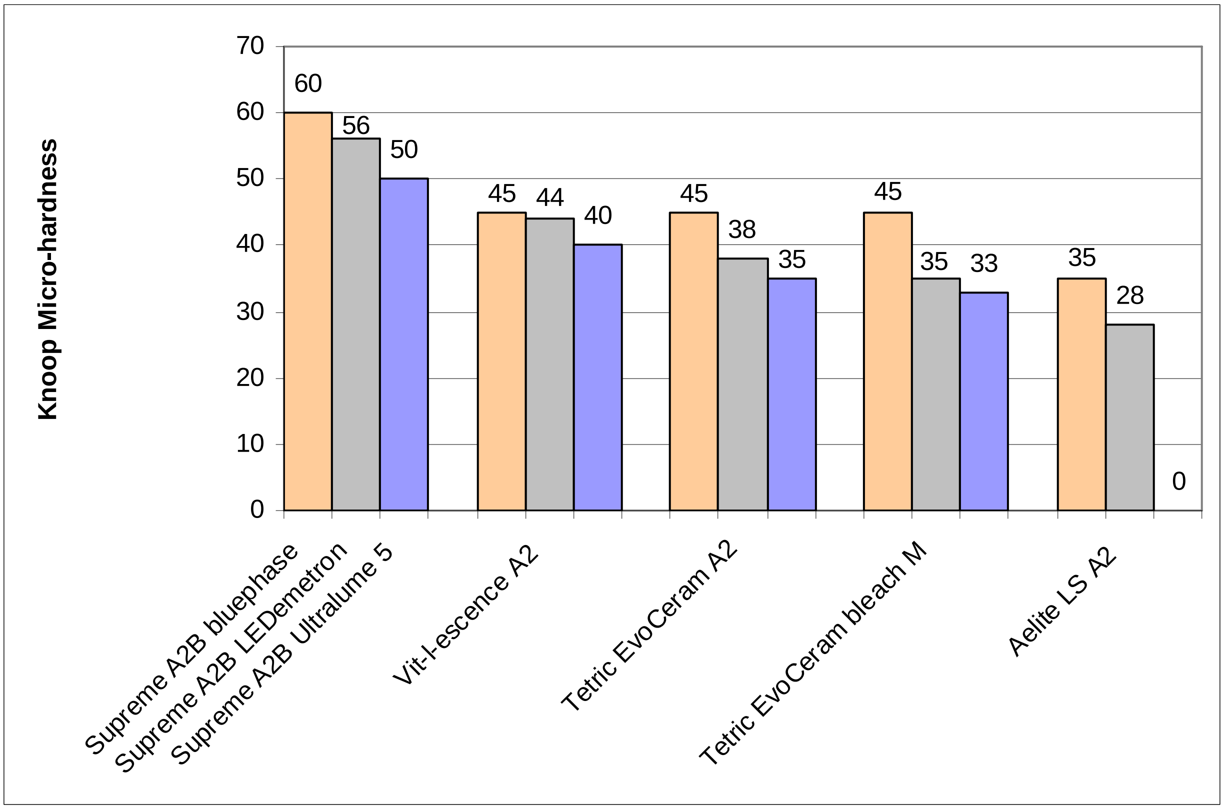


Fig. 12: Micro-hardness on the bottom surface of five different composites after having been exposed to the light of bluephase (orange), LEDemetron II (grey) and Ultralume 5 (blue) for 10 seconds at a distance of 4 mm from the light guide (Price, Halifax, 2007)

Competitor products: Filtek Supreme (3M ESPE), Vit-l-essence, UltraLume 5 (Ultradent), Aelite (Bisco), LEDemetron II (Kerr Hawe)

The light power of the curing light has a considerable effect on the curing depth of the composites irradiated. This is particularly relevant when material has to be cured indirectly through ceramic or composite restorations. In the present case, bluephase has proven its efficacy for curing all the composites tested.

5.1.2 Hardness profile

The hardness profile provides a measure of the polymerization that is achieved throughout the cured composite. The hardness decreases with increasing distance to the illuminated surface. This decrease in hardness depends on the light intensity and composition of the composite. The light intensity decreases as a result of both light absorption by the coloured molecules and scattering by the filler particles. What is known as the “80 % rule” states that if the hardness of the bottom surface is at least 80 % of the top surface the curing depth can be considered acceptable.

Two-millimeter thick test samples were made of Tetric EvoCeram A3 and the top surfaces of these samples were cured with the predecessor model and the bluephase for 10 seconds. After completion of the curing process, the hardness on the top and bottom surfaces was determined and the values compared with each other. The difference between the predecessor model and the bluephase included the wavelength range and the light guide used. While bluephase is equipped with a parallel light guide (∅ 10 mm), the predecessor model used a Turbo light guide (∅ 13 > 8 mm).

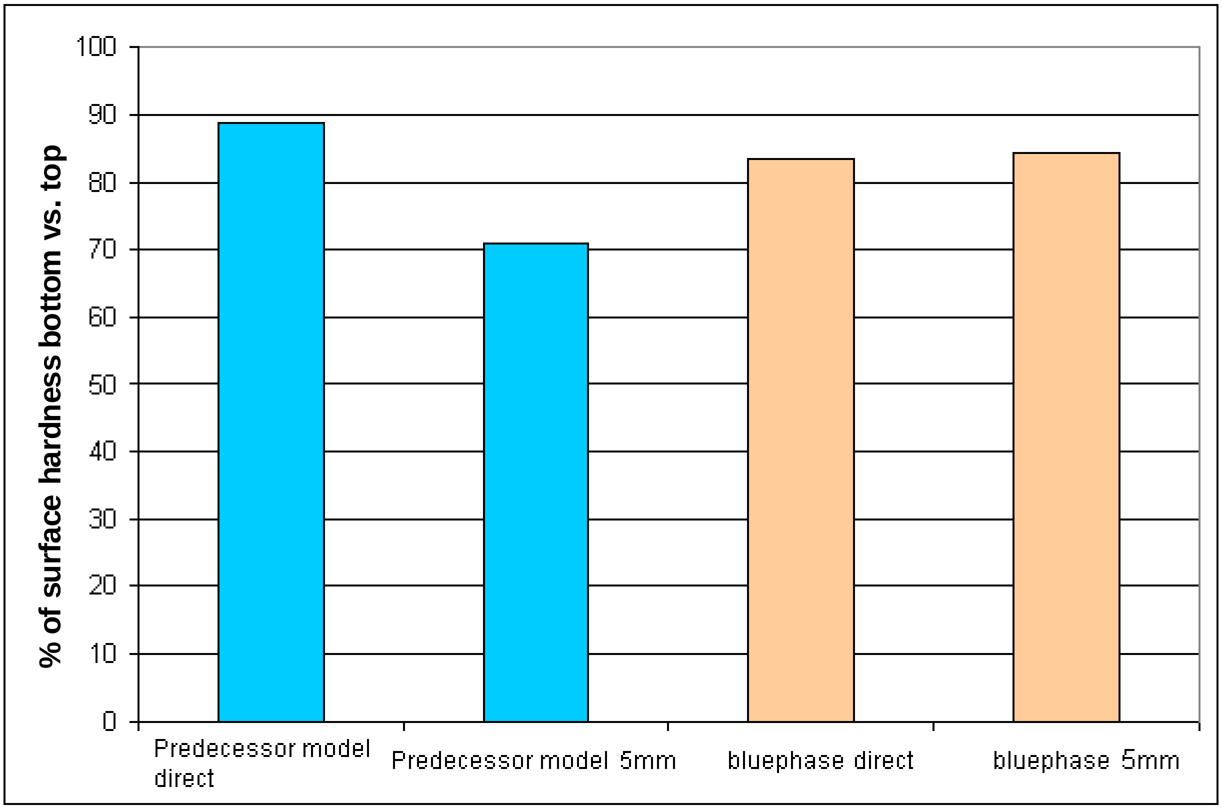


Fig. 13: Differences in the curing quality achieved with curing lights using different light guides (parallel vs. Turbo) at distances of 0 and 5 mm (Price, Halifax, 2007).

The more unfavourable light scattering characteristic of the Turbo light guide is manifested in the difference of the hardness on the top and the bottom if the light guide is held 5 mm above the surface to be cured.

However, a distance to the surface to be cured cannot always be avoided in the dental practice. For curing in deep cavities and hard-to-reach proximal surfaces, the distance to the light guide is the most disadvantageous. In the literature (Price, 2000), it is reported that the light intensity with a parallel light guide is reduced to 50 % and even 23 % with a Turbo light guide if the distance to the surface is 6 mm.

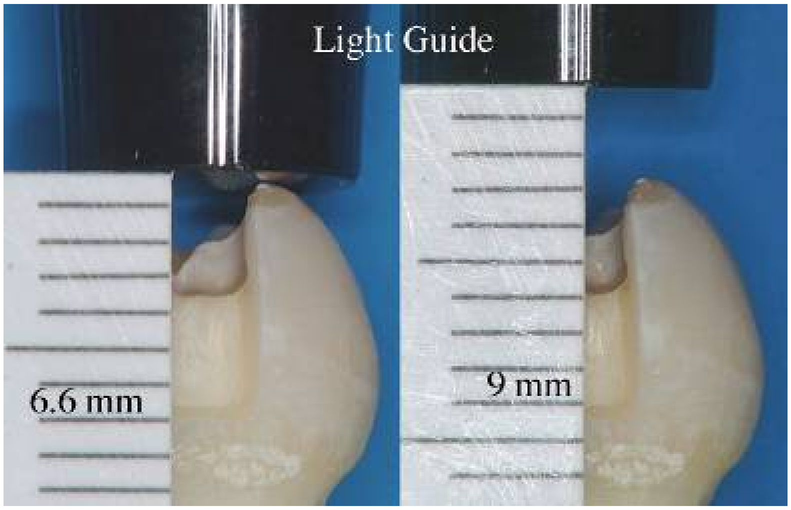


Fig. 14: Distance of the light guide to the composite filling in reality

For simulating real-life conditions, the hardness on the top and the bottom of 2 mm thick samples made of Tetric EvoCeram Bleach M was measured, while the light guide was held 4 mm and 8 mm above the surface to be cured.

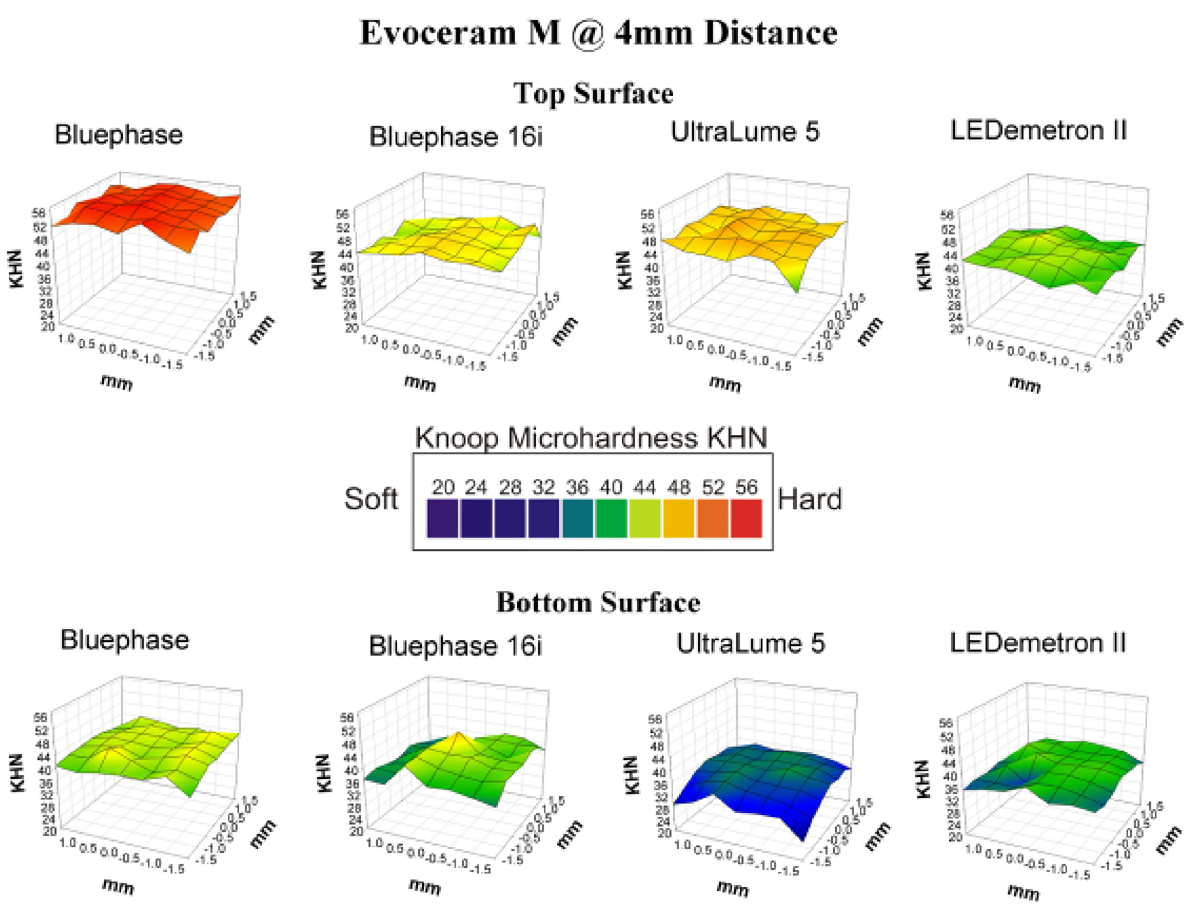


Fig. 15: "Surface Mapping" of the Knoop micro-hardness of Tetric EvoCeram after the material has been exposed to the light of different curing lights for 10 seconds. Distance of the light guide: 4 mm (Price, Halifax, 2007)

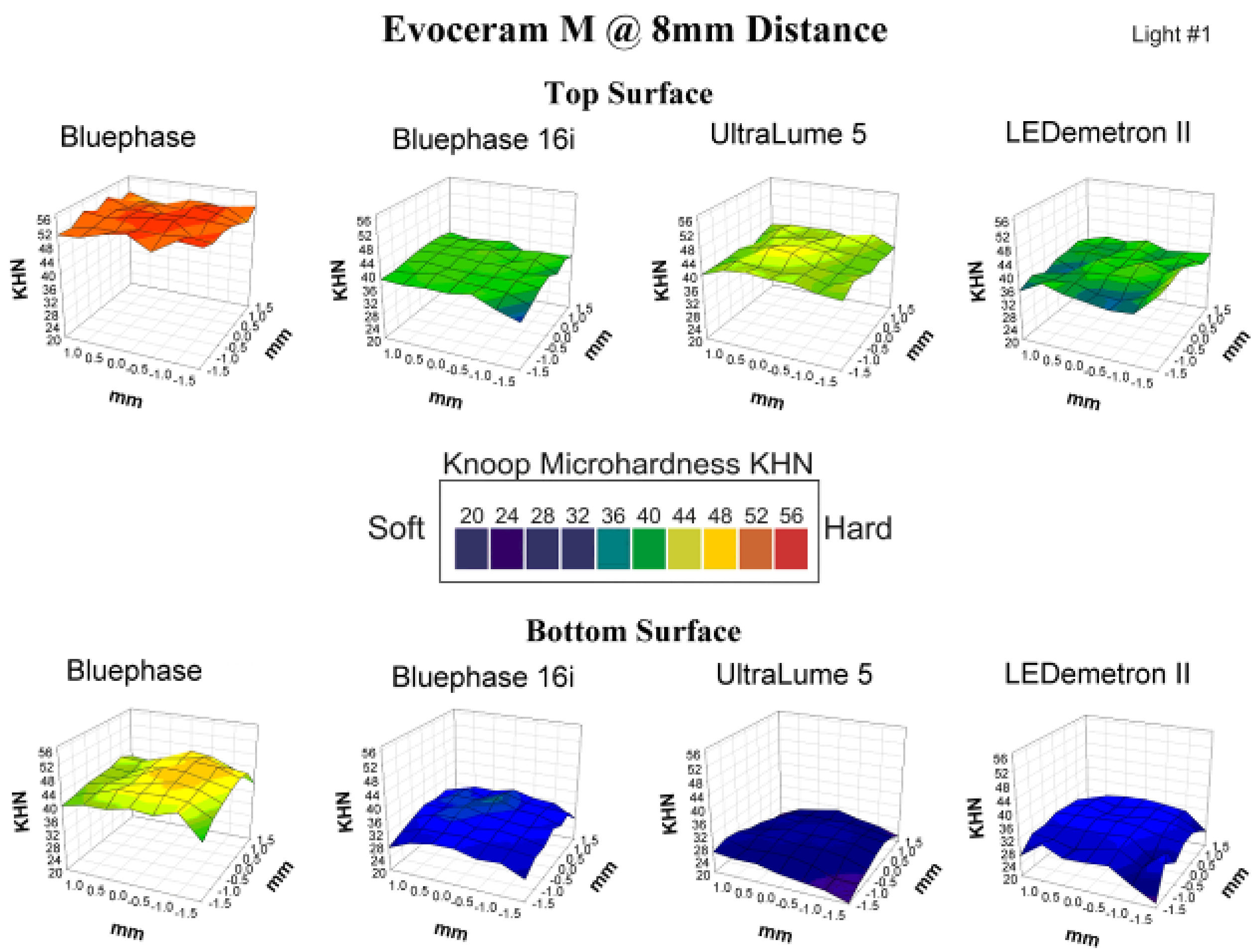


Fig. 16: "Surface Mapping" of the Knoop micro-hardness of Tetric EvoCeram after having been exposed to the light of different curing lights for 10 s. Distance of the light guide: 8 mm (Price, Halifax, 2007)

bluephase confirms that even with an 8 mm distance of the light guide to the surface, the bottom surface of the very opaque Bleach composite is still cured. Thus, bluephase is the clear winner of all the curing lights tested.

5.1.3 Curing of camphor quinone-free or –reduced composites

Given the increasing market share of LED curing lights which cover only a narrow spectral range around 470 nm, the majority of composite formulations has been changed to contain camphor quinone as the initiator. The drawback of camphor quinone is its intense yellow colour, which it only loses during polymerization. As a consequence, the shade of the paste and the cured composite appear to be different. Moreover, the decomposition products may darken under the influence of light over time. In the anterior region in particular, this may pose aesthetic problems.

With the halogen-like spectrum of bluephase, it should be no problem to cure composites with PPD or Lucirin TPO as the initiator.

The table below shows the curing results of experimental composite formulations based on Tetric Ceram tested with bluephase and its predecessor model in comparison with the halogen lamp Astralis 10, which has a similar light intensity.

	Content of CQ	Content of Lucirin	Content of PPD
Composite 1	0.3%		
Composite 2	0.15%	0.4%	
Composite 3		0.8%	
Composite 4	0.15%		0.15%
Composite 5			0.3%

Table 5: Experimental composite formulations with different shares of initiators in the monomer mixture (camphor quinone (CQ), Lucirin TPO, phenylpropanedion (PPD))

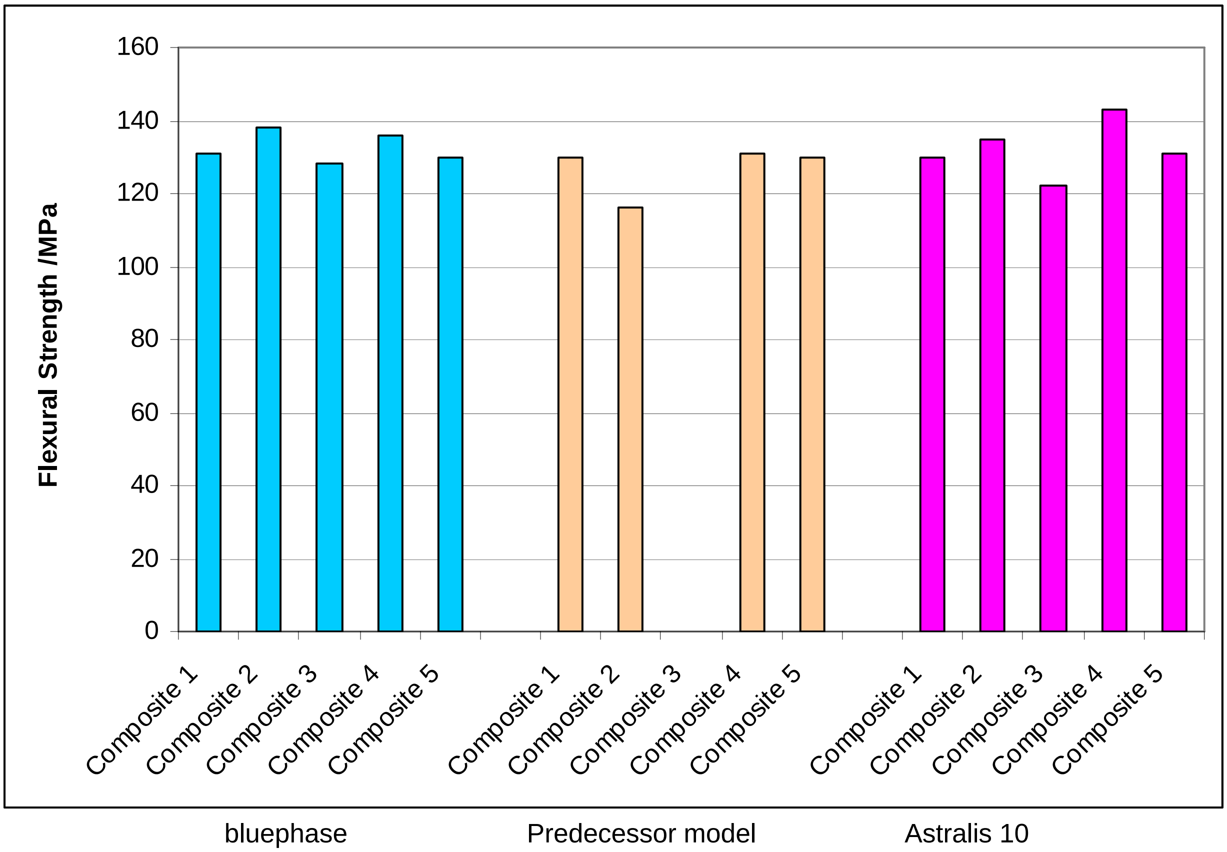


Fig. 17: Flexural strength of different experimental composite formulations with different initiator contents (see Table 2) after having been exposed to the light of the predecessor model, bluephase and Astralis 10 for 20 s using the High Power mode. (R&D, Schaan, 2007)

The narrow spectral range of bluephase allows adequate polymerization of camphor quinone-reduced formulations in a curing time of 20 seconds. However, the polymerization of one composite based only on Lucirin TPB failed. Similarly to the halogen lamp Astralis 10 the broadband LED bluephase allows the curing of all tested composites. Therefore it is justified to speak of a halogen-like light spectrum for bluephase.

In highly acidic adhesive formulations, camphor quinone is subject to gradual chemical changes. This problem is circumvented by using a larger amount of initiator or with acid-resistant initiators, such as Lucirin TPO. Using broadband LEDs should also achieve adequate polymerization of camphor quinone-free formulations.

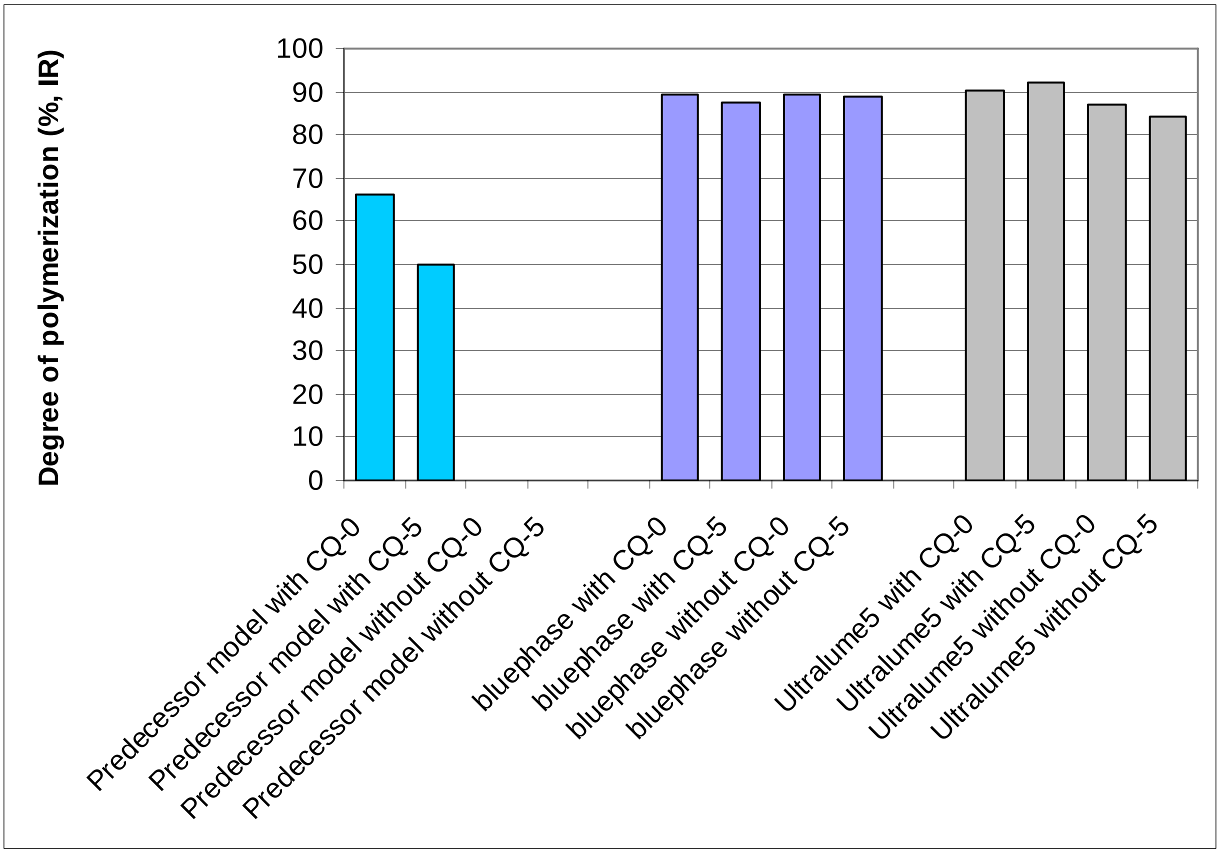


Fig. 18: Curing of the ExciTE adhesive with and without camphor quinone after a curing time of 10 seconds using the Low Power mode with a distance of the light guide of 0 and 5 mm. Measurement of the double-bond conversion using ATR-IR (Ilie, Munich, 2007)

In the above described test, two ExciTE formulations were selected. While one series contained camphor quinone (CQ) as in the sales product, camphor quinone was replaced by Lucirin TPO in the second series. The double-bond conversion in a thin film was examined using ATR-IR-spectroscopy.

While the broadband LED units polymerized both versions of the adhesive, the camphor quinone-free ExciTE could not be polymerized with a conventional LED with a narrow light spectrum.

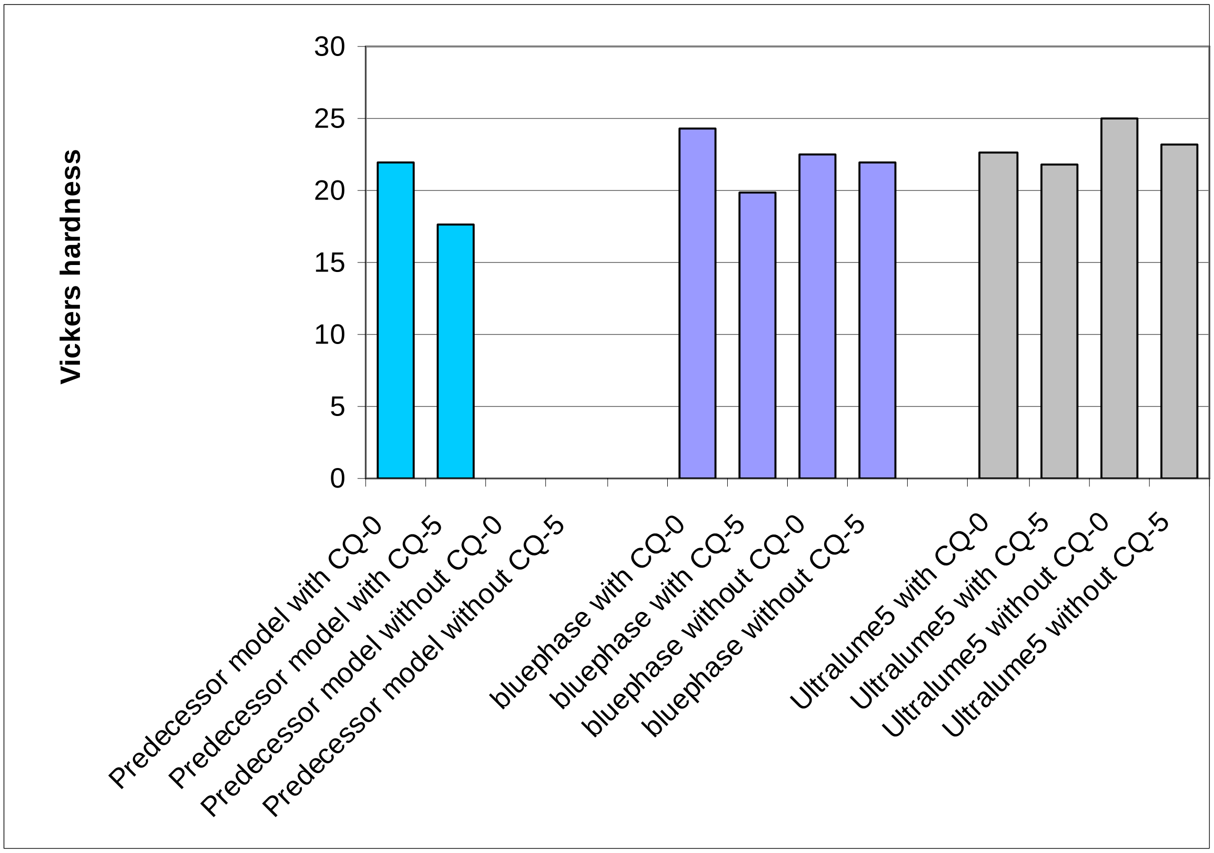


Fig. 19: Curing of the ExciTE adhesive with and without camphor quinone after a curing time of 10 seconds using the Low Power mode with a distance of the light guide of 0 and 5 mm. Measurement of the Vickers hardness. (Ilie, Munich, 2007)

After the Vickers hardness had been determined, the polymerization of the adhesive formulations without camphor quinone with the broadband LEDs was confirmed.

5.2 Curing of adhesives

Inappropriate curing of adhesive cements results in weakened shear bond strength on enamel and dentin. To investigate this issue, the bonding values of ExciTE and AdheSE were compared with each other after these materials were cured with a bluephase light and an Astralis 7 halogen light.

ExciTE: The dentin surface was etched with phosphoric acid gel and then ExciTE was applied and allowed to react for 10 s. Next, the adhesive was light cured for 10 s. Finally, Tetric Ceram was applied in two increments and each increment was light cured for 40 s.

AdheSE: The primer was applied to the dentin according to the manufacturer's instructions. After the primer had been evaporated, the bonding component was applied and light cured for 10 s. Next, Tetric Ceram was applied in two increments and each increment was light cured for 40 s.

The adhesives were light cured with the Low Power mode of the bluephase.

The test samples were stored in water at 37 °C for 24 h prior to measuring the bond strengths.

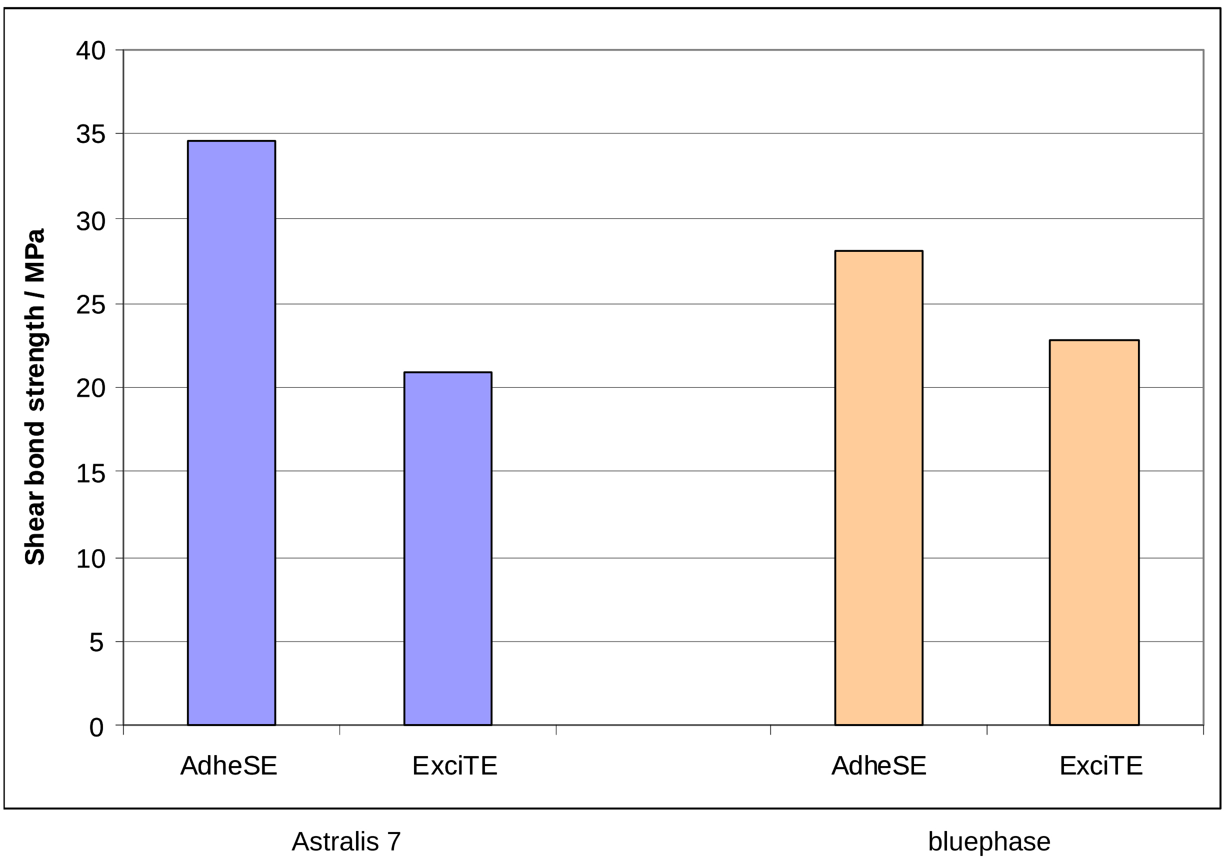


Fig. 20: Comparison of shear bond values of AdheSE and ExciTE on dentin after light curing with bluephase and Astralis 7 (R&D, Schaan, 2007)

Result: When cured with the Low Power mode of the bluephase curing light, both adhesives generated dentin bond strengths that were in the same range as those achieved with the Astralis 7 (Adhesive mode) curing light using identical curing times.

The exothermic reaction time indicates the polymerization speed during the curing process. It is defined by the maximum of released polymerization energy measured by means of a thermosensor. A shorter exothermic reaction time could mean a higher light efficiency.

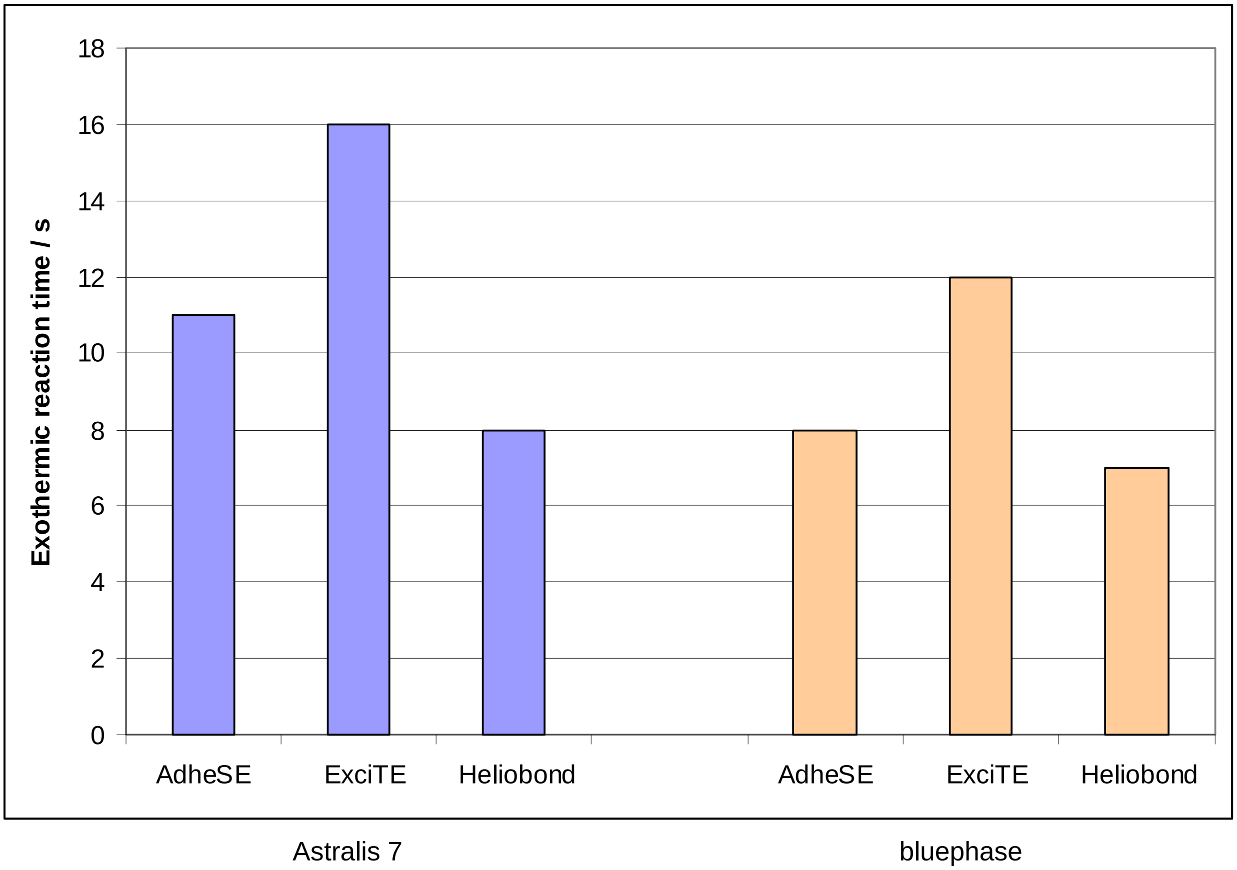


Fig. 21: Exothermic reaction times for AdheSE, ExciTE and Heliobond during light curing with Astralis 7 and bluephase (Low Power mode) (R&D, Schaan, 2007)

The exothermic reaction times for curing with the bluephase light are shorter than with the Astralis 7 light.

5.3 Shrinkage stress

As composites are subject to a reduction in volume during the curing process, a shrinkage stress, which may influence the restoration in a negative way, is formed. The stress that occurs depends on the polymerization kinetics. The faster a reaction is taking place, the higher the shrinkage stress that develops. Therefore, the polymerization stress was compared using the composite Tetric EvoCeram A2 cured with various polymerization lights.

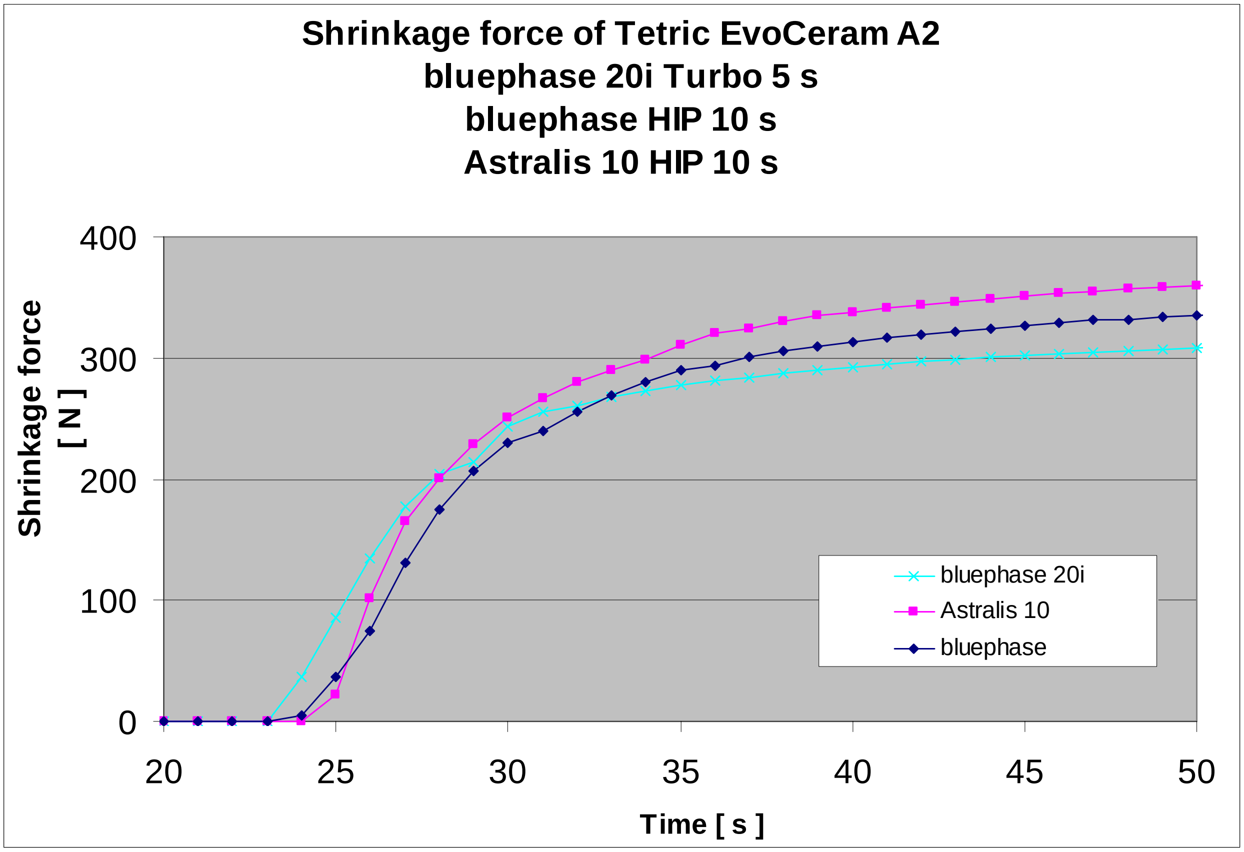


Fig. 22: Measurement of the shrinkage force of Tetric EvoCeram when cured with bluephase, bluephase 20i and Astralis 10 (Burtscher, Ivoclar Vivadent AG 2008).

Due to the rapid polymerization, the shrinkage stress increases at an earlier stage as compared with the regular bluephase. If the entire polymerization period is considered, the absolute value of the overall shrinkage force is not higher than for bluephase or Astralis 10.

5.4 Complete curing through ceramic material

Light- and dual-curing composites are used for the adhesive cementation of indirect restorative materials. Particularly in the case of all-ceramic restorations based on glass-ceramic materials, the adhesive cementation using composites is recommended. Due to the opacity of such materials, however, the amount of light which effectively reaches the composite is considerably reduced. Therefore, most luting composites also contain initiators for self-curing.

For reasons of aesthetics, the self-curing catalyst is often omitted in the case of translucent materials or restorations placed in an exposed and visible area. The catalyst often contains amines, which are not light-stable over the years. Therefore, purely light-curing cementation systems, such as Variolink Veneer, are used in the anterior area for e.g. ceramic veneers.

At this point at the latest, the question whether or not enough light can penetrate through the crown or the inlay to sufficiently cure the composite is raised.

Dr Ilie, who works with Prof. Hickel at the LMU Munich, analyzed the effect of various types of ceramics, layer thicknesses and translucencies on the curing depth of a purely light-curing composite (Variolink II Base).

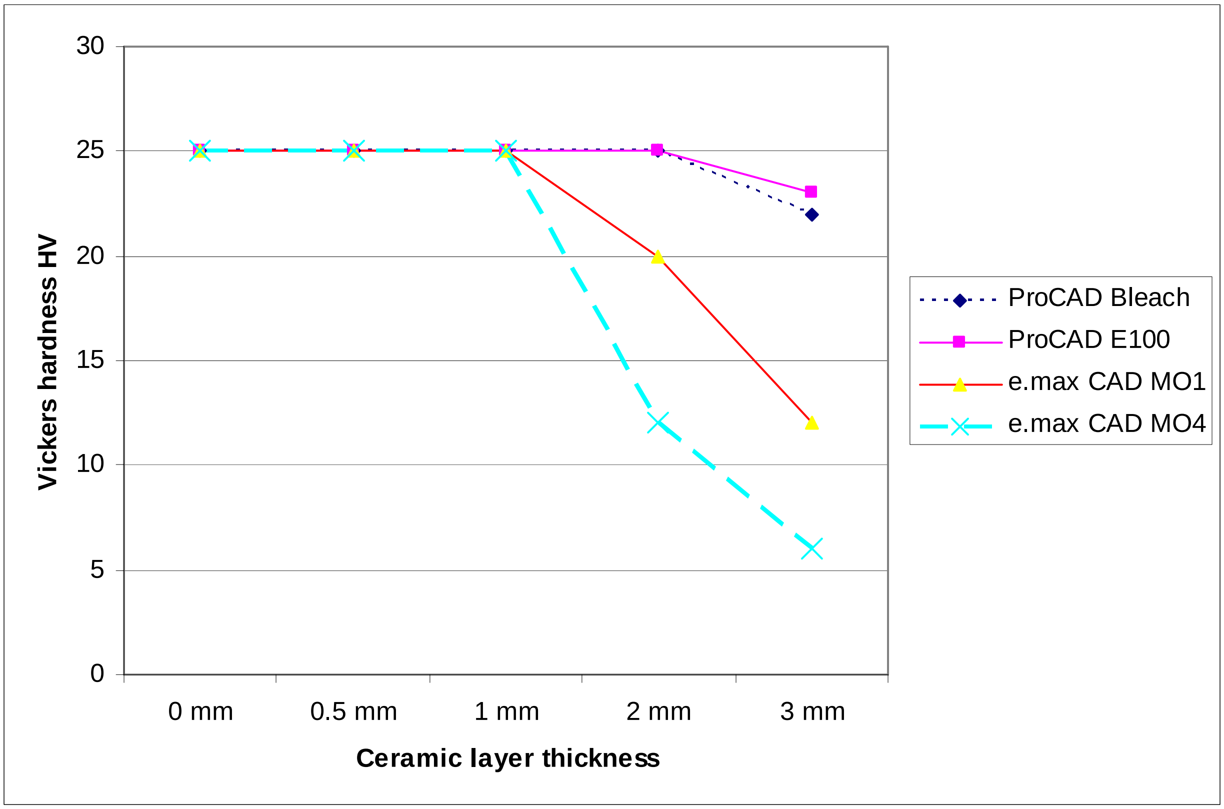


Fig. 23: Vickers hardness of Variolink II Base after curing through ceramic layers of various thicknesses (ProCAD and IPS e.max CAD) (Ilie, Munich, 2007)

ProCAD is a relatively translucent leucite ceramic (comparable with IPS Empress CAD), IPS e.max CAD MO is a rather opaque lithium disilicate framework ceramic. The composite is thoroughly cured through a translucent ceramic layer of 3 mm, while a decrease in hardness is noted already at a layer thickness of 2 mm through a more opaque ceramic. In such cases, it is recommended to use a dual-curing luting composite.

5.5 Heat development and temperature rise around the pulp

The high light intensity of 1200 mW/cm^2 also generates a perceivable heat if the light probe is directed directly at the skin.

Particularly when areas around the pulp are cured, high-performance lights entail the risk of a high temperature development in the pulp chamber that is sufficient to irreversibly damage the tissue.

Prof. Rueggeberg from the Medical College of Georgia developed a method to investigate heating of the pulp. This method has already been adopted by many researchers.

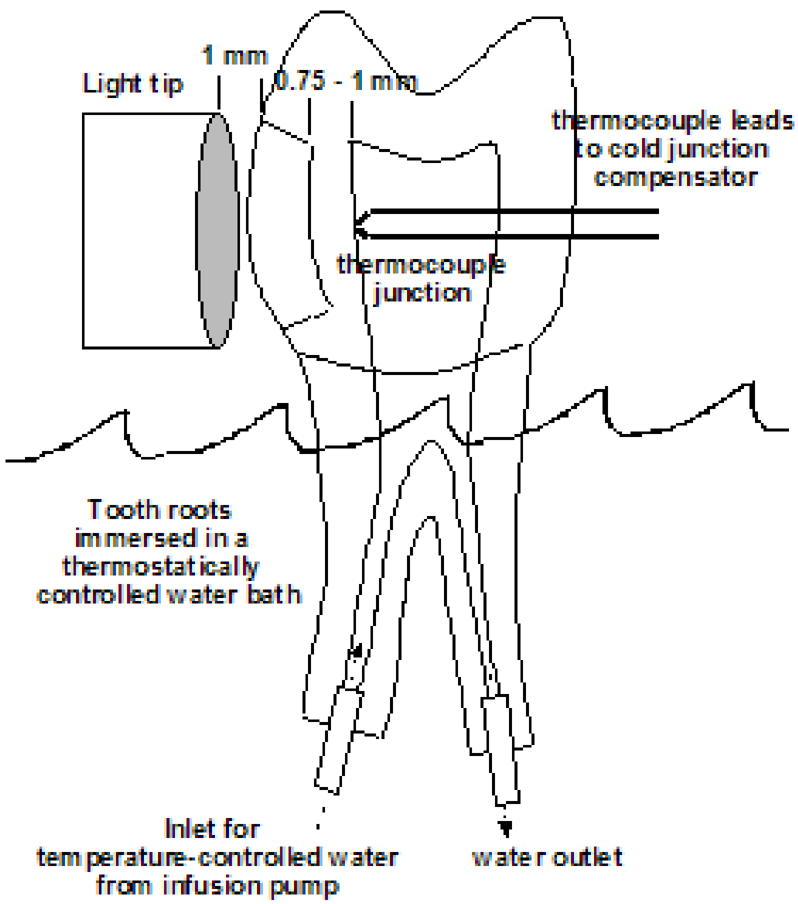


Fig. 24: Diagram of the temperature measurement in the pulp chamber when a buccal cylindrical cavity is irradiated.

A buccal cylindrical cavity is prepared in a premolar. The wall to the pulp chamber should display a thickness of 0.75 to 1 mm. The apical ends of the roots are cut to allow a constant flow of water which simulates the heat exchange of the blood flow. An access to the pulp chamber is prepared opposite the cavity and a temperature sensor is inserted. The tooth roots are immersed in a temperature-controlled water bath of 34.0 ˚C (93.2 ˚F).

The light tip is positioned at a distance of 1 mm to the surface of the cavity.

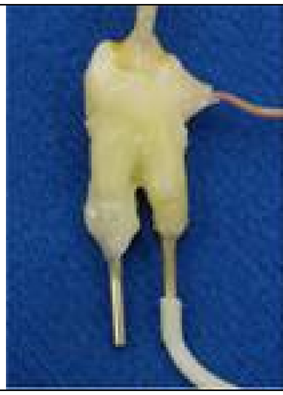


Fig. 25: Photograph of an experimental tooth model	*Fig. 26: Respective X-ray image*

The adhesive is applied before the first composite layer. This is the step where the process is the closest to the pulp. Light-curing is carried out in the Low Power Mode at approx. 650 mW/cm^2.

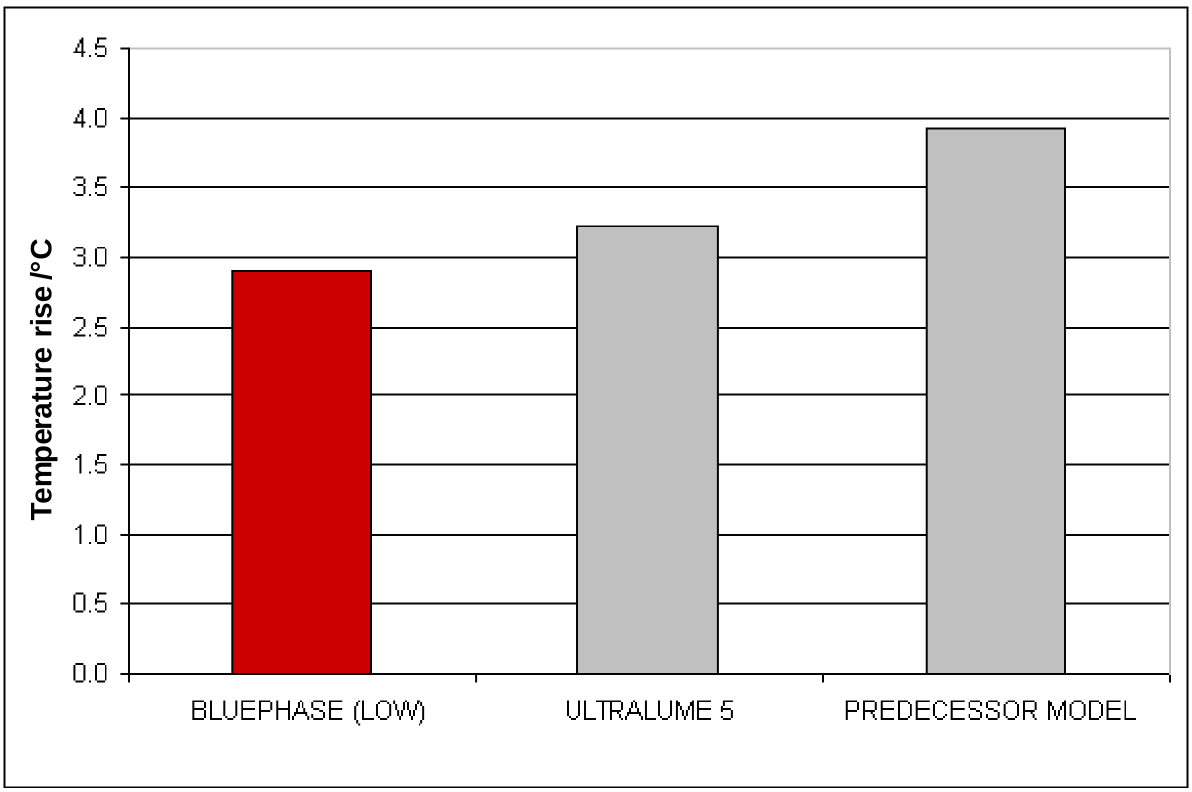


Fig. 27: Temperature increase after a curing time of 10 s in the curing mode for adhesives (Rueggeberg, Augusta, 2007)

The rise in temperature for bluephase is in the range determined for comparable curing lights and, with a value below 3 ˚C (approx. 5.5 ˚F), relatively low.

In a second stage, an increment (approx. 2 mm) of Tetric Ceram is applied in the cavity. The increment is cured using the High Power mode. The temperature is registered after 10 s and 20 s. bluephase is compared with another experimental light form Ivoclar Vivadent AG, Ultralume 5, and the previous model.

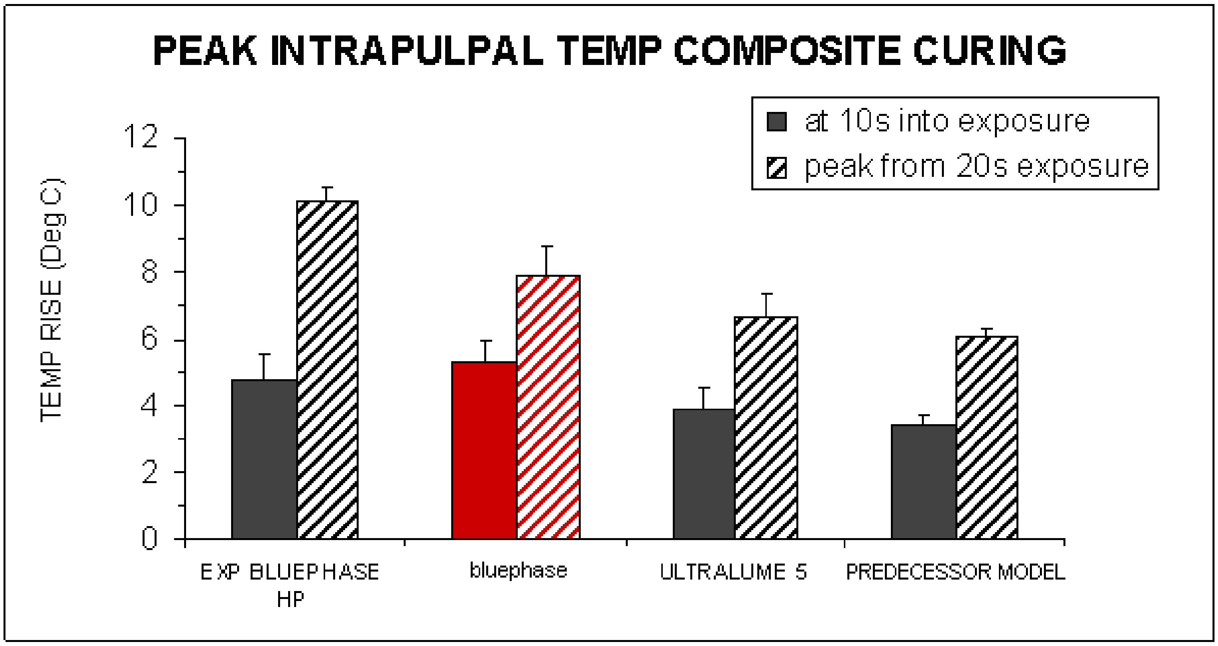


Fig. 28: Temperature rise after curing of the first composite increment using the High Power mode. (Rueggeberg, Augusta, 2007)

A temperature increase of 5.5 ˚C (approx. 9.9 ˚F) is noted after the recommended curing time of 10 s.

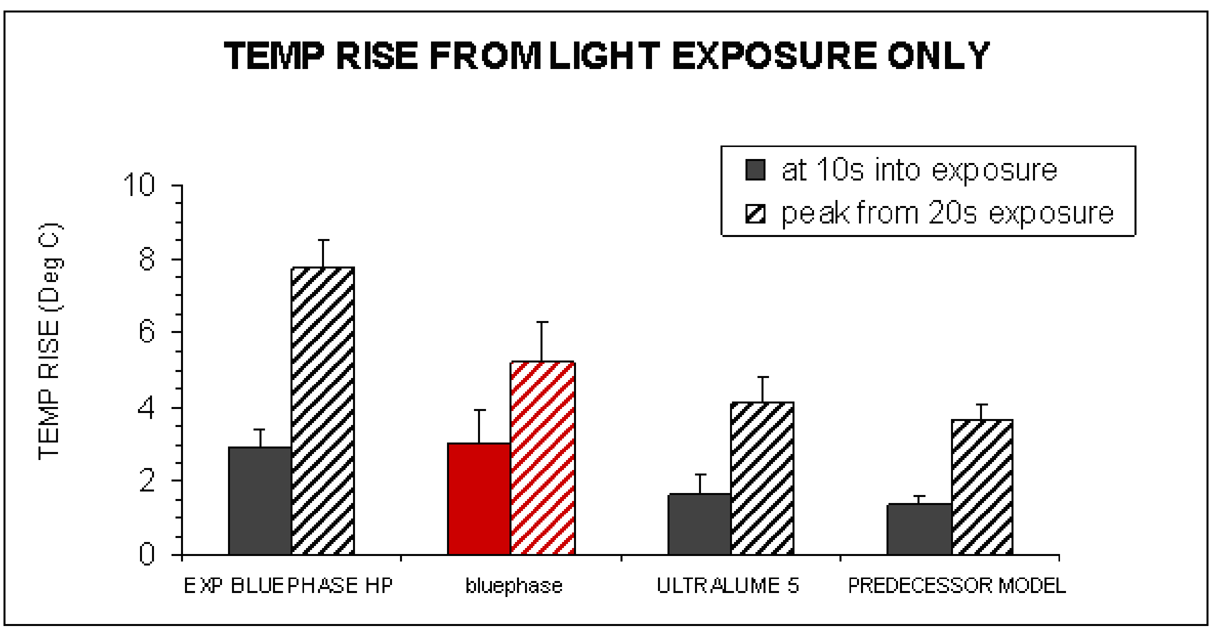


Fig. 29: Temperature increase after direct irradiation of the bottom of the cavity without composite (Rueggeberg, Augusta, 2007)

The effect of the polymerization light on the temperature increase is considerably lower. This measurement also allows the determination of the temperature development exclusively caused by the exothermic setting reaction.

The results of these investigations and further internal tests on the temperature development in the area close to the pulp reveal no increased risk for the vitality of the tooth in comparison with other, already established polymerization lights. According to current knowledge, the use of bluephase is safe if the Instructions for Use are observed and common sense is used.

bluephase 20i has been tested using the same test conditions.

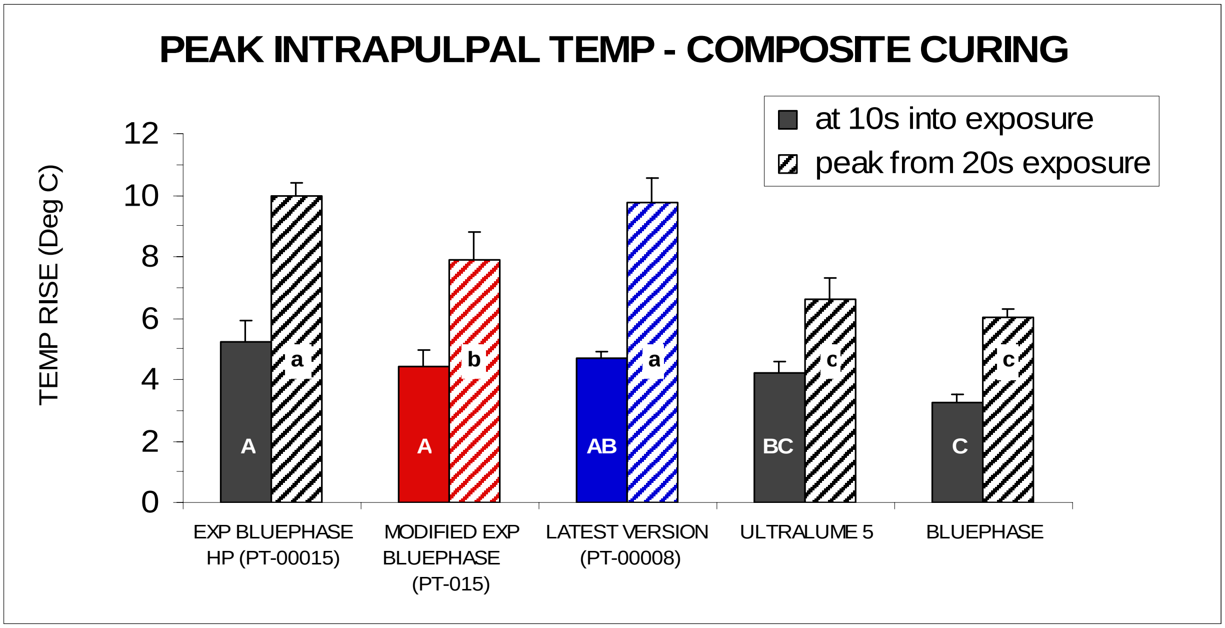


Fig. 30: Temperature increase after irradiation of the first increment of composite material using the High Power / Turbo mode (bluephase 20i, blue bar). (Rueggeberg, Augusta, 2007)

As expected, the prototype PT-00008 (bars in the middle) shows the highest temperature increase for the first composite increment if the Turbo mode is used for curing. Therefore, this intensive mode will be limited to a continuous operation of only 5 s.

5.6 Heat exposure of soft tissue

The influence of direct exposure of soft tissue to the polymerization light has been tested in living rats at the SUNY in Buffalo. According to a standard model, the working group of Prof. Munoz irradiated the cheek tissue in the Turbo program using bluephase 20i for 5 s and 10 s and carried out histological investigations after 30 min, 24 h and 7 d. No necrosis was detected for irradiation times of 5 s. If the tissue was irradiated for 10 s, necroses were observed. However, after seven days the affected tissue had been entirely regenerated. Based also on these results, a curing cycle of 5 s is recommended.

5.7 Clinical experience with bluephase 20i

A prototype of bluephase 20i was used in the internal practice by Dr Peschke. If used according to the indications (5 s in the Turbo program) no negative or critical event was observed in a patient. The patients did neither report an unpleasant heat development nor was a tooth devitalized. The experiences made by Prof. Munoz in a field test in Buffalo allow the same conclusion. No negative event related to the high light intensity of the LED light was reported.

5.8 External investigations with the bluephase meter at the University of Mainz

Investigations in the US, for example, have shown that conventional radiometers are not suitable for comparing different polymerization lights.

Light	Type	Tip	L.E.D. Radiometer (Kerr)	Optilux Radiometer	LED Radiometer (SDI)	Cure Rite
			(mW/cm²)			
Optilux 501	HAL	8mmT	800	800	625	1,337
Spectrum 800	HAL	8mm	600	500	590	722
LEDemetron II	LED	8mmT	1,300	1,000+	1,385	1,862
bluephase 16i	LED	8mmT	1,400	1,000+	1,343	2,000+
Sapphire	PAC	9mm	1,575	1,000+	960	2,000+

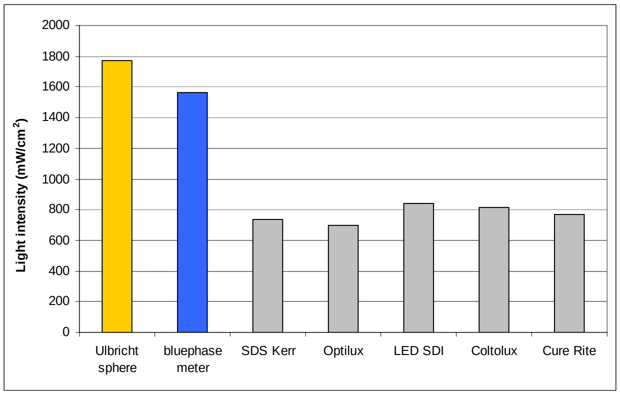
Fig. 31: Light intensities of different polymerization lights measured with four radiometers (Reality Vol. 20, 2006)

The objective of one study was to examine whether the bluephase meter is able to accurately determine the light intensity of the polymerization light to be tested. The light intensity measured with the integrating sphere served as the standard. The values determined are still results of a preliminary final report. A first prototype of the bluephase meter was used for the study. Thus, no value could be determined for the Radii. The light intensity of the Elipar Tri Light with the 12 mm light guide is below the detection limit.

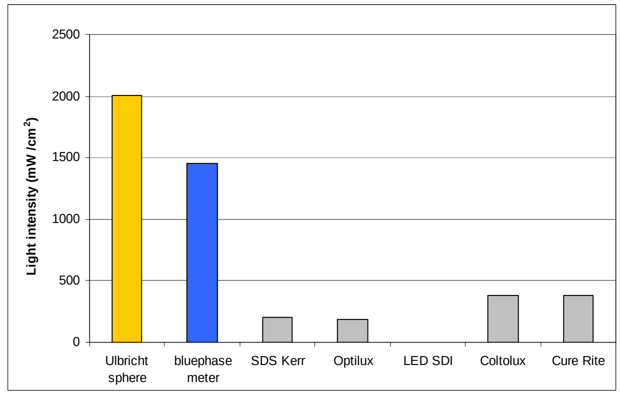
	Mean values	Mean values	Mean values	Mean values	Mean values	Mean values	Mean values
Light source	**Integrating sphere**	**bluephase meter**	**LED (SDS Kerr)**	**Optilux (Kerr)**	**LED SDI**	**Coltolux (Coltene)**	**Cure Rite (Dentsply)**
Elipar Free 3M ESPE	**1131**	**1118**	**1166**	**1000**	**1226**	**1163**	**1311**
bluephase	**1351**	**1197**	**1200**	**1000**	**1421**	**1284**	**1333**
bluephase 16i (12 mm)	**671**	**664**	**425**	**435**	**560**	**634**	**434**
bluephase 16i (6 mm)	**2419**	**1563**	**735**	**695**	**838**	**812**	**766**
Mini LED (Satelec 5 mm)	**1555**	**690**	**788**	**708**	**966**	**1016**	**1031**
LED Demetron II (7 mm)	**1239**	**976**	**1140**	**1000**	**1487**	**1330**	**1511**
Smart Lite PS Dentsply (7 mm)	**1186**	**921**	**800**	**790**	**1052**	**1034**	**1192**
Translux Power Blue Hereus Kulzer (6 mm)	**1170**	**924**	**787**	**696**	**913**	**729**	**818**
Radii (SPI)	**1874**	**0**	**869**	**751**	**1943**	**0**	**0**
Optilux 501 Kerr (10 mm)	**493**	**808**	**600**	**585**	**518**	**738**	**772**
Optilux 501 Kerr (7 mm)	**912**	**863**	**634**	**714**	**612**	**1000**	**987**
Elipar Tri Light (12 mm)	**295**	**0**	**200**	**190**	**0**	**374**	**374**
Elipar Tri Light 3M ESPE (8 mm)	**628**	**570**	**269**	**302**	**372**	**628**	**628**
Elipar Tri Light 3M ESPE (3 mm)	**2008**	**1452**	**200**	**190**	**0**	**381**	**381**
Astralis 10 (10 mm)	**1406**	**1854**	**1150**	**1000**	**1102**	**1586**	**1722**

Table 5: Determination of the light intensities (in mW/cm^2) of various curing lights using different radiometers compared to the integrating sphere. The actual dimensions of the light guides used for calculation are shown in parentheses.

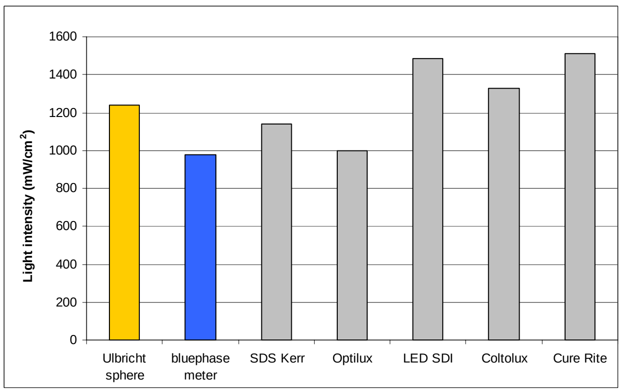
For illustrating the large data size, the results of four curing lights are shown in diagrams (Fig. 4).



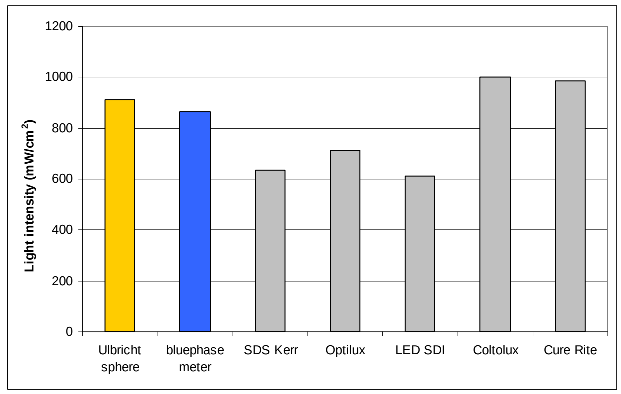
bluephase 16i (7 mm)



Elipar Tri Light (3 mm)



LEDemetron II (7 mm)



Optilux 501 (7 mm)

Fig. 32: Diagrams of the light intensities of four different curing lights measured by means of different radiometers compared to the integrating sphere.

The values determined with the bluephase meter are the closest to that measured with the integrating sphere. Since the actual light guide has to be determined first before the integrating sphere is used, the results may deviate due to a faulty and difficult to determine value. The advantage of the buephase meter is that the line sensor automatically considers the actual dimension of the light guide. Consequently, the bluephase meter is the only radiometer tested which is suitable for determining absolute light intensities in addition to the integrating sphere.

Conclusion of the study (quotation):
"…the bluephase meter seems to be the most suitable measuring device for the dental practice compared to the integrating sphere due to the simple measuring principle and the costs of the device. Since other hand radiometers available do not consider the internal diameter of the light guide, they do not seem appropriate for comparing the light intensities of different polymerization lights."

5.9 Extramural studies with bluephase

Effect on in vitro intrapulpal temperature rise during a restorative scenario using experimental light curing units
F. A. Rueggeberg, Medical College of Georgia

An evaluation of the spectral output and the effects of distance on the light intensity from quartz tungsten halogen and light emitting diode curing lights
R. Price, Dalhousie University, Halifax

Evaluation einer LED Prototyp-Lampe: Analyse der Belichtungseffizienz gemessen an der Konversationsrate und mechanischen Eigenschaften von Adhäsiven
N. Ilie, University of Munich

Efficiency and temperature development of a new experimental LED light curing unit
I. Krejci, University Geneva

Untersuchung verschiedener im Markt befindlicher Radiometer im Vergleich zur Ulbricht-Kugel und zum neu entwickelten IV Radiometer
C.P. Ernst, Universität Mainz

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Ivoclar Vivadent AG
Research and Development
Scientific Services
Bendererstrasse 2
FL - 9494 Schaan
Liechtenstein

Contents: Dr Thomas Völkel
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