

Bluephase® Style

The curing light



Scientific Documentation



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1. Introduction

1.1 Light curing in dentistry

Photopolymerization, i.e. light-initiated curing, is an integral part of modern dentistry. Countless composites, composite-based luting materials and adhesives are polymerized using light. The success and longevity of these light-activated materials is directly related to the efficacy of the light curing process. Four basic types of curing light remain in use: Halogen lights, plasma arc curing lights, laser lights and light emitting diode (LED) based lights. The former and latter have proven the most influential.

1.1.1 A short history of light curing

As dental restorative materials advanced, so did the technology to cure these materials. The two-component resin-based tooth-coloured materials available in the 1960s, were chemically-cured only. These self-cured composites were based on radical polymerization initiated by the decomposition of benzoyl peroxide. In 1962, Bowen synthesised a Bis-GMA monomer formulation filled with finely ground quartz¹ – a step towards modern composite formulations. An ultraviolet (UV) activated fissure sealant was one of the first light-cured materials to become commercially available.² The first commercial dental curing light using UV-light was developed in the 1970s. These lights were reportedly ineffective, achieving limited depth of cure due to the limited ability of UV light to penetrate deep within the material.³ They were also potentially harmful to the eyes and soft tissues, with concerns raised regarding corneal burns and cataract formation, due to the short wavelength energy from UV-lights.⁴ The next logical step was to introduce visible-light-activated composites. Camphorquinone was the photoinitiator most commonly used in these materials.^{5,6} The first report on a dental filling material that could be cured with visible blue light was published in the late 1970s.⁷ Dr Bassoiun of the Turner School of Dentistry in Manchester, UK placed the first visible-light cured composite in 1976. The optimizing of a visible-light curing photo-initiator system was key and involved using camphorquinone plus a tertiary amine co-initiator. This combination remains standard to this day. The light unit consisted of a quartz tungsten-halogen (QTH) source with a heat absorbing glass and a bandpass filter allowing only light between 400 and 550 nm to pass i.e. the wavelength range necessary to activate camphorquinone.

1.2 Types of curing light

Halogen lights (Quartz Tungsten Halogen / QTH) utilizing blue light became popular during the 1980s. The halogen lamp is an incandescent lamp with a tungsten filament contained within an inert gas and a small amount of a halogen such as iodine or bromine.⁸ Halogen lights were/are considered reliable and can cure all composite materials, however high temperatures are produced, requiring noisy fans to cool the units down, plus the lifetime of the bulb is limited to approximately six months of clinical use.⁸ During the 1990s advances were made in terms of light output and faster curing times. Output values ranged from an average 400-500 mW/cm² to 3000 mW/cm². Typical exposure times to provide uniform curing in a 2 mm thick increment ranged from 40 - 60 seconds.⁹ High output QTH lights with 10 second curing times were introduced in response to the high output and shorter curing times of plasma arc curing lights¹⁰ that came later to the market.

Plasma arc curing (PAC) lights were introduced to dentistry in 1998.⁸ The source consists of two tungsten electrodes enclosed in a high pressure gas-filled chamber. A high electrical potential is developed between the two electrodes forming a spark, ionizing the gas and providing a conductive path (a plasma) between the electrodes.¹⁰ The generated plasma emits a bright light and this high output led to reduced curing times of a few seconds.^{8, 11} The price of these lights was very high and one of the problems encountered, (along with some LED and argon lasers) was the inability to cure all composites - due to an incompatibility between the photoinitiators used in the material and the light-emission wavelength of the curing unit.¹¹ Even when the initiator and wavelength of the emitted light used were mutually compatible, a number of studies indicated that the short curing times recommended were nevertheless insufficient.^{12, 13, 14}

Laser Lights achieve a high light intensity but failed to really capture the dental light market. They build up considerable heat, tend to be larger and less portable and were/are very expensive.⁸ In the USA, dental auxiliaries were also prohibited from using these lights, and as such, they became outdated relatively quickly. The argon-ion laser was first marketed to enhance the effects of vital tooth bleaching in Europe and is still often used for that purpose today.¹⁵

Light Emitting Diode (LED) Lights emitting blue light, were introduced to dentistry in the mid-90s with the first commercially available light arriving in 2000. LEDs convert electrical energy into optical radiation. Far more efficient than previous light sources used in dentistry, they are light-weight and can be battery powered for easy portability and ease of use.¹⁷ Most produce a relatively narrow spectrum of light in the 400 to 500 nm range (with a peak at around 460 nm). LED curing lights have become increasingly popular and several generations co-exist. Advantages include their relatively long service life of around five years of clinical use, low curing times, high light intensity and reasonable cost.⁸ They are available in many variations: large or small, corded or cordless, polywave or monowave. Mahn⁸ notes that several studies have shown that LED lights are able to polymerize composite materials to an equivalent depth of cure and with equivalent compressive¹⁸ and flexural strengths^{19, 20} as those polymerized using halogen lamps at the same light intensity. LED lights are rapidly replacing their halogen lamp predecessors as the standard practice light source.²¹

1.3 Generations of LED light

There are currently three generations of LED light to speak of. The first generation of LEDs featured a relatively low light output of approximately 400 mW/cm², with the second generation reaching approximately 1000 mW/cm². The 1st and 2nd generations of LED lights using just one type of LED (single peak / monowave technology) were unable to cure certain composite materials due to wavelength emissions incompatible with the initiator wavelength curing ranges. In order to be cured successfully, the composites had to contain the light initiator camphorquinone, whilst other initiator systems such as acyl phosphine oxide e.g. Lucirin TPO were contraindicated due to wavelength "incompatibility". This was a considerable drawback in contrast to halogen lamps which emitted a broader spectrum of light and were therefore able to cure composites containing all types of initiator. The newer 3rd generation of LED lights often features even higher light output and circumvents this wavelength-incompatibility problem by utilizing dual/multi peak i.e. polywave technology. Though not technically correct - the term broad-band technology is also sometimes applied to this group of LED units.¹⁶ This utilizes different LEDs in one curing light to cover a wider emission spectrum from approximately 385 – 515 nm (i.e. a similar emission spectrum to that of halogen lamps) but with two or more spectral peaks. This enables the polymerization of restorative materials that utilize non-camphorquinone based initiators. Curing units of this generation are therefore usually capable of curing any dental restorative material.¹⁰ Most Bluephase products now belong to this generation of lights.

1.4 Effective curing of composite restorative materials

The successful curing of composite materials is a two-way interdependent process between the restorative material and the curing light. For the light, the wavelength emission and light intensity are key and for the composite, the critical factors are the initiators used, shade, optical translucency and any resulting shrinkage.

1.4.1 Depth of cure

Determining in vivo whether or not a composite is completely cured remains a challenge for dentists. The uppermost layer is seen to be hard, however deeper layers are invisible and may remain unpolymerized. The more translucent and lighter coloured a composite the greater the light penetration and therefore depth of cure. There are a number of ways to establish depth of cure (in vitro) in dental materials. The international standard ISO 4049 for polymer based restorative materials suggests measuring depth of cure via preparing cylindrical specimens 6 mm long and 4 mm wide, or if a depth of cure greater than 3 mm is claimed, the length should be at least 2 mm longer than twice the claimed depth of cure. After curing according to the manufacturer's instructions, the material is removed from its mould, the inhibition layer and other uncured material is scraped away and the height of the remaining material is measured. This value (divided by 2) is considered to be the depth of cure. Alternatively, Vickers hardness (utilizing a square-diamond pyramid indenter) and Knoop hardness profiles (utilizing an elongated – diamond pyramid indenter) of the cured material, are also suitable for determining depth of cure. Cured specimens are usually prepared in cylindrical moulds and the hardness at the top and bottom of the cylinder is measured. For a hardness profile throughout the material, cured specimens are cut vertically into two pieces. The cut surfaces are polished and the hardness is determined at intervals from the top to the bottom. Hardness is often expressed as a percentage of the surface hardness which is considered 100%.²² In a study by Professor David Watts of the University of Manchester, UK, an acceptable depth of cure was considered achieved when the bottom hardness corresponded to at least 80% of the surface hardness.²³ The first UV curing lights achieved limited depth of cure due to poor UV transparency. Halogen, plasma arc, laser and LED curing lights were/are all capable of achieving adequate depth of cure, given certain conditions.

1.4.2 Polymerization shrinkage and incremental layering

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. 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 postoperative sensitivity, secondary caries, debonding and even failure of the restoration. Designing new composites that shrink less is one way of solving this problem. The other method is to reduce shrinkage stress by using an appropriate polymerization technique. Using the traditional incremental-layering technique, the composite is applied in (up to 2mm) increments and each layer is polymerized individually. As the material is polymerized in smaller quantities, the theory is that less shrinkage stress develops. A possible decrease in volume can also be compensated for by the layer that is applied on top. This layering technique has been part of standard dental teaching for many years.^{16, 24} Newer bulk fill materials however, such as Tetric EvoCeram Bulk Fill and Tetric EvoFlow Bulk Fill can now be cured in larger increments of up to 4 mm. This is possible due to their enamel-like and dentin-like translucencies of 15% and 9.8% respectively, plus the inclusion of the photoinitiator Ivocerin, which acts as a polymerization booster. Tetric EvoFlow Bulk Fill also utilizes Aessencio technology a proprietary development from Ivoclar Vivadent involving matching the refractive index of the unpolymerized monomer mixture to that of the fillers resulting in a highly translucent paste that polymerizes at depth, but nevertheless cures to a relatively low dentin-like translucency.

1.5 Light initiators and the role of wavelength

Light-curing composite materials set via radical photopolymerization. This is an electromagnetic radiation (light)-induced process which results in the formation of a polymer. Incoming photons are absorbed by photoinitiator molecules. The energy absorbed excites the molecules and in their active state, radicals are formed if one or several activators are present. The free radicals then trigger the polymerization reaction. Initiator molecules can however only absorb the photons of a specific spectral range. All customary composite filling materials are polymerized with visible blue light, therefore the light-absorbing initiators in the composites have an inherent yellow colour as this is the complementary colour to blue light. On curing, this yellow colour largely disappears.

Camphorquinone

The initiator camphorquinone is found in many standard composite materials. The peak sensitivity of camphorquinone is near 470 nm in the blue wavelength range. Due to its particularly intense yellow colour, alternative lighter-coloured initiators have also been sought and used in dentistry. E.g. for use in composite bleach shades or colourless protective varnishes.

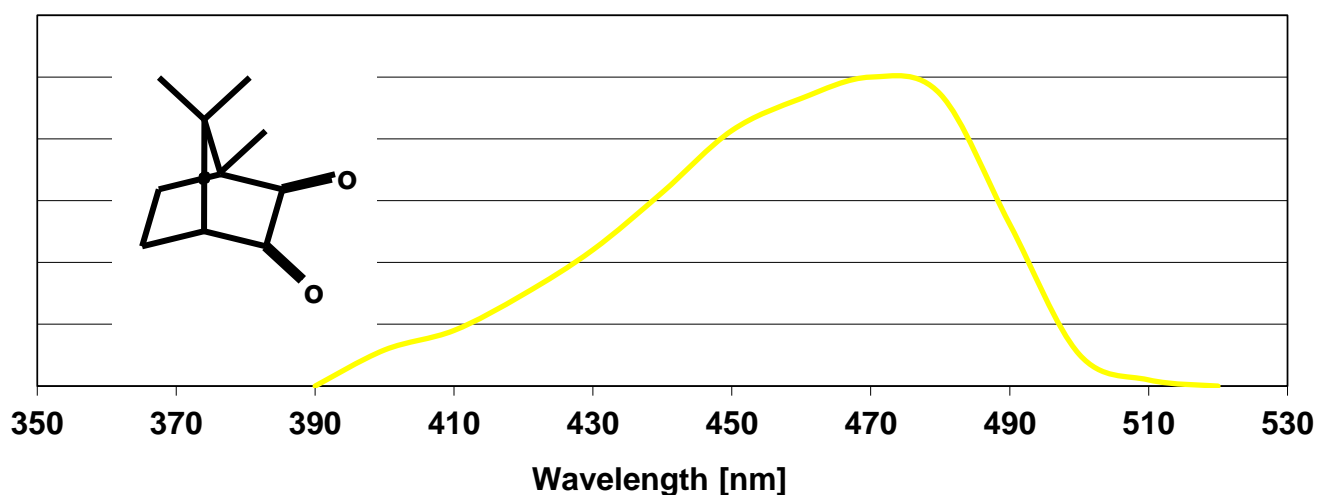


Fig. 1: Absorption spectrum of camphorquinone

Phenyl propanedione

PPD (phenyl propanedione) is another alpha diketone light initiator, featuring two neighbouring carbonyl groups: The absorption spectrum of PPD extends from the UV wavelength range to approx. 490 nm.

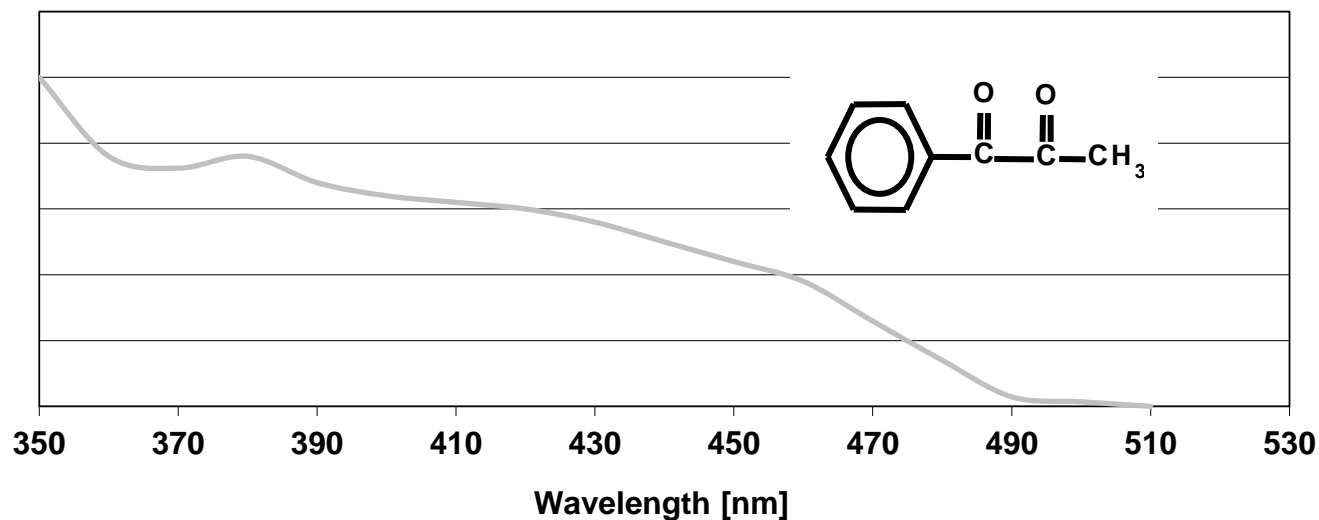


Fig. 2: Absorption spectrum of phenyl propanedione (PPD)

Acyl phosphine oxide

The photoinitiator acyl phosphine oxide such as Lucirin TPO has gained in popularity because its inherent yellow colour is very light and almost completely bleaches out following polymerization. It predominantly absorbs light in the UV range – with a sensitivity peak at a considerably lower wavelength range compared to camphorquinone.

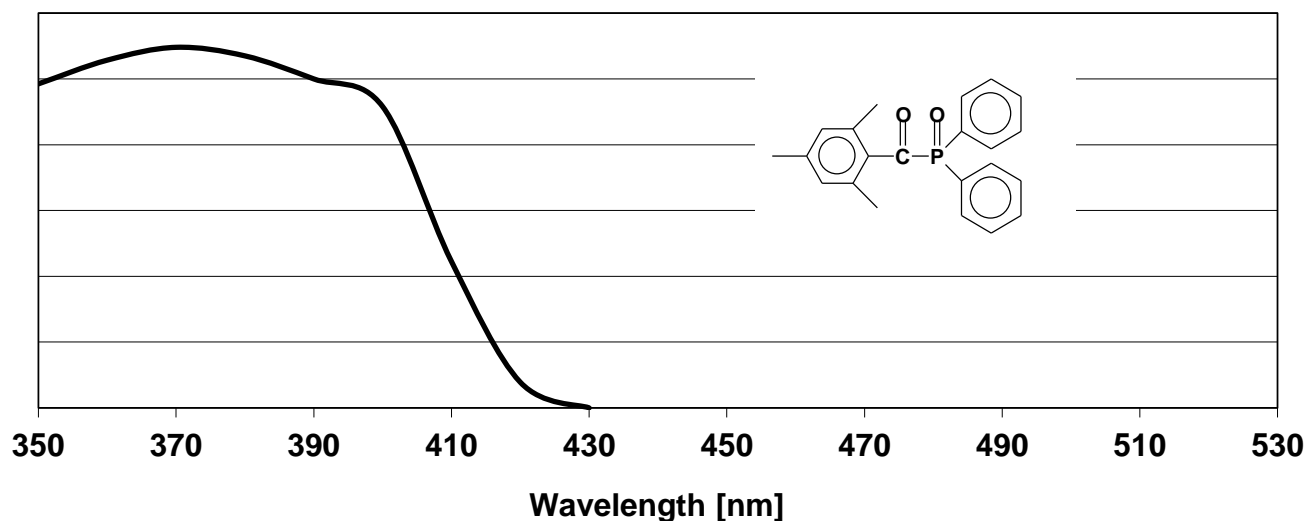


Fig. 3: Absorption spectrum of acyl phosphine oxide e.g. Lucirin TPO

It was not always possible to cure acyl phosphine oxide and PPD with conventional LED lights of the first and second generation, since their narrow spectral output hardly covered the absorption spectra of these initiators. As previously mentioned, third generation LED lights also emit light at lower wavelength ranges, which excites acyl phosphine oxide and PPD similarly to halogen lights.

Ivocerin®

Ivocerin is a recently developed photoinitiator from Ivoclar Vivadent. It is currently used together with camphorquinone-amine in the bulk fill composites Tetric EvoCeram Bulk Fill and Tetric EvoFlow Bulk Fill, which can both be applied and cured in up to 4mm increments. This new initiator is characterized by high quantum efficiency, high absorption capacity and excellent bleaching properties. Ivocerin absorbs light at a higher wavelength range than acyl phosphine oxide, and can therefore be activated by all commercially available halogen and LED lights.

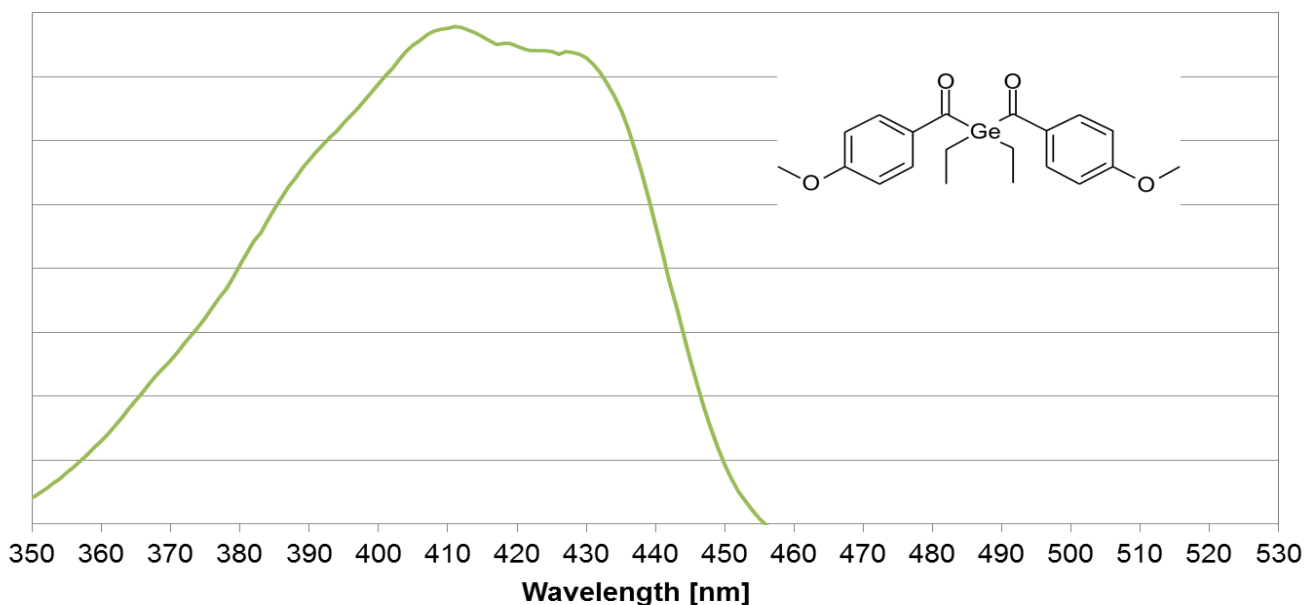


Fig. 4: Absorption spectra of Ivocerin

1.6 Light output

As previously discussed, the long-term success of light-activated dental materials is highly dependent on the efficacy of the light curing process. The light output of the curing light is key here. Light output is best measured using an integrating sphere (see section 1.7). The light emitted from the light guide is measured, determining the exact emissive power in mW. Appropriate filters ensure that only light in the effective wavelength range is measured and the light intensity in mW/cm² is calculated on the basis of the cross-section of the light guide.

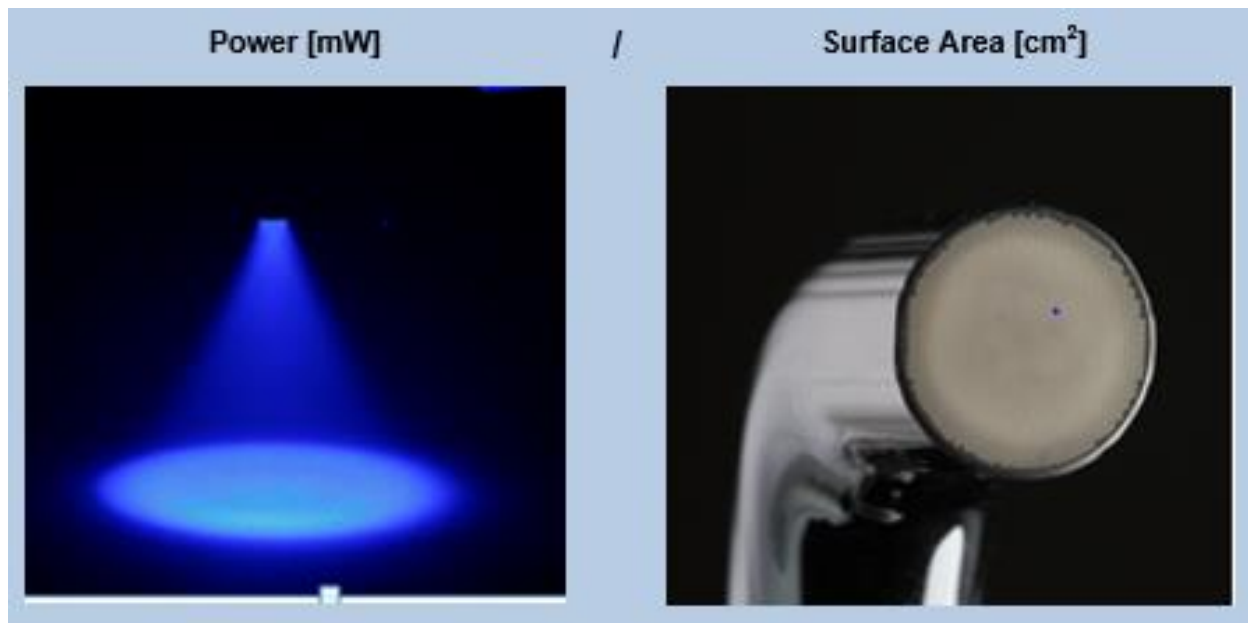


Fig. 5: Light intensity calculation: Light intensity = Power [mW] / Surface Area [cm²]

1.6.1 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 time of 20 seconds at a light intensity of 800 mW/cm² results in a dose of 16,000 mWs/cm². As a rule of thumb, a dose of between 4,000 and 16,000 mWs/cm² is recommended to sufficiently cure a composite increment of 2 mm (depending on the shade and translucency), with higher doses typically required for darker and less translucent composites.

$$\frac{\text{Dose}}{\text{Intensity}} = \text{Maximum Curing Time}$$

If we take this maximum value of 16,000 mWs/cm², various curing times can then be calculated depending on the light intensity of the curing light to be used. Logically the curing time to achieve the same degree of curing can therefore be reduced the higher the intensity of the light unit - helping save time during dental treatment. This is illustrated in the table below:

Required dose (mWs/cm ²)	16,000	16,000	16,000	10,000
Intensity of the light (mW/cm ²)	400	800	1,600	1,000
Recommended curing time (s)	40	20	10	10

Table 1: Maximum curing time recommendations according to the “Total Energy” concept when using lights of varying intensity

A dose of 10,000 mWs/cm² (see right side of Table 1) has been found to be sufficient for curing up to 4mm increments of the Ivoclar Vivadent bulk fill products Tetric EvoCeram Bulk Fill and Tetric EvoFlow Bulk Fill. Curing these materials using the Bluephase Style with a light intensity of 1,200 mW/cm² for 10 seconds, is therefore absolutely sufficient in terms of required dose.

Various studies¹⁸⁻²⁰ have shown that LED lights and halogen lights with identical intensities and curing times achieve comparable depths of curing and hardness profiles. Table 2 shows the results of internal depth of cure measurements using the old composite Tetric Ceram A3.5. Depth of cure was measured according to ISO 4049 with a curing time of 20 seconds. The values shown were the depth of cure divided by two as stipulated in the standard. There was no statistical difference between the curing efficiency of LED-lights and halogen lamps at the same light intensity.

Intensity (mW / cm ²)	Depth of cure in mm (LED)	Depth of cure in mm (Halogen)
400	2.40	2.43
600	2.54	2.55
700	2.65	2.67
800	2.73	2.69

Table 2: Comparison of depth of cure of Tetric Ceram after curing with an LED and a halogen lamp of identical intensity for 20 seconds. *P. Burtscher, V. Rheinberger, IADR Poster 2002*

1.6.2 Light guide

The light guide has a big influence on the efficiency of polymerization lights. If a curing light is designed without a light guide but equipped with an LED mounted at the front of the light-emission window, much of the intensity is lost due to scattering at a certain distance from the object to be cured. Light guides comprised of fibreglass rods have proven invaluable in reducing this loss due to scattering. Many curing lights are equipped with a tapered light guide that features an emission window of a smaller diameter than the shaft. The diameter of the Bluephase Style 20i light guide for example, decreases from 10 mm to 8 mm. This allows the light to be concentrated over a smaller surface area, achieving a high power density, i.e. higher light intensity per surface area – which saves energy. If the tapering is extreme however e.g. from 13mm to 8mm it can have an adverse effect on the light-scattering characteristics. The scattering angle becomes wider and the light intensity decreases more rapidly as the distance from the composite to be cured increases. This is also a particular problem in curing units where the LED is mounted right at the front of the light-emission window.

Light guides and curing distance

Large curing distances cannot always be prevented in daily working routines however, for example when curing in deep cavities (Fig. 6), or when curing luting composites through a ceramic restoration. Price et al,²² reported that light intensity is reduced to 50% of its full intensity at a distance of 6 mm for a parallel light guide but to a very low 23% of its full intensity for a tapered light guide, at that distance. Parallel walled light guides, can therefore be seen to have some advantage in this respect.

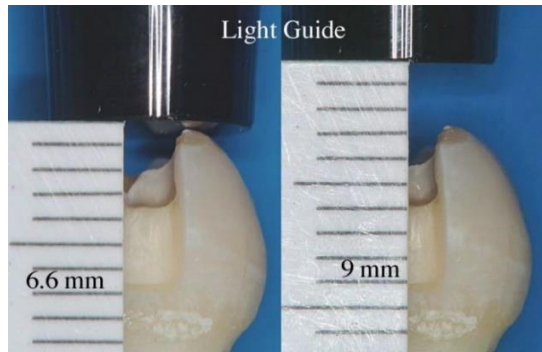


Fig. 6: Distance between the light guide and the composite material to be cured, in reality.

Photo: R Price, Dalhousie University, Halifax, Canada

Bluephase Style is equipped with a 10 mm parallel light guide. Bluephase Style 20i features a very slightly tapered light guide (10mm > 8mm) allowing a higher light intensity to be achieved. The graph below shows the loss of power for various lights (from the initial maximum set at 100%) associated with increasing distance from the material to be cured, when measured with an integrating sphere. Bluephase Style with its parallel light guide, features the least reduced light output. The lights with tapered light guides, Bluephase Style 20i and DXM Cybrid XD (10mm - 8mm) and Kerr Demi Plus (13mm – 8mm) exhibit slightly higher loss of light power. Dentsply Smartlite PS features an LED built in at the light tip and this exhibits the greatest loss of power at distance.

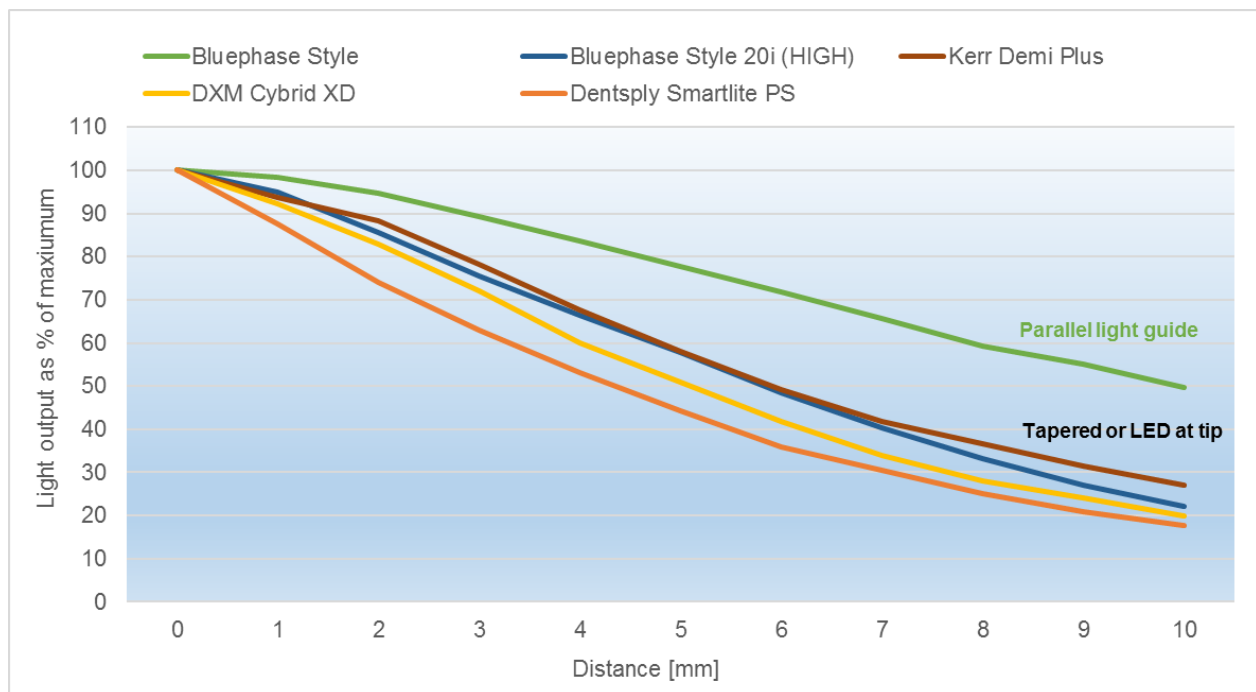


Fig. 7: Normalized light power of various LED lights with parallel and tapered light guides: Decrease in power as percentage of maximum with increasing distance from material. R&D Ivoclar Vivadent AG, Schaan, August 2016

The pictures below, further illustrate the light scattering characteristics of curing lights with different shaped light guides or LED positions.

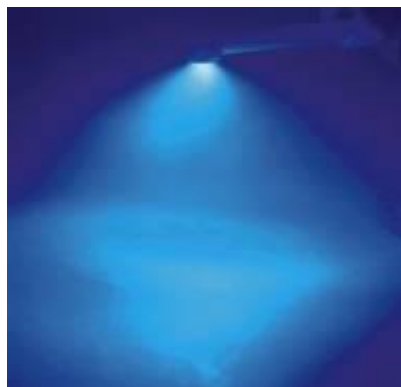


Fig. 8a: Diffuse light scattering when LED is mounted at front



Fig. 8b: Light scattering of a very tapered light guide (13 > 8 mm)



Fig. 8c: Homogeneous light scattering of a parallel light guide

1.7 Measuring/checking light intensity

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 curing lights in use, offer 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 sensitivity and even necessitate endodontic treatment. Although the light output is always stipulated by light manufacturers, studies have indicated that curing lights often operate at sub-optimal levels.

An Australian survey of 214 lights in use in dental practices found that over 50% were not functioning satisfactorily – with an obvious reduction in light intensity in older light units in particular.²⁵ A comprehensive study conducted by the University of Mainz (Prof. Ernst) in dental practices in the Rhine-Main area in 2005, also showed that many curing lights do not achieve the specified light intensities stated by the supplier. In extreme cases, they did not even achieve half of the stipulated power.²⁶ Over half showed no impairments but 37% were contaminated with bonding agents or composite material at the light tip and 5% were also damaged.²⁶ The table below shows a selection of the lights tested in this investigation. The old Bluephase (G1) light was also tested in the study and achieved one of the highest average light intensity values relative to the given specifications.

Device	Manufacturer	Light intensity [mW/cm ²]		Mean light intensity value relative to manufacturer specifications. Manufacturer specification = 100%
		Manufacturer's specifications	Measured mean value	
Bluephase	Ivoclar Vivadent	1100 (± 10%)	1066	96.9%
Smartlite PS	Dentsply	950	927	97.6%
Mini L.E.D.	Satelec	1250	872	69.8%
FlashLite 1401	Discus dental	1400	859	61.4%
Radii	SDI	1400	825	58.9%
L.E.Demetron 1	Kerr Hawe	1000	699	69.9%
Elipar Freelight 2	3M Espe	1000	602	60.2%
Translux Power Blue	Heraeus Kulzer	1000	513	51.3%
Elipar Freelight 1	3M Espe	400	231	57.7%

Table 3: Measured vs. given light intensity of curing lights in the dental practice C. P. Ernst et al. 2006²⁶

It is prudent therefore to regularly check the light power of curing lights, but there is a substantial lack of awareness amongst dentists of the need for maintenance and regular checking of the light intensity of dental curing units.²⁵

Light output can be measured with an integrating sphere or via commercially available radiometers such as the Bluephase Meter II from Ivoclar Vivadent.

1.7.1 Integrating spheres

The integrating sphere is an expensive but approved physical measuring device for accurately determining the absolute light intensity of curing lights. If it is calibrated regularly, it is possible to achieve an accuracy of +/- 5%. Since the integrating sphere measures the light emission power as an absolute value in mW, the spectral output in mW/cm² is determined by defining the light emission area or the respective diameter of the light guide. This area has to be measured individually for each curing 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 prone to error and may result in significant deviations in the determination of the light intensity, due to the exponential influence of the squared denominator i.e. (cm²).

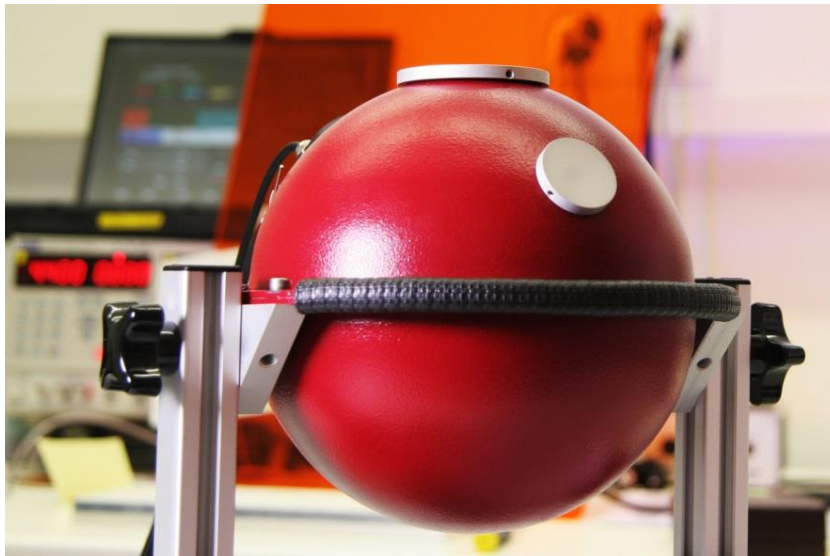


Fig. 9: Integrating sphere for measuring light output

1.7.2 Radiometers

Commercially available radiometers are suitable for taking approximate measurements of light intensity. They cannot be calibrated and therefore do not provide precise results. In the practice or dental laboratory, radiometers are primarily used to observe the drop in power of a given curing light over time, so that the customer can react if the required light intensity is no longer achieved. The diameter of the diffuser cap also 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, as the light power is not evenly distributed over the emission window but decreases from the centre to the periphery. The different scattering characteristics of various light guides also have an adverse effect on the measured values, due to the distance between the light guide and the sensor.



Fig. 10: Various commercial radiometers

Radiometers are useful for quick routine tests to check the light output of a curing light in the dental office or laboratory. If the limitations mentioned, 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 can vary between 5 and 13 mm in current curing units, radiometers available to date are not generally suitable for determining the absolute light intensity.

Bluephase Meter II

Bluephase Meter II is a small, handy radiometer for determining the light intensity of dental curing lights. In contrast to conventional radiometers, the Bluephase Meter II utilizes a novel measurement principle. This allows for unmatched measuring accuracy with a tolerance of (max.) $\pm 10\%$ compared to the values generated by a calibrated integrating sphere.

Light intensity can be measured in three simple steps: first the diameter of the light guide is determined using the integrated template, this value is then entered into the device and the sensor is irradiated with the lamp to be tested. Light intensity is measured automatically in mW/cm^2 or alternatively in mW . Bluephase Meter II features a broadband measurement spectrum of 380-550 nm and is therefore suitable for all types of curing lamp - halogen, plasma, LED etc.



Fig. 11: Bluephase Meter II

The accuracy of the Bluephase Meter II was investigated in a number of studies detailed in section 4.7.

2. Bluephase® Style Line – The smallest LED for every use

Bluephase Style curing lights are stylish, compact LED-based curing units that produce energy-rich blue light. Their slim, light, ergonomic design sits comfortably in everyone's hand. The Bluephase Style lights are suitable for curing both composites and adhesives (applied near to the pulp).

2.1 Bluephase® Style

The Bluephase Style curing light features “Polywave Technology”, developed by Ivoclar Vivadent, and emits a light intensity of 1200mW/cm². This represents an approximate 10% increase in performance on the previous Bluephase Style generation (1100 mW/cm² from 2012 to 2015). The light, which is produced in a range of colours, is now also available in green.



Fig 12: Bluephase Style – Polywave LED curing light available in grey, pink, blue and green

As discussed in section 1, in the past, (largely pre - 2008) only composite materials containing the photoinitiator camphorquinone could be cured with conventional LED curing lights i.e. 1st and 2nd generation LED devices. Due to wavelength-range limitations, other initiator systems, such as acyl phosphine oxide e.g. Lucirin TPO, were contraindicated, which was a considerable drawback compared to the previous generation of halogen lights. Given the success of LED lights, many dental manufacturers tackled this issue by modifying the composition of their composites, which in some cases, resulted in compromised esthetics or storage stability.

Polywave technology however involved modifying the LED curing unit, rather than the composite. Due to the inclusion of two blue LEDs and one violet light-emitting LED (see Fig 13), it features a second spectral peak at approximately 410 nm in addition to the peak at approximately 470 nm. Overall the polywave Bluephase Style covers a wavelength spectrum of between 385 and 515 nm.

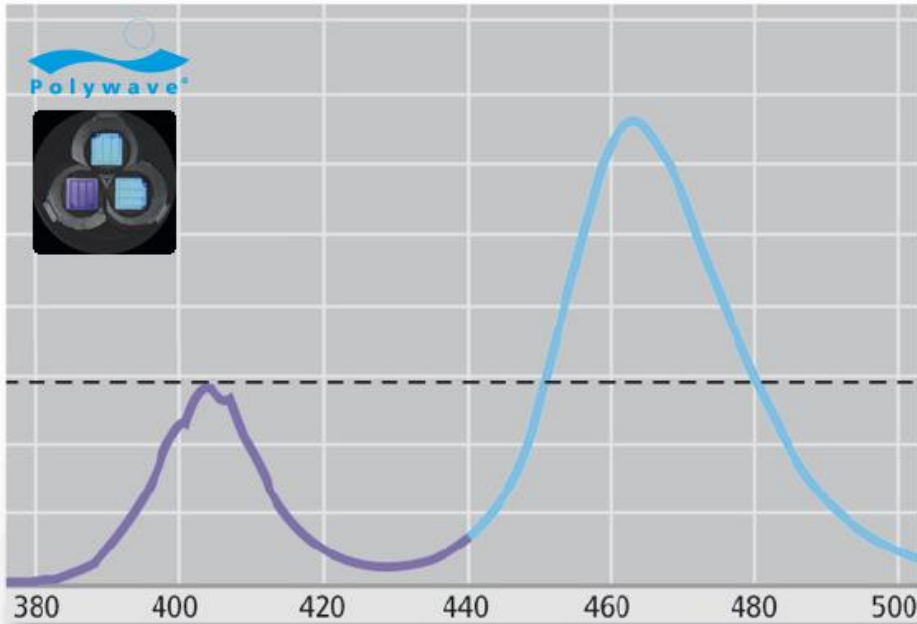
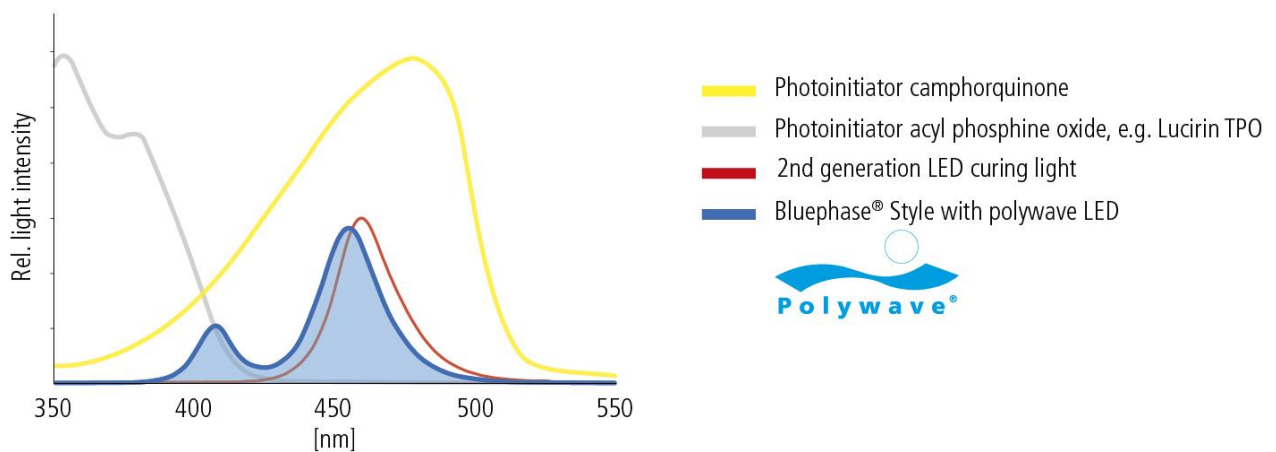


Fig. 13: Blue and violet LEDs involved in the dual peak Polywave Technology

This emission spectrum is similar to the effective range of halogen lamps, and can therefore be used with all composites and photoinitiator systems.

Wavelength spectrum



Source: R&D Ivoclar Vivadent AG, Schaan, 2014

Fig. 14: Schematic representation of the wavelength range, two spectral peaks and light output of Bluephase Style, relative to the photoinitiators camphorquinone and acyl phosphine oxide.

Bluephase Style features an autoclavable, parallel light guide with a shortened tip. The tip's large diameter of 10mm, allows the single curing of large restorations i.e. multiple curing can often be avoided. The parallel form reduces the inevitable loss of light intensity when the distance from the irradiated surface increases (see section 1.6.2) and can also be turned 360°.

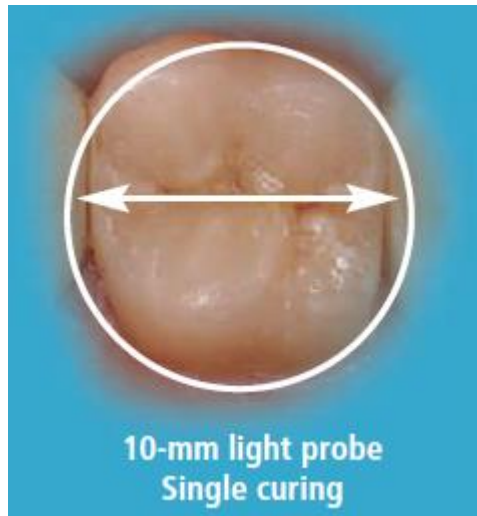


Fig. 15: Single curing possible with 10 mm light guide

Should the battery run out, the click and cure function assures continued working using a network cable.

2.2 Bluephase® Style 20i

The Bluephase Style 20i is a cable free, high performance curing unit, emitting a light intensity of up to 2000 mW/cm². Like Bluephase Style, Bluephase Style 20i utilizes "Polywave Technology" and is suitable for the rapid curing of all light-cured dental materials within the wavelength range of 385 - 515nm.



Fig. 16: Bluephase Style 20i

The unit is used in HIGH (1200 mW/cm²) or TURBO (2000 mW/cm²) mode, depending on the indication. Using the TURBO mode, materials can be cured efficiently in just 5 seconds. In contrast to Bluephase Style, Bluephase Style 20i features a slightly tapered 10>8 mm light guide which focusses the light, aiding the high light-intensity capacity of the unit. The TURBO program can be particularly useful, when curing luting cements through indirect restorations, as depending on the material thickness, colour and opacity of an indirect restoration, the light that reaches the luting composite is variably reduced.



Fig.17: User interface of Bluephase Style 20i featuring HIGH and TURBO mode

Should the battery run out, the click and cure function also assures uninterrupted working with this unit, using a network cable.

2.3 Bluephase® Style M8

Bluephase Style M8 features the same design as the other Bluephase Style lights, but utilizes "Monowave Technology" and operates at a lower light intensity of $800\text{mW}/\text{cm}^2$. It covers a wavelength range of 430 - 490 nm and composites can be cured in 15 seconds. Like the Bluephase Style and Bluephase Style 20i, its cordless design uses state of the art lithium-polymer batteries.



Fig. 18: Bluephase Style M8

3. Technical Data




	 Bluephase® Style M8	 Bluephase® Style	 Bluephase® Style 20i
Light intensity	800 mW/cm ² ± 10%	1200 mW/cm ² ± 10%	2000 mW/cm ² ± 10%
Every hand (Ergonomic design)	✓	✓	✓
Every material (Wavelength range)	- (430-490 nm)	✓ (385 -515 nm)	✓ (385 -515 nm)
Every indication (Continuous operation of at least 10 minutes)	✓	✓	✓ (HIGH POWER)
Every time (Click & Cure: optional corded operation)	-	✓	✓
Curing programs HIGH POWER TURBO	800 mW/cm ² -	1200 mW/cm ² -	1200 mW/cm ² 2000 mW/cm ²
Curing times for selected composites 2mm Tetric EvoCeram 4mm Tetric EvoCeram Bulk Fill Tetric EvoFlow Bulk Fill	15 seconds 15 seconds	10 seconds 10 seconds	5 seconds 5 seconds
Light guide	10 mm/parallel, black shortened tip		10 > 8 mm/tapered, black, shortened tip
Power supply	Lithium-polymer battery Capacity: Approx. 20 minutes Charging time: Approx. 2 hours		
Weight of handpiece	120 g (incl. battery and light guide)		
Dimensions of handpiece (without light guide)	L= 180 mm, B = 30 mm, H = 30 mm		
Weight of charging base	195 g		
Dimensions of charging base	D = 125 mm, H = 70 mm		
Warranty	2 years (Battery: 1 year)	3 years (Battery: 1 year)	

Table 4: Technical data pertaining to Bluephase Style M8, Bluephase Style and Bluephase Style 20i

4. Results from internal and external studies

4.1 Curing composites

The principle indication of curing lights is the polymerization of composite restoratives. The degree of cure is dependent upon a number of parameters, light intensity being one of the most important. (see Section 1.6.1).

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 and modulus of elasticity during polymerization. The depth of cure of composites (see section 1.4.1) is directly related to the light power of the curing light and spectroscopic methods (e.g. infrared spectroscopy) can be used to determine the chemical conversion of the monomers used.

An evaluation of six light-emitting diode curing lights to cure two composites at a distance of 4 and 8mm from the end of the light guide. R. Price, Dalhousie University, Halifax, Canada

Composite cure can be measured by determining the hardness of a composite post-curing. In the following investigation Dr Price tested the degree of cure, of two different composites when cured with various curing lights. Tetric EvoCeram in shade A3 and Tetric EvoCeram Bleach M were tested. A3 represents a standard shade whilst the bleach shade contains additional opaquing agents which can also affect the depth of cure. Samples were prepared in white Delron rings 2 mm thick and 6 mm in diameter. A thin Mylar strip was placed over the top and bottom surfaces of the composite before curing to prevent the formation of an oxygen-inhibition layer. The specimens of the composites were then irradiated with the various lights according to the manufacturer's instructions regarding curing times. Once cured, the specimens were stored for 24 hours in a lightproof container at room temperature. The Mylar strips were then removed and 25 Knoop micro-hardness readings were made 1mm apart in a 4 by 4 mm box pattern (5x5 grid) in the centre of the top and bottom surfaces of each specimen.

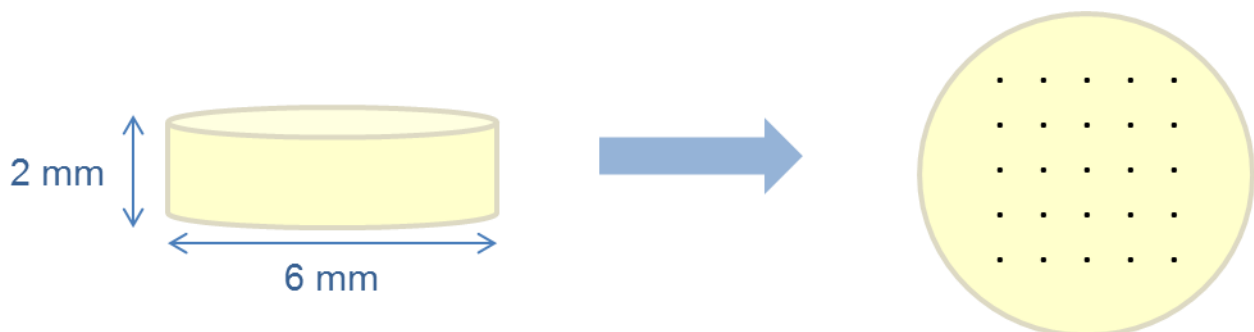


Fig. 19: Representation of specimen design with Knoop micro-hardness readings

In the clinical setting it is also often necessary to cure at quite a distance from the material to be cured. The distance between the light guide and the composite can often exceed 5 mm, thus in this study the Knoop hardness values were measured after curing at a distance of both 4 mm and 8mm from the composites. Depending on the scattering behaviour of the curing light and the light guide, the light intensity can decrease dramatically with increasing distance from the material to be cured. The following graphs show the Knoop hardness values (from the bottom of the sample) after curing the composites from a distance of 4 mm (Fig. 20) and 8 mm (Fig 21).

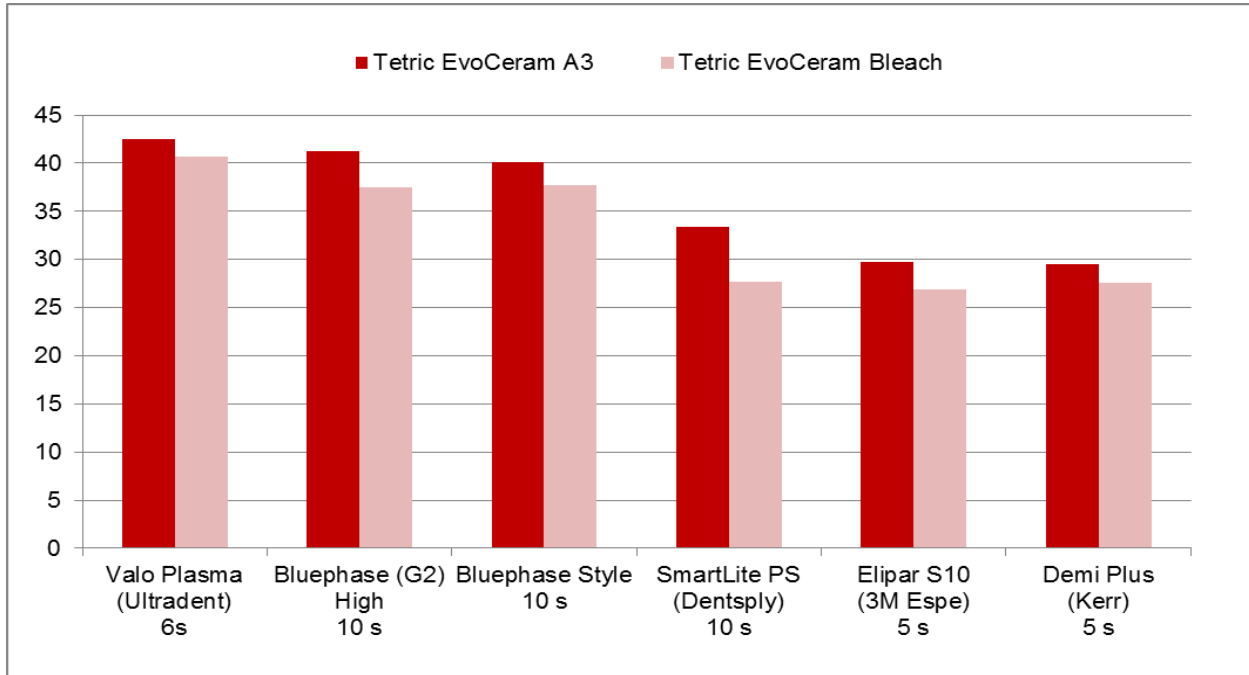


Fig. 20: Knoop hardness values from the bottom surface of samples after curing from a distance of 4 mm with various LED lights. R. Price, Dalhousie University Halifax, May 2011.

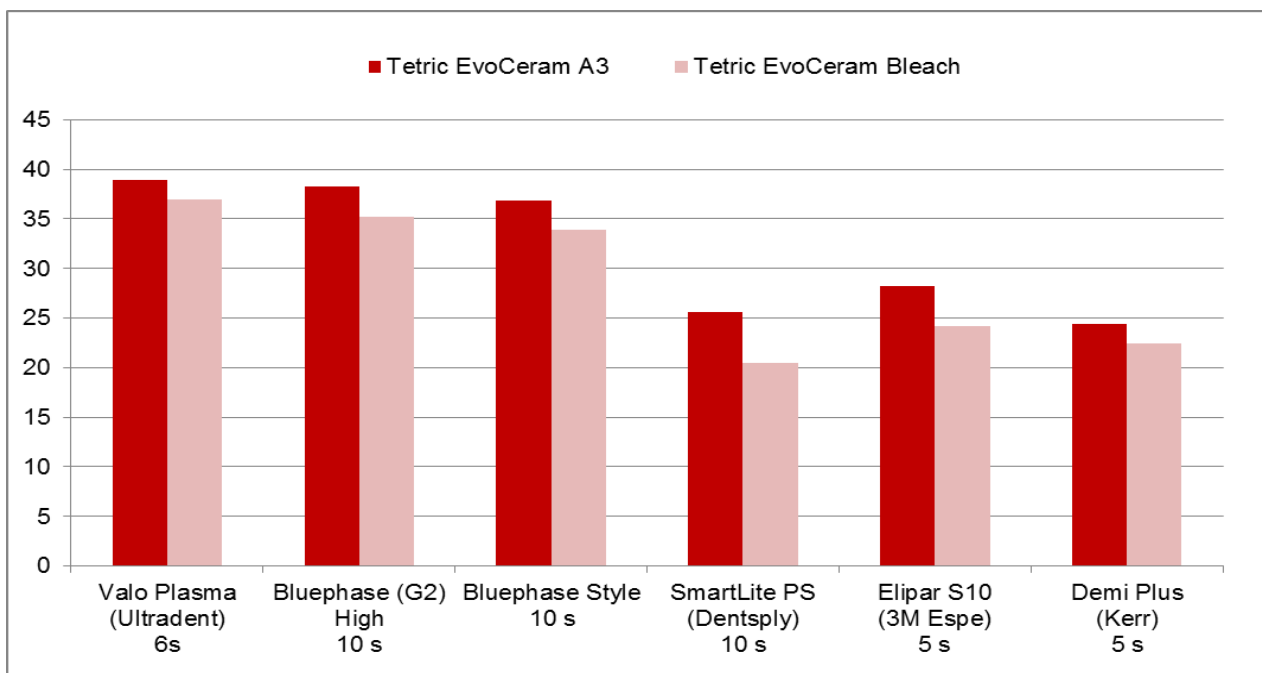


Fig. 21: Knoop hardness values from the bottom surface of samples after curing from a distance of 8 mm with various LED lights. R. Price, Dalhousie University Halifax, May 2011.

The light intensities of the lights used are shown below, along with the time cured (according to manufacturer instructions) and resulting light output according to the “Total Energy Concept”

	Valo Plasma (Ultradent)	Bluephase G2 [HIGH]	Bluephase Style	SmartLite PS (Dentsply)	Elipar S10 (3M ESPE)	Demi Plus (Kerr)
Light Intensity of Curing Unit mW/cm ²	3,200	1,200	1,100*	950	1,200	1,100 – 1,300
Seconds cured	6	10	10	10	5	5
Dose (mWs/cm ²)	19,200	12,000	11,000	9,500	6,000	6,500

Table 5: Light intensities, curing times and resulting dose of the curing lights used. R. Price, Dalhousie University Halifax, May 2011.

*Older Bluephase Style version with 1100mW/cm²

The results showed that Bluephase Style and Bluephase (G2) achieved an equivalent or even better degree of cure when compared to other commercially available lights. The polywave lights (Valo, Bluephase Style and Bluephase G2) were better at curing both composites than the single peak lights (Smartlite PS, Elipar S10 and Demi Plus) The Knoop hardness values, were as expected, slightly lower when the materials were cured at a greater distance from the material i.e. 8 mm as opposed to 4mm. Valo Plasma was the only corded device.

Depth of cure of Tetric EvoCeram Bulk Fill cured with Bluephase (G2) and Bluephase Style in comparison to other composites. A. Rzanny, M Facht, University Clinic, Jena, Germany, 2012

Objective: To establish the performance and suitability of the Bluephase Style curing light in comparison to Bluephase (G2), on the basis of the depth of cure achieved in various composites.

Methods: After curing for 10 seconds with Bluephase (G2) or Bluephase Style, the depth of cure of the conventional and bulk fill composites: Tetric EvoCeram (A3), Tetric EvoCeram Bulk Fill (IVA) and Venus Bulk Fill (Universal) was calculated using a Penetrometer and Vickers hardness values were established.

Depth of cure

Specimens with a diameter of 6 mm and a height of 10 mm were fabricated and cured for 10 seconds with either lamp. The length of the cured section of the material was calculated immediately after polymerization. A Penetrometer (AP4/3 Feinmess Dresden) was used to measure the depth of the uncured material on the underside. The difference in length was then divided by two (as stipulated in the standard DIN EN ISO 4049).

Vickers hardness

Each composite was applied in a 4 mm high and 8 mm wide Teflon mould and covered with a foil at the top and bottom. The light guide of the respective lamp was placed directly onto the foil and the composite was cured for 10 seconds. The Vickers hardness at the surface and bottom of the sample was calculated (load 5 kg/20 seconds at 23 °C) using a Zwick 3212 machine - immediately after polymerization, after 24 hours and after 7 days.

Results:**Depth of cure (acc. ISO 4049)**

There was no significant difference between curing lamps for any of the composites. Both bulk fill composites Tetric EvoCeram Bulk Fill and Venus Bulk Fill far exceeded the manufacturer indicated allowable increment thickness (4 mm) in terms of depth of cure (approx. 5 mm). Tetric EvoCeram is not a bulk fill composite and is intended to be applied in 2 mm increments.

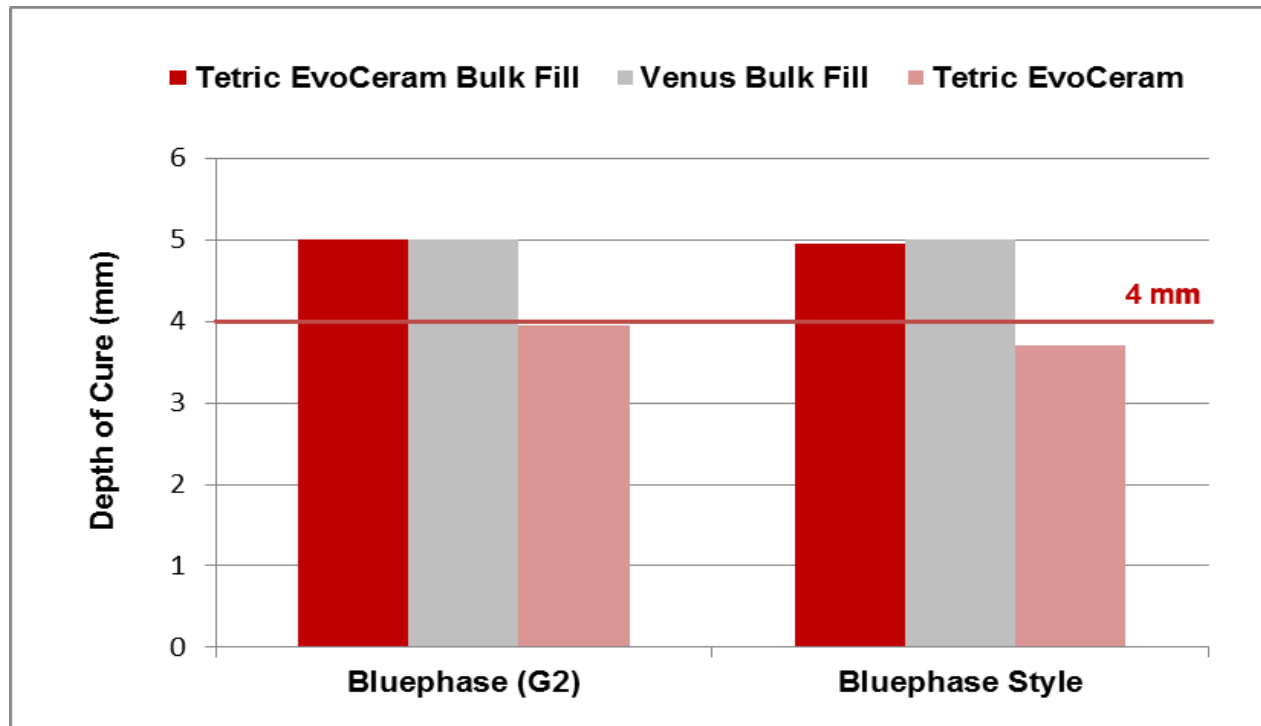


Fig. 22: Depth of cure of Tetric EvoCeram Bulk Fill, Tetric EvoCeram and Venus Bulk Fill when cured with Bluephase G2 and Bluephase Style for 10 seconds. *A Rzanny et al, Universitätsklinikum Jena, 2012*

Vickers hardness

The Vickers hardness results for Tetric EvoCeram Bulk Fill (in 4 mm increments) all exceeded the 80% ratio necessary. When cured with Bluephase (G2), the ratio was 87.6% after 24 hours and 83.6% after 7 days. When cured with Bluephase Style it was 80.3% after 24 hours and 87.5% after 7 days.

Conclusion: The authors conclude that both Bluephase G2 and Bluephase Style are equally suitable for polymerizing the three composites investigated.

4.1.1 Curing of various initiator systems

Due to the increasing market share of LED curing lights which covered just the narrow spectral range around 470 nm; the majority of composite formulations had camphorquinone added as an initiator. The drawback of camphorquinone however, is its intense yellow colour, which only reduces during polymerization. The shade of the un-polymerized paste and the cured composite may appear quite different. Moreover, the decomposition products in the composite may darken under the influence of light over time. This can pose an esthetic problem – notably in the anterior region. New composites and e.g. composites in bleach shades may be camphorquinone-reduced or free and increasingly feature new photoinitiators such as Ivocerin.

Bluephase Style is capable of activating all photoinitiators currently used in dentistry, as indicated by the investigations below.

Flexural Strength

In an internal investigation samples of Tetric Ceram-based composite formulations were produced with varying shares of initiators (see table 6).

	% Camphorquinone (CQ)	% Acyl phosphine oxide e.g. Lucirin TPO	% Phenyl propanedione (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 6: Experimental composite formulations with different shares of initiators in the monomer mixture

The 5 types of composite were cured with three different curing lights. The graph below shows the curing results in terms of flexural strength, of these experimental formulations tested with Bluephase G2 (contains equivalent LEDs to Bluephase Style), the predecessor Bluephase light and the halogen lamp Astralis 10. The samples 25 x 2 x 2 mm were cured for 2 x 20 seconds with each light.

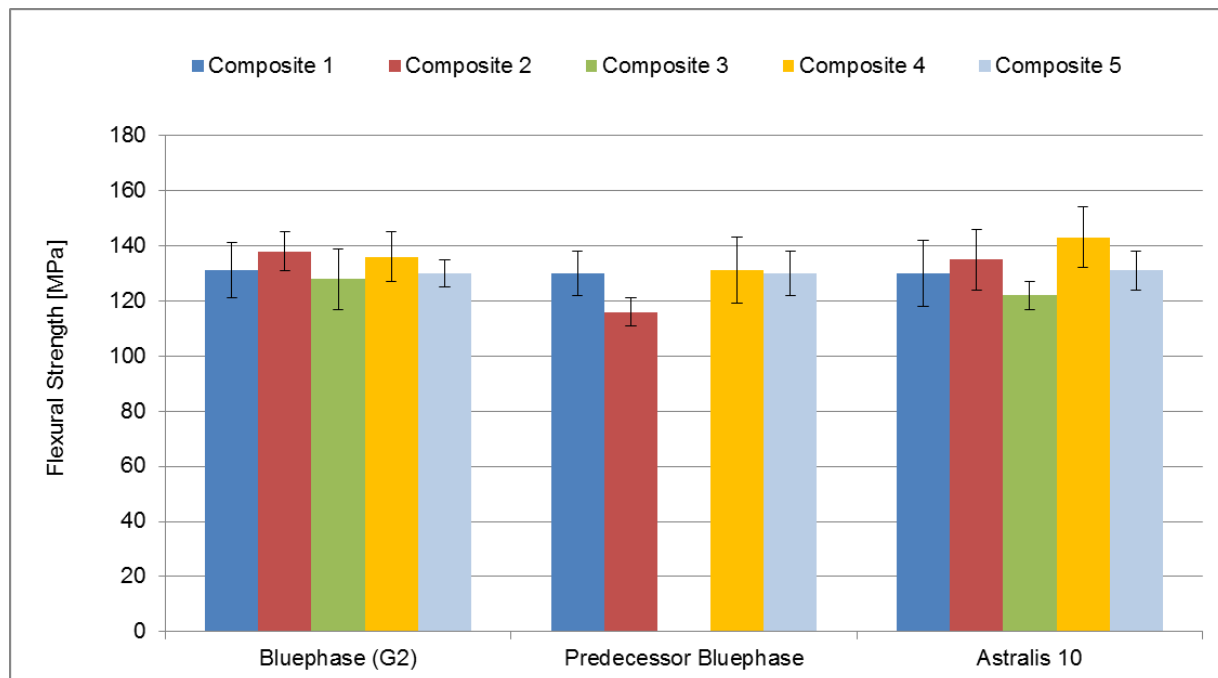


Fig. 23: Flexural strength of different experimental composite formulations (1-5) with different initiator contents (see Table 6) after having been exposed to the light of Bluephase (G2), the predecessor Bluephase model and the halogen light Astralis 10 for 2 x 20 s. *R&D Ivoclar Vivadent AG, Schaan, Jan 2008*

As shown in figure 23, the broad spectral range of the Bluephase (G2) enables the adequate polymerization (as shown by the flexural strength) of camphorquinone-reduced (Composites 2 and 4) and camphorquinone-free formulations (Composites 3 and 5).

In comparison, the predecessor Bluephase model with its narrower spectral range was unable to cure Composite 3 which contained only acyl phosphine oxide (e.g. Lucirin TPO) as the light initiator. Similar to the halogen lamp Astralis 10, the broadband LED Bluephase (G2) was able to cure all the tested composites.

As the LEDs used in Bluephase Style units are the same as those in the Bluephase (G2) it can be assumed that equivalent results would be achieved with Bluephase Style lights.

Curing Tetric EvoCeram Bulk Fill featuring the photoinitiator Ivocerin

Internal investigations were carried out with Tetric EvoCeram Bulk Fill and Bluephase Style, both with the light guide placed directly on the composite and with the light guide 8mm away from the composite surface to be cured. The following graph and data shows the percentage Bottom/Top Vickers Hardness (at various depths between 0 and 5.5 mm) for Tetric EvoCeram Bulk Fill in shade IVA when cured for 10 seconds with Bluephase Style.

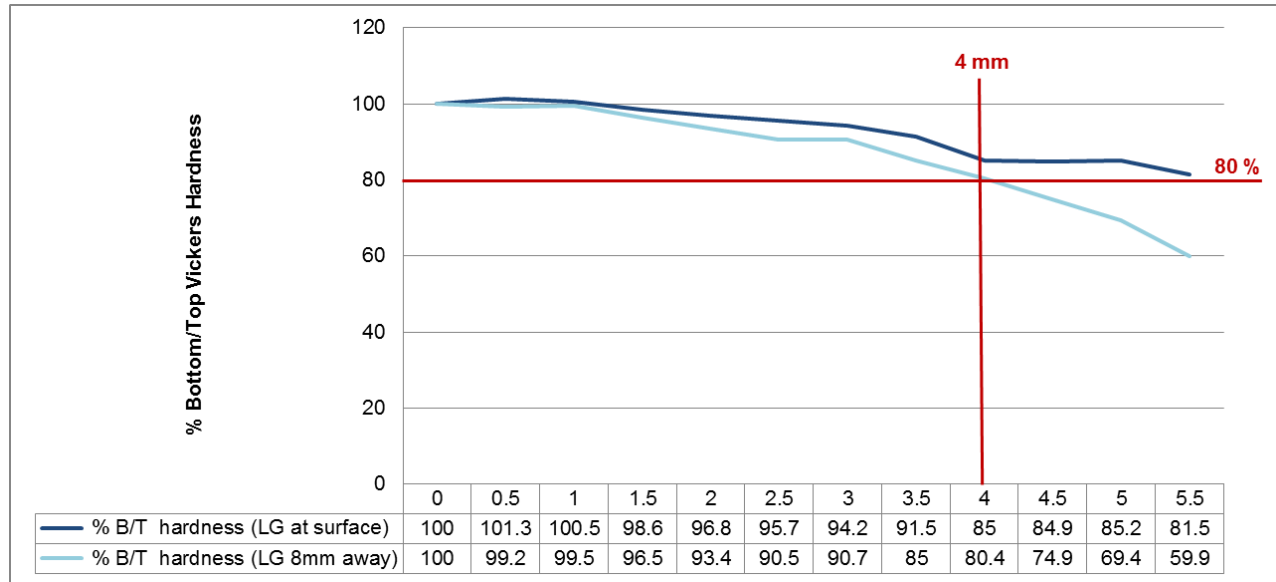


Fig. 24: Percentage Bottom/Top Vickers Hardness at various depths of Tetric EvoCeram Bulk Fill after curing for 10 seconds with Bluephase Style. *R&D Schaan August 2011*

The graph shows that even when the light guide is placed at an 8mm distance from the surface of the composite the 4 mm bulk increment was cured successfully. The B/T Vickers hardness percentage was 85% of the hardness at the surface (at 4mm depth) when the light guide was placed at the surface of the composite and 80.4% when placed at a distance of 8 mm.

4.2 Curing adhesives

The incomplete polymerization of adhesives leads to weakened shear bond strengths on enamel and dentin. As with composites, camphorquinone is also often used in light-cured adhesives, however it is subject to gradual chemical changes in highly acid formulations – a problem notably with the emergence of self-etching adhesives. This problem is often circumvented by using larger amounts of initiator (camphorquinone) or by using more acid-resistant initiators such as acyl phosphine oxide e.g. Lucirin TPO. As with the camphorquinone-free composite-filling formulations, the “broadband” LED lights also enable the adequate polymerization of camphorquinone-free adhesive formulations.

Shear bond strength of adhesives

An internal study investigated the bonding values of Excite F, Syntac and AdheSE One F after curing with Bluephase (G2) and Bluephase Style. Excite F and Syntac are conventional etch-and-rinse adhesives and AdheSE One F is a self-etching adhesive.

Tetric EvoCeram was applied in two increments, and each increment was light-cured for 40 seconds. In the case of the Bluephase (G2) light, the Low Power mode was used to cure the adhesive. The test samples were stored in water at 37 °C (98.6 °F) for 24 hours prior to measuring the bond strengths.

The bond strength values of adhesives on dentin and enamel achieved with Bluephase Style and Bluephase (G2) in adhesive mode, after the same curing time (10 seconds), were comparable. Figure 23 shows that both lights cured the different types of adhesive effectively.

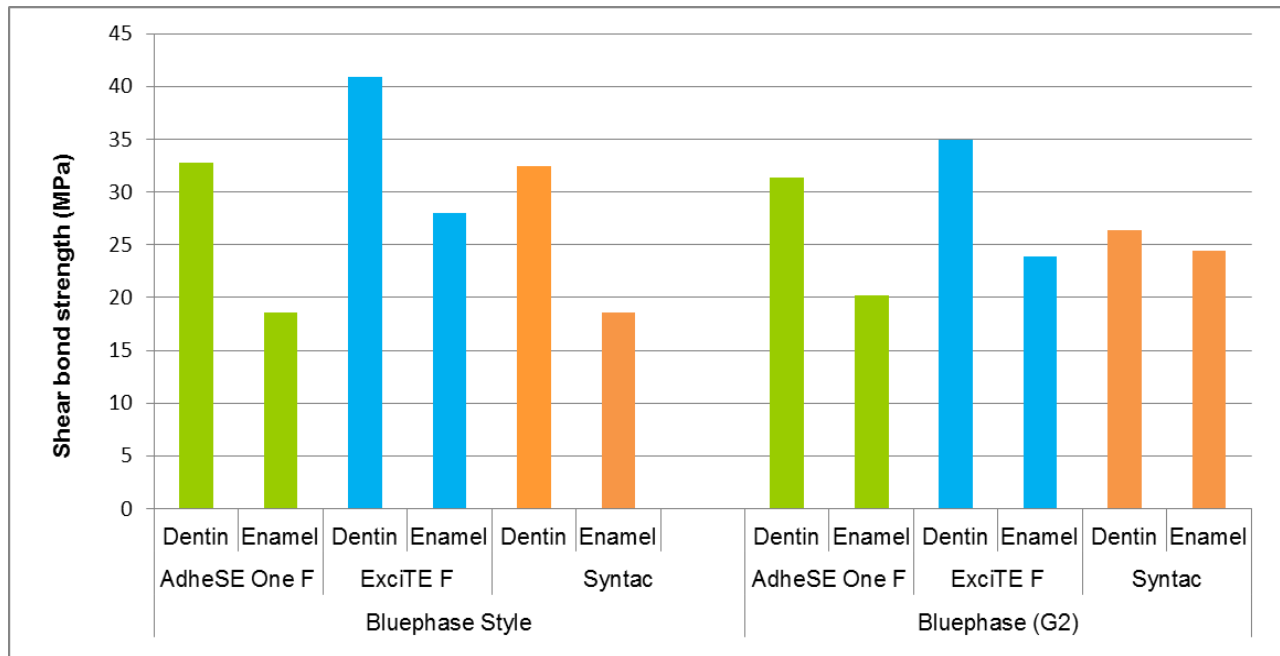


Fig. 25: Comparison of shear bond strength values of AdheSE One F, Excite F and Syntac on dentin and enamel after curing with Bluephase Style and Bluephase (G2) R&D, Ivoclar Vivadent, Schaan 2010

4.3 Curing through ceramics

Light-curing and dual-curing composite cements are used for the adhesive cementation of indirect restorative materials. Adhesive cementation with composites is particularly recommended for all-ceramic restorations based on glass-ceramic materials. Due to the opacity of these materials, the amount of light that effectively reaches the adhesive composite is considerably reduced, therefore, most luting composites contain self-curing initiators as well as light-curing initiators. The self-curing catalyst usually contains amines however, which are not light-stable over the years, and may discolour somewhat. Thus in clinical situations where an esthetic result is paramount, such as in anterior regions, dentists may choose to avoid using self-curing adhesive cements.

Ilie N, Hickel R. Product evaluation: Variolink Esthetic LC, Klinikum der Universität München, Ludwig Maximilians Universität, March 2015

Objective: To evaluate Variolink Esthetic LC, a purely light-curing, permanent adhesive luting cement for inlays, onlays and veneers when cured with Bluephase Style through different ceramics. Variolink Esthetic LC is indicated for luting restorations with a low thickness of < 2mm and with sufficient translucency such as IPS e.max HT. For lights such as Bluephase Style that emit $\geq 1000\text{mW/cm}^2$, a polymerization time of 10 seconds per mm of ceramic and segment is indicated. Curing through a 2 mm ceramic layer would require 20 seconds of curing per segment.

Methods: Variolink Esthetic LC, was investigated with the ceramic materials: IPS Empress CAD (HT A2/V12) and IPS e.max CAD (HT A2/C14) in thicknesses of 0, 0.5, 1, 1.5 and 2mm. Each test group contained 12 thin flat samples of Variolink Esthetic LC. The luting composite, was applied into a ring of 0.5mm height, covered with a thin glass plate (150 μm), covered with ceramic and then polymerized through the ceramic. Micromechanical properties were calculated from the top of the samples according to the standard DIN 50359-1:1997-10 and Vickers hardness values were extrapolated.

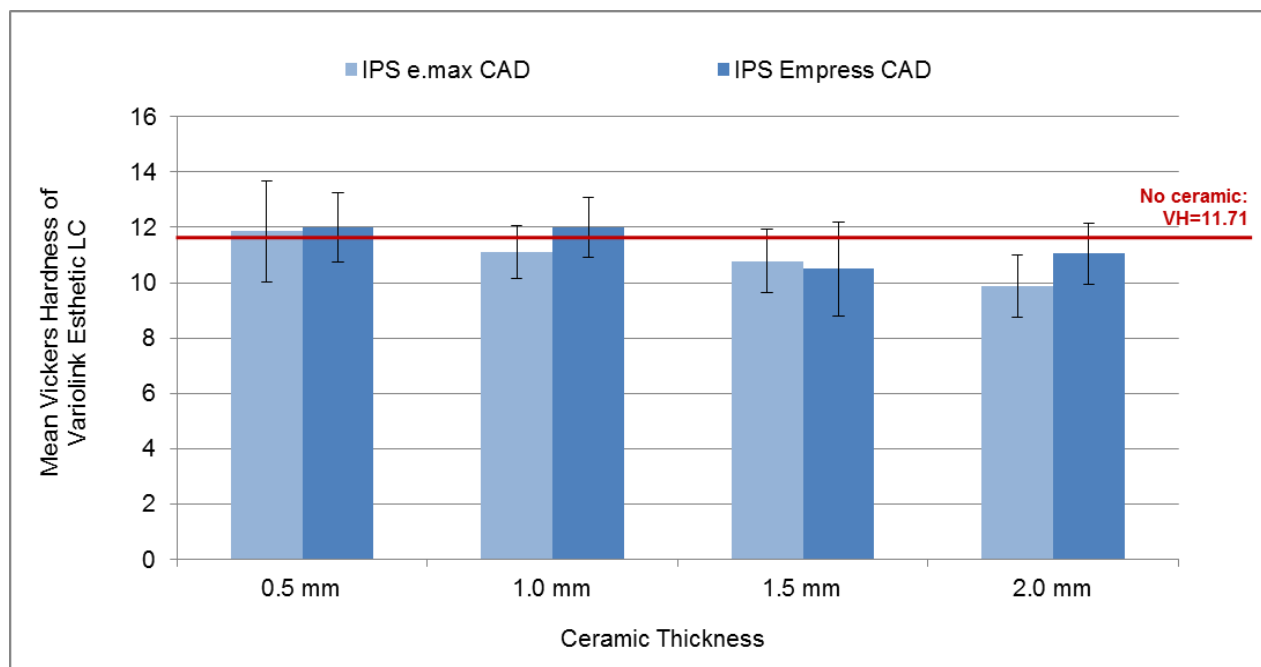


Fig. 26: Mean Vickers hardness of Variolink Esthetic when polymerized with Bluephase Style for 10 seconds, through various thicknesses of IPS e.max CAD and IPS Empress CAD. *Ilie N. Product evaluation: Variolink Esthetic LC, March 2015*

Results: The graph above shows the Vickers hardness values after polymerizing Variolink Esthetic LC for 10 seconds with Bluephase Style through various thicknesses (0.5 mm to 2 mm), of the two ceramics. The Vickers hardness (VH) when cured without any ceramic is shown by the red line at 11.71 VH. A slight and general decrease in VH with increasing ceramic thickness can be observed. There was no significant difference between the two ceramics at 0.5 mm or 1.5 mm but the difference was significant at 1.0 mm and 2.0 mm – here the Vickers hardness was higher in the IPS Empress CAD samples. IPS Empress CAD (HT A2/V12) is slightly more translucent than IPS e.max CAD (HT A2/C14). As noted a higher polymerization time of 20 seconds is recommended for a ceramic thickness of 2mm – here the Vickers hardness values were also calculated, revealing a value of 12.23 for IPS e.max CAD and 14.91 for IPS Empress CAD.

Conclusion: Bluephase Style cured successfully through both ceramics.

Light intensity through ceramics with Bluephase Style 20i

The reduction in light intensity experienced with various Ivoclar Vivadent ceramic materials in various opacities, was tested with the Bluephase Style 20i in TURBO mode. The reduction in light intensity varies depending on the ceramic type, colour, opacity and thickness. Light intensity was measured with ceramic samples of 1, 2 or 3 mm using an integrating sphere.

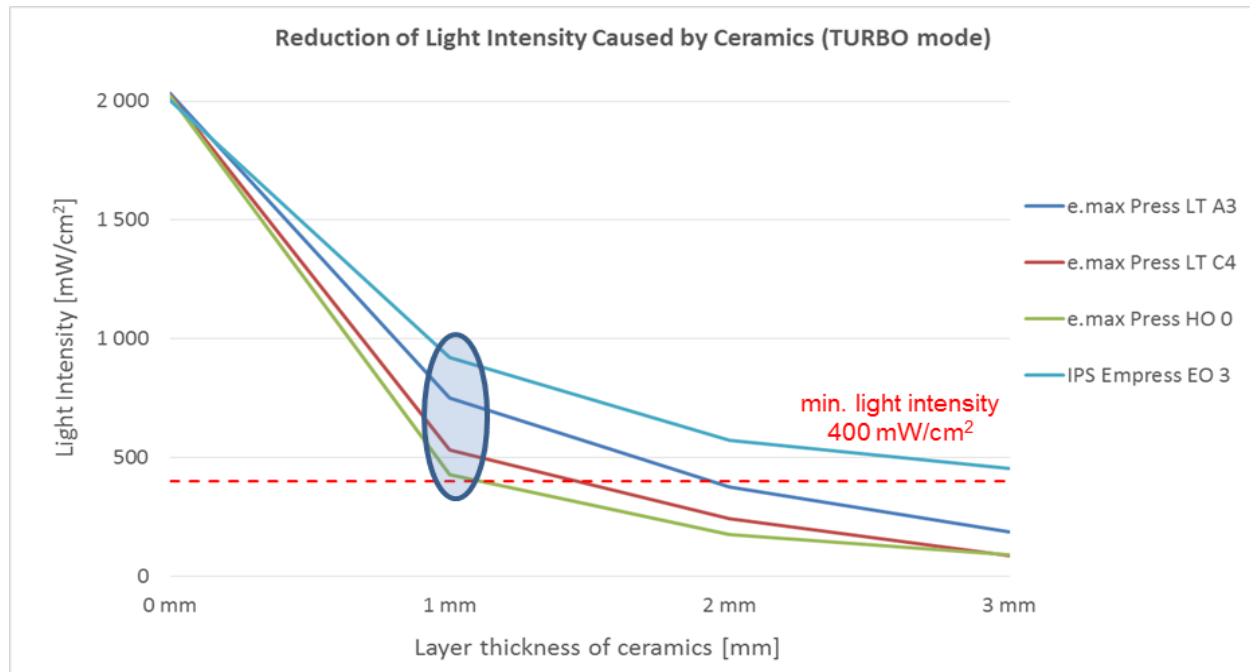


Fig. 27: Reduction in light intensity caused by various ceramics at various thicknesses with Bluephase Style 20i.

The graph above, shows that even at a material thickness of just 1 mm, the tested ceramics reduce the initial light intensity (at 0 mm) from between 50 to 80%. However, if 400mW/cm² is considered the minimum light intensity for curing direct composite restorations, the advantage of the high performance (2000mW/cm²) Bluephase Style 20i curing light is clear as at 1 mm thickness the light intensity is above the 400mW/cm² level for all the materials.

4.4 Heat development around the pulp

Bluephase Style emits a light intensity of $1200 \text{ mW/cm}^2 (\pm 10\%)$, and Bluephase Style 20i of $2000 \text{ mW/cm}^2 (\pm 10\%)$. This light intensity generates perceptible warmth, which can be felt when the light beam is simply directed at the skin. When areas close to the pulp are to be cured, high performance lights entail the risk that the temperature development in the pulp chamber is so high that irreversible tissue damage could occur.

Prof. Rueggeberg from the Medical College of Georgia developed a method to investigate heat development within the pulpal chamber.

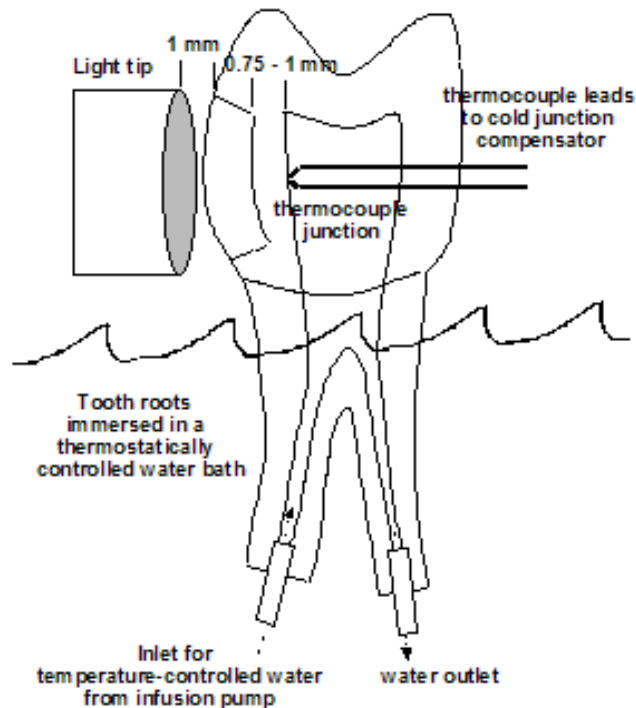


Fig. 28: Diagram of measuring temperature in the pulpal chamber when a buccal cylindrical cavity is irradiated.

A buccal cylindrical cavity is prepared in a premolar, such that the wall to the pulpal chamber has a thickness of 0.75 to 1 mm. The ends of the roots are cut apically to allow a constant flow of water which simulates the heat exchange of the blood flow.

An access route 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) and the light guide is positioned at a distance of 1 mm from the surface of the cavity.



Fig 29a and b. Photograph of an experimental tooth model with respective X-ray image

The adhesive is applied in the cavity before the first composite layer. This process takes place the closest to the pulp and is considered the most critical light-curing step in terms of tissue-impact.

In vitro intrapulpal temperature rise using a commercial and an experimental light curing unit. F. Rueggeberg, The Medical College of Georgia, Augusta, USA, Nov. 2010

Rueggeberg investigated a range of curing lights including the polywave lights: Bluephase (G2), Bluephase 20i (equivalent max. light intensity to Bluephase Style 20i) and Bluephase Style, and compared the temperature increase in the standard cavity after irradiation for various periods of time. The accepted standard maximum rise in temperature is 5.5 °C. This change, is assumed to avoid irreversible damage to the pulp. Figure 27 shows the results of irradiating a cavity without any composite (to mimic the situation when curing an adhesive) for 10 seconds. The Valo plasma light was used according to manufacturer information for 2 x 3 seconds in the plasma mode – and exhibited the highest temperature rise. A high light intensity may well represent a risk to the pulp and soft tissue. Bluephase (G2) was tested in two modes. The “G2 ADHESIVE MODE”, exhibits a temperature rise of just 3.16 °C - well below 5.5 °C and the “G2 HIGH POWER” reaches the threshold at 5.51 °C, however the high power mode is not intended to be used for curing the adhesive layer. For the Bluephase 20i lamp: “BP20i LOW POWER” exhibited a minimal temperature increase of 3.66°C and “BP20i HIGH POWER“, raised the temperature by 6.07°C. The Bluephase 20i lamp (like the Bluephase Style 20i) is however used for just 5 seconds during curing not 10. At the 5 second mark, marked by the red dashed line the temperature rise is well below the 5.5°C threshold. “CABRIO” refers to the original Bluephase Style (1100 mW/cm²), which exhibited a rise of 4.9 °C – also well below the 5.5°C threshold.

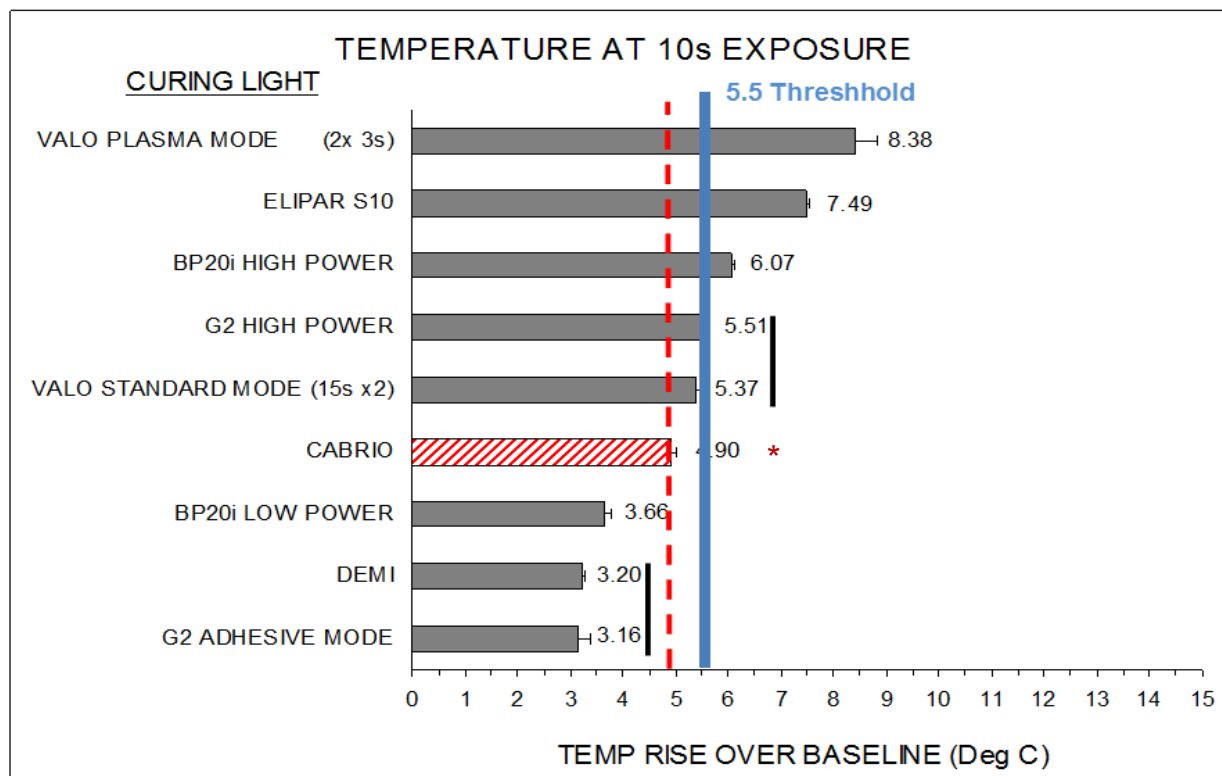


Fig. 30: Comparison of the temperature increase after irradiation with various curing lights and programs. F. Rueggeberg, Augusta, USA, 2010.

* CABRIO = Bluephase Style

The results of these investigations revealed no increased risk for the vitality of the tooth in comparison with other established curing lights.

In vitro – 5 second intrapulpal temperature rise with Bluephase Style 20i and Bluephase 20i

Internal temperature investigations for the indicated curing time of 5 seconds with the new Bluephase Style 20i curing light confirm the results by Rueggeberg.

An upper jaw molar was used for the experiment in which the cusps were ground flat in order to create a reproducible surface for the light guide of the curing light. An MOD cavity was created and a temperature sensor placed in the tooth root. The tooth was mounted in a deionized water bath (37°C) which served as the source for the water flow through the pulp (approx. 36°C). Liquid Strip was first applied to the cavity and polymerized at a 0.5mm distance, with one of the lights for 5 seconds. Then Tetric EvoCeram Bulk Fill was applied in a 3mm layer and polymerized for 5 seconds, followed by a second 3mm layer of Tetric EvoCeram Bulk Fill which was also polymerized for 5 seconds. Temperature recordings were made for the entire filling procedure. Six fillings and measurements were made on the same tooth for each curing light. The mean temperature increase after curing for 5 seconds with the Bluephase 20i lamp was 4.1°C and 3.7°C for the new Bluephase Style 20i unit. There was no statistically significant difference between the groups and the rise was well below the 5.5°C threshold for both lamps.

4.5 Exposure of soft tissues to heat

The influence of direct exposure of soft tissue to the curing light was 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 the Bluephase 20i unit (equivalent in light intensity to Bluephase Style 20i) for 5 seconds and 10 seconds and carried out histological investigations after 30 minutes, 24 hours and 7 days. No damage was detected for irradiation times of 5 seconds. If the tissue was irradiated for 10 seconds, some damage was observed. However, after seven days the affected tissue had regenerated entirely. These results confirmed the suitability of the 5 second curing time for the high intensity 2000 mW/cm² lamps.

4.6 Monowave vs. polywave LEDs

Bluephase Style and Bluephase Style 20i utilize state of the art polywave technology covering a wavelength spectrum of 385 - 515 nm. Bluephase Style M8 utilizes standard monowave technology, covering a wavelength range of 430 - 490 nm. The blue and ultraviolet LEDs used in Bluephase Style are essentially equivalent to those used in the polywave light Bluephase (G2), which was launched in 2008. A number of studies using the Bluephase (G2) have illustrated certain advantages of polywave technology.

Miletic et al²⁷ investigated the degree of conversion (DC) over 48 hours of composite resins containing different initiators cured by either polywave or monowave LED lights. Three groups of resin mixture were prepared as shown in the table below. The groups contained combinations of camphorquinone (CQ), Lucirin TPO (TPO) and ethyl-4-dimethylaminobenzoate (EDMAB).

Group 1	Group 2	Group 3
n=10	n=10	n=10
0.2 wt % CQ	1 wt % TPO	0.1 wt % CQ
0.8 wt % EDMAB		0.4 wt % EDMAB
		0.5 wt % TPO

Table 7: Groups of composite resins with various initiator combinations

Half of the samples in each group (n=5) were cured using the Bluephase G2 light or its predecessor model the monowave Bluephase G1. The DC was measured using micro-Raman spectroscopy within 5 minutes then 1, 3, 6, 24 and 48 hours post-irradiation. The polywave light produced the highest DC in group 2 then group 3 followed by group 1. The monowave light resulted in the highest DC in group 1 (no TPO) followed by group 2 and 3 ($p < 0.05$). Bluephase G2 performed better than its predecessor in the two TPO containing groups and marginally better in the CQ/amine group. This is in accord with the findings of Ilie and Hickel (2008)³⁰ who reported that CQ could be completely replaced by TPO in commercial adhesives. The monowave Bluephase did nevertheless achieve DC values of >70% in the TPO only material – it has been reported that the photon absorption efficiency of TPO increases significantly with increased light intensity and is associated with a larger availability of photons in the higher energy absorptive region of the photoinitiators.²⁸ There were no significant changes in DC after initial curing in all groups, suggesting that the DC did not increase after curing but rather persisted over the 48 hour period.

An earlier study by Santini and Miletic et al²⁹ also found the use of polywave LEDs including Bluephase G2 improved the DC and Knoop hardness of materials containing TPO.

As mentioned Ilie and Hicel³⁰ found that CQ could be completely replaced by TPO in commercial adhesive systems when polywave light curing units were used for polymerization. To test this both Heliobond and Excite were prepared as standard (with CQ) and in experimental form (with CQ replaced by TPO). The adhesive formulations were evaluated after curing for 10 seconds and 20 seconds with two dual wavelength/polywave units (Bluephase G2 and Ultralume 5/Ultradent) and one regular/monowave LED (Bluephase). Vickers hardness and modulus of elasticity were assessed after 24 hours in distilled water at 37°C. They also found that increasing the polymerization time and decreasing the distance between the light and the sample surface resulted in better mechanical properties of the adhesives. Bluephase G2 was able to cure all the tested adhesive formulations.

Price et al (2010)³¹ compared the ability of four different LEDs to cure five composite resins in 10 seconds at 4 and 8 mm distances. Two monowave lights Bluephase 16i and LEDemetron II/Kerr were used and two polywave lights – Bluephase G2 and Ultralume 5/Ultradent. At 4 and 8 mm the Bluephase G2 delivered the broadest spectral range of wavelengths, greatest irradiance and energy density as measured with a spectroradiometer. The Bluephase G2 always produced harder, better cured (4-9 KHN harder) resin compared to the other three lights at both distances ($p < 0.01$).

4.7 Radiometer Accuracy: Bluephase Meter II

The following studies tested the accuracy of the Bluephase Meter II radiometer in comparison to other commercially available radiometers. The Bluephase Meter II consistently produced the most accurate power values.

Power accuracy of a new dental radiometer. R.B. Price, J.E. Harlow, J.O. Kearns. Dept. of Clinical Dental Sciences, Dalhousie University, Halifax, Nova Scotia, Canada. AADR Poster #0412, Los Angeles, CA, USA, March 2016³³

Objective: To compare the accuracy of Bluephase Meter II with a laboratory standard power measurement device in measuring the light output from seven contemporary LED curing lights: Bluephase 20i, Bluephase Style, Bluephase G2, Elipar DeepCure-S/3M Espe, Translux 2Wave/ Heraeus Kulzer, Valo/Ultradent and The Light 405/GC.

Methods: The power output in mW from seven dental curing lights was measured in different modes using the Bluephase Meter II and the PowerMax Pro/Coherent. The PowerMax Pro (PMP) is a laboratory grade power meter that provides broad wavelength sensitivity and has a 30 mm x 30 mm sensor area. This meter has a very fast response time ($< 10 \mu\text{s}$) that enables it to measure short exposure times. Measurements were repeated ten times in a random order for a total of 220 measurements overall.

Results: When compared to the power values from the 'gold standard' PowerMax Pro meter, the Bluephase Meter II reported values that were slightly lower. However, for the lights tested, the small difference between the values from the PMP and the Bluephase Meter II (-4.9 to +7.4%) was well within the meter manufacturer's specifications of $\pm 10\%$.

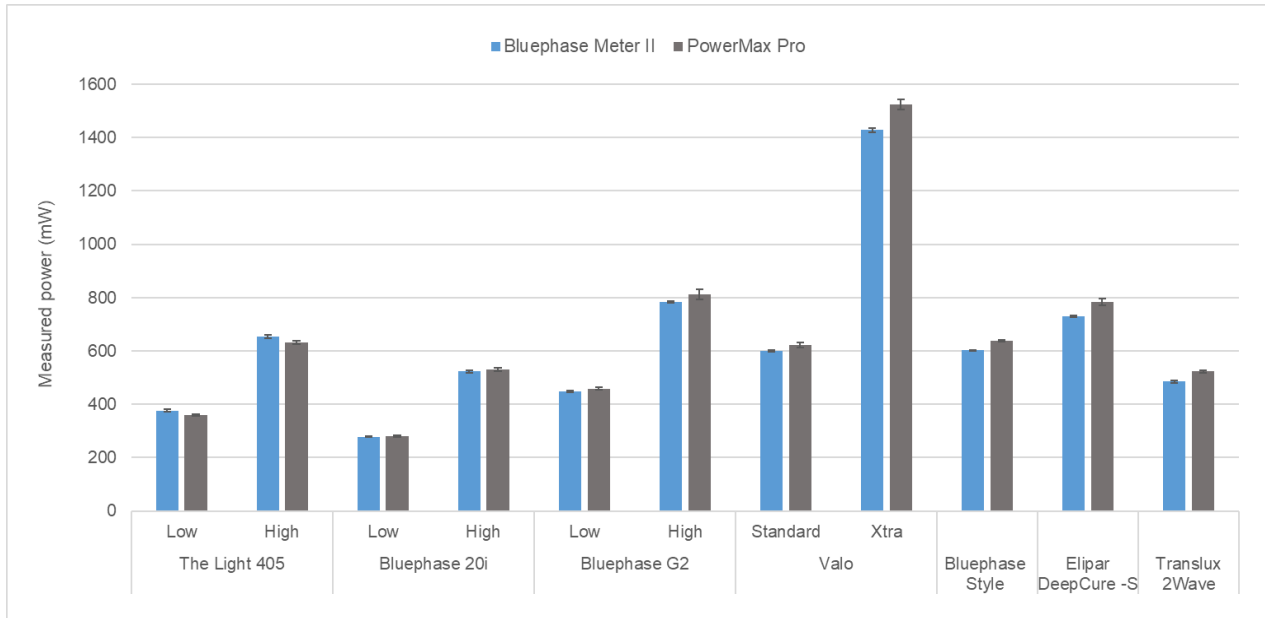


Fig. 31: Power output (mW) of various LED lights, as measured by the Bluephase Meter II and the PowerMax Pro laboratory grade radiometer. *R. Price et al Dalhousie University, Halifax, Canada.*

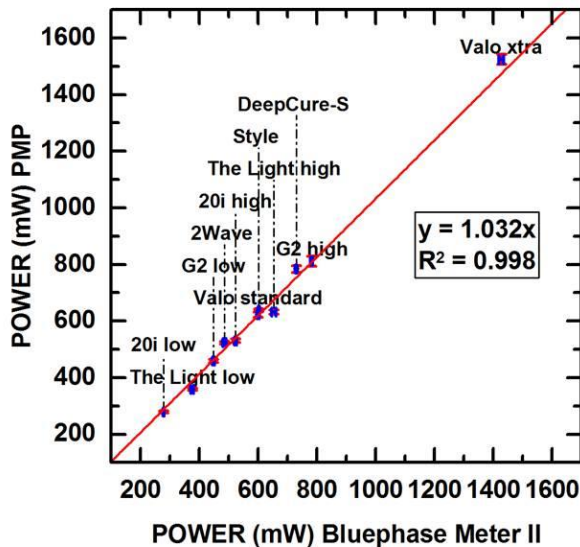


Fig. 32: Linear regression model of the light power emitted (mW) from various lights, as measured by the Bluephase Meter II and the PowerMax Pro radiometer.

Graph: AADR Poster, March 2016. Courtesy of R. Price et al, Dalhousie University, Halifax, Canada.

Conclusions: Overall there was no significant difference between the PMP and the Bluephase Meter II power values. There was a near perfect linear correlation between the power values recorded by the PMP and the Bluephase Meter II ($R^2 = 0.998$). The Bluephase Meter II met the manufacturer’s specifications and was able to accurately and repeatedly measure the power output from the seven models of LED curing lights.

Ability of four dental radiometers to measure the light output from nine curing lights. C.A.K. Shimokawa, J.E. Harlow, M.L. Turbino, R.B. Price. Faculty of Dentistry, Dalhousie University, Halifax, Nova Scotia, Canada and University of Sao Paulo, Brazil.³²

Objective: To evaluate the accuracy of four dental radiometers when measuring the output from nine light curing units (LCUs).

Methods: The light output from nine light-emitting diode LCUs was measured with a laboratory-grade power meter (PowerMax-Pro 150 HD) and four dental radiometers (Bluephase Meter II, SDI LED Radiometer, Kerr LED Radiometer, and LEDEX CM4000). Ten measurements were made of each LCU with each radiometer. Analysis of variance (ANOVA) followed by Tukey tests ($\alpha=0.05$) were used to determine if there was a difference between the calculated irradiance values from the power meter and those from the radiometers. Where applicable, the LCUs were ranked according to their power and irradiance values. The emission spectra from the LCUs was measured using an integrating sphere attached to a fibre-optic spectrometer (N=10). The beam profile of the LCUs was measured with a beam profiler camera.

Results: Of the dental radiometers, only the Bluephase Meter II could measure power. ANOVA showed no significant difference between power values (mW) measured with the laboratory-grade meter and the Bluephase Meter II ($p=0.527$). The difference between the mean irradiance reported by the various radiometers for the same LCU was up to 479mW/cm² however. The ranking of the power values obtained using the laboratory-grade meter was the same for the Bluephase Meter II.

Conclusions: When compared to the calculated irradiance values (mW/cm²) from the laboratory-grade power meter, the Bluephase Meter II provided the most accurate data. Considering the great variation between the irradiance values provided by radiometers and their overall inaccuracy when compared to a laboratory-grade meter, dentists should not place too much faith in the absolute irradiance value. Irradiance measurements from hand-held dental radiometers are affected by the effective tip diameter, the light beam profile and the emission spectrum.

Evaluating the Accuracy of Commercial Dental Radiometers. A. Altaie, K. Davda, J. Kang and D.J. Wood. School of Dentistry, University of Leeds, UK. IADR Poster #0684, Seoul, South Korea, June 2016.³⁴

Objective: To study the accuracy of four commercial dental radiometers in measuring the light output of six different LED light curing units compared to a 'gold standard' spectrometer/integrating-sphere assembly.

Methods: Gold standard output measurements (n=3) were taken using the integrating sphere for each of 6 LED curing lights. Lights used included two polywave units; Bluephase Style and D-Light Duo/GC and four monowave units; Elipar S10/3M Espe, Elipar DeepCure/3M Espe, Demi Plus/Kerr Dental and Demi Ultra/Kerr Dental. Output measurements (n=3) were then made using four different radiometers, namely Bluephase Meter, Bluephase Meter II, L.E.D. Radiometer by Demetron (DM) and SDI LED Radiometer (SDI) for the same curing lights and compared to the integrating sphere values. Lights were mounted on a custom device to align the tip of the curing unit over the radiometer sensor centre. The Intraclass Correlation Co-efficient (ICC), a statistic that specifically evaluates reliability between quantitative measurements, was used to determine radiometer accuracy. Using ICC an f-value of between 0.8 - 1.0 implies a statistically reliable measurement.

Results: The ICC test, showed that only the Bluephase Meter II radiometer was statistically reliable ($f = 0.9$) in measuring light output. The other radiometers exhibited the following f -values: Bluephase Meter ($f=0.7$), SDI LED Radiometer ($f=0.6$) and Demetron ($f=0.3$).

The light output measurements were underestimated in both Bluephase Meter II (-4%) and Demetron (-14%) and overestimated in the case of Bluephase Meter (+8%) and SDI LED Radiometer (+34%).

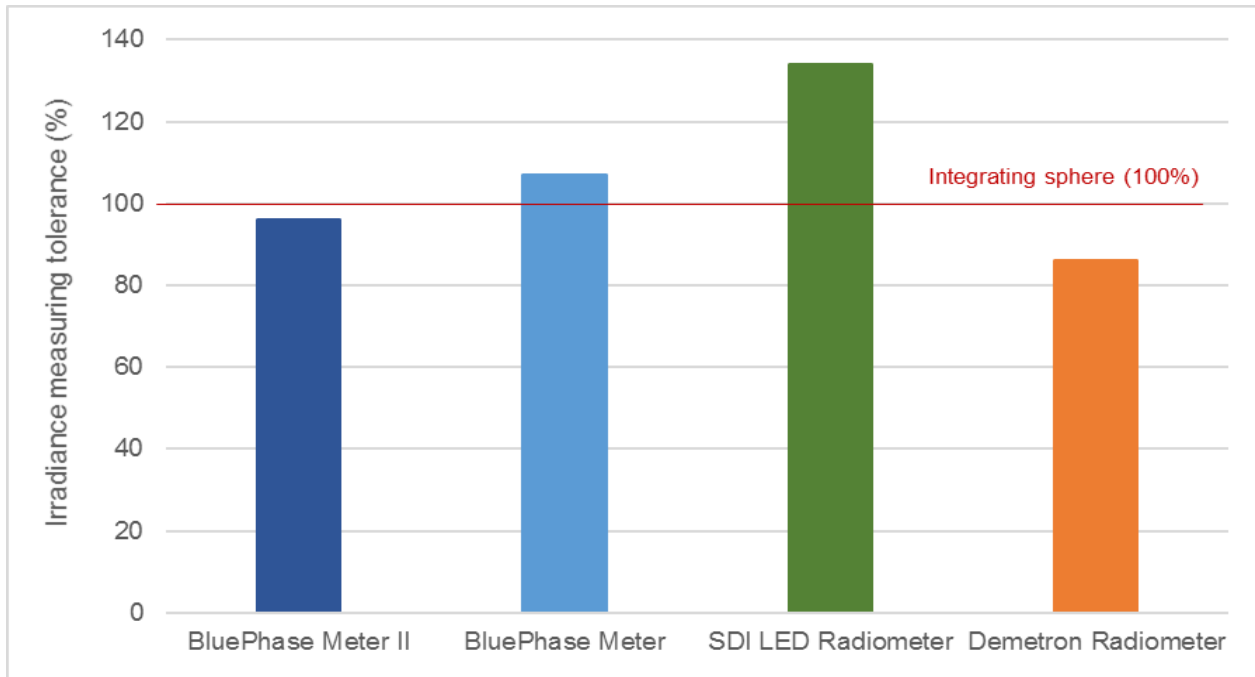


Fig. 33: Measuring tolerance of various radiometers in comparison to integrating sphere. A. *Altaie et al, Leeds University, UK.*

Conclusions: Sufficient light output is critical in successfully curing dental composites and dentists should regularly check the output (and/or light intensity) from their own light curing units. Commercial radiometers demonstrated huge differences in measured outputs. The recently introduced dental radiometer Bluephase Meter II performed significantly better than the other dental radiometers, with a measuring tolerance of 96%. This could be attributed to its large sensor which takes into account the light guide tip diameter when calculating light output.

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