Next Generation Smart Light Curing Technology

Loop™
LED Curing Light

Garrison®

bluelight

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Foreword

Bluelight Analytics was founded in 2009 at Dalhousie University in Nova Scotia, Canada. Since its inception, the company has been a leader in light measurement technology, leveraging its expertise to enhance clinical and business outcomes for dentists, dental service organizations (DSOs), and manufacturers worldwide. To date, Bluelight devices have measured over 200,000 light-curing units (LCUs) across more than 58,000 dental clinics, resulting in the creation of the world's largest database of light-curing measurements. This extensive data, combined with numerous interactions with dental clinics and staff, has been instrumental in identifying and addressing light-curing challenges within dental practices.

Chris Felix is a materials scientist with over 20 years of expertise in light-cured dentistry. Throughout his career, he has collaborated with numerous dental manufacturers on product evaluations and contributed to various research projects alongside leading industry experts. As a founder of Bluelight Analytics, Chris has worked with thousands of dental practices worldwide, helping to improve the quality and effectiveness of light-cured procedures.

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Executive Summary

This white paper explores the performance of the Garrison Loop LED Light Curing Unit (LCU), comparing it to another high-end curing light, the Valo Grand. With light curing integral to over 50% of dental procedures, the Loop introduces advanced capabilities designed to address persistent challenges in restorative workflows.

Key takeaways include:

- The Loop's innovative features include self-assessment and automatic output calibration, minimizing the burden on clinical staff to ensure consistent performance, while incorporating safeguards to protect against accidental or ineffective exposures.

- The Closed Loop algorithm delivers performance enhancements that mitigates variability of energy delivery supporting dental practices in achieving restorations with ideal mechanical properties and more predictable outcomes.

- This analysis highlights the Loop as a valuable option for clinicians seeking innovative, high-performance curing light technology.

The Garrison Loop represents a forward-thinking approach to light curing, offering new capabilities to meet the evolving needs of restorative dentistry.

Introduction

One of the most influential clinical educators of our time, Gordon Christensen, stated, “One of the most negligent areas in restorative dentistry is adequate light curing.” [1] He attended the most recent Northern Lights Light Curing Conference in 2023 to support leading material researchers, educators, and manufacturers gathered to discuss how to address this overlooked problem.

It’s vital to recognize that light curing is a critical step in more than half of the revenue-generating procedures performed by general dental practitioners. Unfortunately, light curing problems are often not immediately apparent; if the blue light turns on and the material hardens, it seems that the job is done. However, when materials later exhibit issues such as discoloration, increased wear, de-bonding, and fractures - or when patients return with post-operative sensitivity - growing evidence suggests that inadequate light curing is responsible for a significant portion of these problems.

Problem Awareness & Cost

Practitioners see these issues manifest in various ways, impacting clinical staff stress levels, dental practice revenues, and patient well-being. Patients who experience complications within days or weeks of a procedure often require emergency visits, which must be accommodated in an already busy schedule. This creates stress for clinical staff, who may have to work through lunch or extend their hours. Practitioners must troubleshoot the causes and find a remedy while also explaining the situation to patients, who are understandably unhappy to be back in the chair.

Emergency return visits are a common occurrence in dental practices for a variety of reasons. While many practices log these visits in scheduling systems or patient records, tracking the associated costs and identifying trends could provide valuable insights for improving efficiency and patient outcomes.

A large review of patient records published in 2019 [2], which included 22 general dental practitioners who placed 31,000 direct class II restorations, showed a large range in annual failure rates between 3.6 % to 11.4 %. It appeared that variability amongst practitioners was more significant than materials used or patient factors, indicating there are actions practitioners can take to reduce premature failure of these restorative procedures.

More than half of dental restorations placed are replacements, with the two leading causes being composite fracture and secondary caries. [3,4] It’s been well established in-vitro, since in-vivo testing would be unethical, that an under-cured composite is more susceptible to fracture under lower forces as compared to when it is fully cured. Additionally, an under-cured bond and/or composite produces a weaker bond, which fails under lower forces as compared to fully cured ones, leading to increased risk of microleakage which leads to secondary caries. [5] Although there are other potential contributing factors related to these failures, light curing is certainly a significant one.

Some issues can take years to manifest, however, post-operative sensitivity and pain is common within days or weeks after placing a direct posterior restoration. Occlusal adjustments are typically the first troubleshooting step, which incurs a chair time cost, and if the symptoms are not resolved, the cost of replacement represents an opportunity loss equivalent to treating a new patient.

A major challenge faced by dental material researchers and manufacturers is isolating light curing effects and connecting the dots between the light curing process and clinical outcomes. It's not ethical to intentionally under or over cure materials in patients to study negative effects. However, materials are well studied in the lab to understand their limitations and conditions for success. There are many studies on the physical and chemical properties of light cured dental materials, and put simply, when they are not light cured adequately, they experience increased levels of discoloration, wear, toxicity, and fracture. [6,7]

Materials are initially tested in laboratories under ideal conditions to develop instructions for use based on a set of standardized tests. When newly approved materials are introduced, they are subjected to clinical conditions that can often impact their success depending on the varying instructions for use. The important takeaway here is that material brands and shades have different light curing requirements and delivering at least the minimums outlined in the instructions for use, including output level, exposure time, and wavelength, is the best way to avoid under curing problems. It's also important not to arbitrarily overcompensate by doubling or tripling the curing time without some degree of caution. The average new LCU produces over 1,000 mW/cm^2 (~ 800 mW of power) which is enough to damage the soft tissues if not managing the heat they produce.

Most direct restorations are placed in posterior locations which can be challenging for an operator to access with an LCU in the same manner as they are used in a lab during material testing. Reduced visibility, patient movement, and operator technique significantly affect the delivery of light to materials. [6] LCU design characteristics, such as tip size, tip angle, beam profile, performance at distance, damage, debris, or source degradation, further impact these challenges and result in a large variability in light delivery to materials. [8]

A recently recorded unpublished case study involved a practitioner that experienced a spike in patient emergency return visits, 37 patients in 6 weeks, due to symptoms of post operative sensitivity after the placement of direct composite restorations. After troubleshooting all they could on their own, they reached out to have their LCUs tested. Two of their three LCUs were in critical condition with significantly reduced light output. Replacing the two defective LCUs solved their problems. The cost to the practice is estimated to be over ten thousand dollars in lost productivity, let alone the stress experienced by the practitioner, staff, and patients.

Like all medical devices, LCUs require proper use and regular maintenance to ensure optimal performance. Over time, even high-quality LCUs may experience wear, damage, or degradation that can impact clinical outcomes if not addressed through routine testing and servicing.

LCU Advancements

The good news is that challenges related to light curing can be managed and issues virtually eliminated with some education and the right choice of products. Innovative manufacturers, such as Garrison Dental, have recognized these challenges and have been working to address them. This document will highlight LCU advancements built into the Garrison Loop LED LCU and how these advancements address four critical elements: design, performance, safety, and maintenance. Each section will compare the Loop to one of the industry leading LCU models, the Valo Grand (Ultradent Products, South Jordan, UT).

Design – Tip Size, Beam Profile, & Tip Angle

Tip Size

The design of LCUs has evolved significantly over the years, and understanding their key characteristics can provide valuable insights on how they impact the effectiveness of light delivery. One critical feature is the tip size—the area from which the light exits.

In older halogen-based LCUs, tip sizes were often as large as 14 mm in diameter, making it relatively easy for users to fully cover dental restorations. However, with the advent of LED LCUs, tip sizes were significantly reduced, typically ranging from 7 to 8 mm. While this compact design improved portability, it also made it more difficult to achieve full coverage, particularly in posterior restorations where overlapping materials intraorally became more challenging.

To address these limitations, many of the latest high-performance LED LCUs have incorporated larger tip sizes, with diameters of at least 10 mm. This adjustment allows for more comprehensive coverage of an adult tooth’s surface, improving both efficiency and clinical outcomes.

Beam Profile

While tip size is a crucial factor, the distribution of light intensity across the tip is equally important. To better understand this distribution, beam profiling—a technique commonly used in laser physics—has been adapted for dental LCUs.

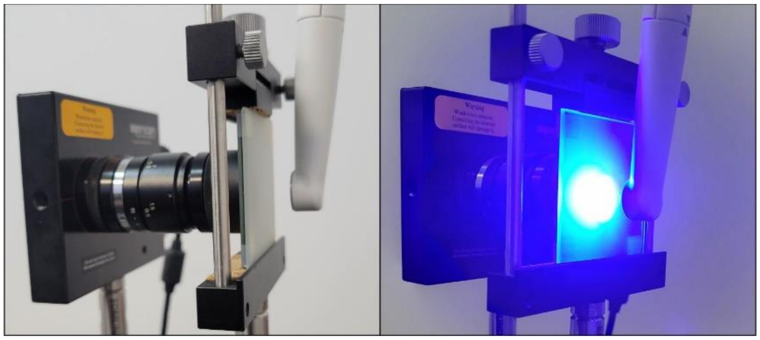
Unlike lasers, which typically maintains a consistent beam distribution over distance, the light emitted by common LCU sources naturally disperses over shorter clinically relevant distances, changing the beam's distribution. This variability can impact the uniformity and effectiveness of light delivery, influencing the degree of polymerization in dental restorations.

To measure beam profiles, a laser beam analyzer camera (Model SP503U, Ophir-Spiricon, Logan, UT) and the LCU are both mounted on x-y-z positioning devices secured to an optical bench, as shown in Figure 1. The light from the LCU is projected onto a diffusive surface of a frosted quartz target (DG2X2-1500, Thorlabs, Newton, NJ).

The LCU tip is precisely centered with respect to the camera. Once the LCU is activated and its output stabilizes, an image of the light distribution is captured using optical analysis software. The software is calibrated based on the pixel scale and dimensions of the camera, allowing for accurate measurements of light intensity across the projected beam.

To further analyze the spectral characteristics of the emitted light, optical filters (Thorlabs, Newton, NJ) are applied, enabling differentiation of the spectral output across various wavelengths.

Figure 1 – Laser beam analyzer

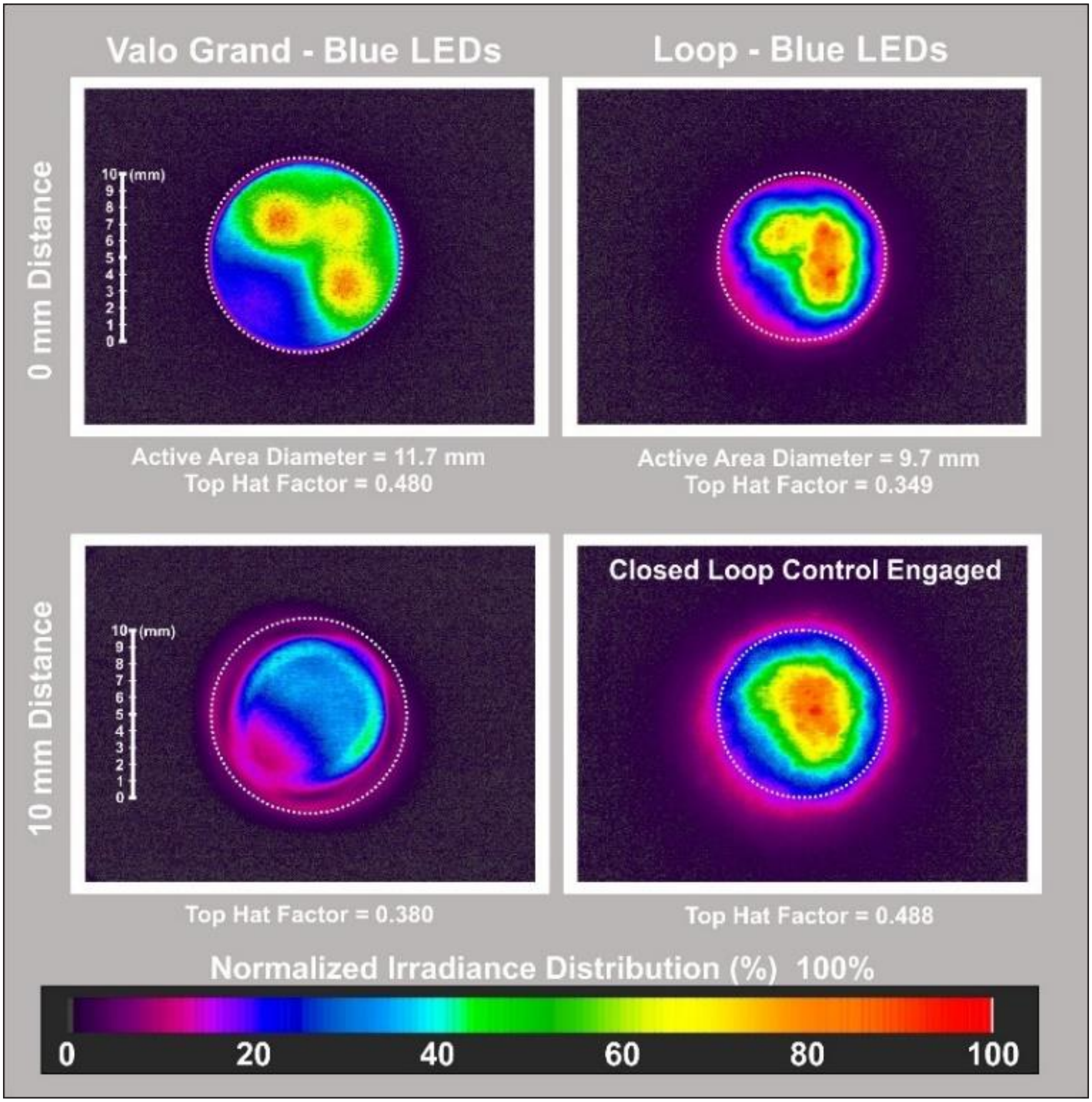


As visible light travels from the LCU tip, it naturally disperses, reducing the amount of light that reaches the target area where the restorative material is placed. To mitigate this dispersion, most LCUs are designed with reflectors and/or lenses to help focus and direct the light.

The Loop system incorporates an optical feedback that senses the actual light intensity at the target. When a change in distance occurs and alters the actual intensity at the target, this change is identified, and the system compensates by automatically increasing the light output to maintain the required intensity at the target.

Figure 2 illustrates the relative distribution of light intensity for the blue LEDs at distances of 0 mm and 10 mm. The Valo Grand maintains a significant amount of intensity within the target area due to the well configured optical components. The Loop maintains a consistent level of intensity within the target area thanks to the Closed-Loop feedback mechanism, which includes a real-time increase in power output as the distance increases. One advantage, or a benefit of this approach is the expansion of the beam size, which enhances coverage and facilitates easier overlap of the restorative material, leading to more predictable polymerization.

Figure 2 – Beam profiles of the Valo Grand and Loop at 0 mm and 10 mm. The Closed-Loop is engaged at 2 mm then backed off to 10 mm.



Tip Angle

The next important design characteristic is the angle of the tip, which has improved significantly with the introduction of LED sources. Although many LED LCUs continued to use fiberoptic light guides, some LCU models have placed the LEDs in the light tip, which has greatly improved intraoral accessibility as seen in Figure 3. Loop and Valo Grand have both incorporated low profile light tip designs which are much more durable compared to the glass tips which are more susceptible to damage. One additional tip design feature found on the Loop is the ability to rotate the tip. This provides more options for the user in the positioning of the light tip.

Figure 3 – Valo Grand and Loop positioned over the distal surface of the last molar.

Performance – LCU Output, Spectral Wavelengths, Distance, & DOC

LCU Output

ISO 10650:2018 is the current LCU standard for measuring the radiant exitance (LCU output) expressed in power (mW) per unit of area (cm^2), which is commonly stated in milliwatts per square centimeter (mW/cm^2).

The LCU output measurements were conducted using a National Institute of Standards and Technology (NIST, Gaithersburg, MD) traceable calibration standard. A 6-inch integrating sphere (Labsphere, North Sutton, NH), shown in Figure 4, was connected to a spectrometer

(USB4000, Ocean Optics, Dunedin, FL) to capture and analyze the emitted light.

Figure 4 - 6-inch Labsphere integrating sphere

Table 1 summarizes the power output and radiant exitance for each operational mode of the Loop and Valo Grand LCUs, (n=1) providing a detailed comparison of their performance under various settings

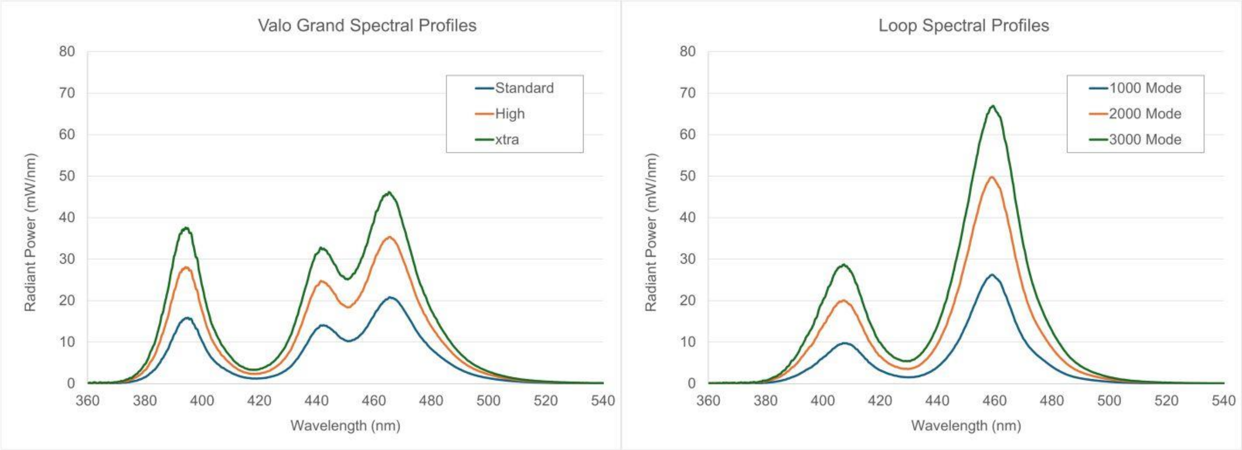
Table 1 - Power and radiant exitance for each mode of the Valo Grand and Loop

LCU – Mode	Power (mW)	Radiant Exitance (mW/cm^2)
Valo Grand – Standard	1036 ± 5	964 ± 4
Valo Grand – High	1822 ± 7	1695 ± 6
Valo Grand - Xtra	2437 ± 8	2267 ± 8
Loop – 1000	832 ± 9	1059 ± 11
Loop – 2000	1720 ± 15	2190 ± 19
Loop - 3000	2440 ± 21	3107 ± 27

Spectral Wavelengths

Figure 5 illustrates that both the Loop and Valo Grand LCUs deliver a consistent increase in power across their respective spectra as the modes are adjusted. The spectrum of the Valo Grand features three distinct peaks, indicating the presence of three different LED chip types. In contrast, the Loop spectrum exhibits two peaks, corresponding to its use of two LED chip types.

Figure 5 – Spectral Profiles of Valo Grand and Loop in all modes.



Currently, most intraoral light-cured dental materials utilize camphorquinone (CQ) as the primary photoinitiator. CQ has a peak absorbance wavelength in the blue region of the spectrum, around 468 nm, making it highly effective with blue light-emitting LCUs.

A small percentage of materials incorporate additional photoinitiators, such as trimethylbenzoyldiphenylphosphine oxide (TPO), which is most efficiently activated by ultraviolet (UV) wavelengths below 400 nm. However, TPO and other UV-based initiators have declined in popularity likely due to the limited penetration of UV light through dental materials compared to blue light. [8]

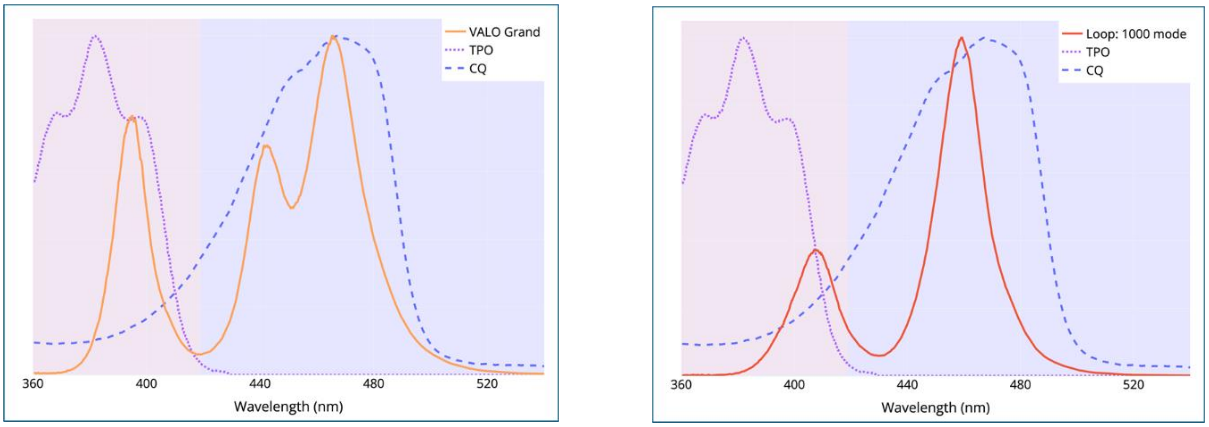
A recent advancement in photoinitiator technology, Ivocerin (Ivoclar Vivadent, Schaan, Liechtenstein), which is still used in combination with CQ, has an absorption peak of 408 nm and is efficiently sensitive from 400 nm to 430 nm [9]. This combination enhances curing efficiency and depth, making it a valuable addition to modern light-cured dental materials. The Loop's lower wavelength peak of 408 nm makes it highly effective for curing materials containing Ivocerin, optimizing polymerization depth and efficiency.

The LCU spectrum are also used to understand how efficiently the light produced by the LCU is absorbed by the photoinitiators commonly used in light activated dental materials. Using the normalized energy absorption spectrum ($a_{norm(\lambda)}$) of the photoinitiator in methyl methacrylate (MMA) [10], the absorption spectrum efficiency is calculated using the formula.[11, 12]

$$\eta_{abs} = \frac{\int i_{(\lambda)} \; a_{norm(\lambda)} d\lambda}{\int i_{(\lambda)} d\lambda}$$

This formula is used to convolve the energy absorption spectrum of the photoinitiator with the intensity spectrum for the tested LCU to produce $\eta_{abs}(\%)$. For CQ, $\eta_{abs}(\%)$ is described as CQ Efficiency and for TPO, $\eta_{abs}(\%)$ is described as TPO Efficiency. In each case, $\eta_{abs}(\%)$ represents the percentage of the LCU's total power output that is efficiently absorbed by the selected photoinitiator. $\eta_{abs}(\%)$ can then be multiplied by the LCU's total power output to produce the total relative effective power. This is the portion of the LCU's total power output that is useful when curing dental materials that contain CQ or TPO. Figure 6 shows the overlay of the LCU emission spectrum normalized to the CQ and TPO absorption spectrum.

Figure 6 – Normalized spectral emission and photoinitiator absorbance spectrum



Valo Grand CQ Efficiency (65.1%) and TPO Efficiency (18.6%), Loop CQ Efficiency (72.2 %) and TPO Efficiency (10.4 %)

Distance

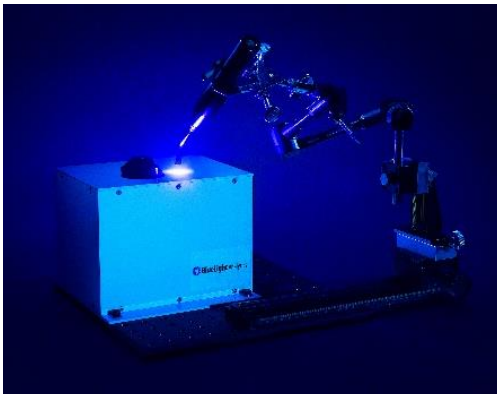
Since materials are typically not cured with the LCU tip in direct contact, distance is an important variable to consider. LCUs vary widely in their performance over distance. Some units, particularly those without optical components, function as point sources that follow the inverse square law for visible light. This means that when the distance from the light source is doubled, the intensity is reduced to one-fourth of its original value.

An average LCU equipped with a reflector around the light source experiences an intensity loss within an average target area of approximately 10 % for every millimeter of distance. LCUs with well-tuned optics can minimize this loss, but typically, only laser-type sources are capable of maintaining a consistent intensity over longer distances.

The Loop takes a unique approach to address this issue by incorporating a feedback mechanism that automatically increases its source output as the distance from the target surface increases, thereby maintaining consistent incident intensity on the target surface.

A bench-top integrating sphere with an attached spectrometer (MARC Light Collector, BlueLight Analytics), shown in Figure 7, was used to measure irradiance from 0 to 10 mm in 1 mm increments. To ensure consistent testing conditions, 0.3 mm thick anodized aluminum apertures were used to maintain a similar active area for each LCU. A 12 mm diameter aperture was employed for the Valo Grand, while a 10 mm aperture was used for the Loop.

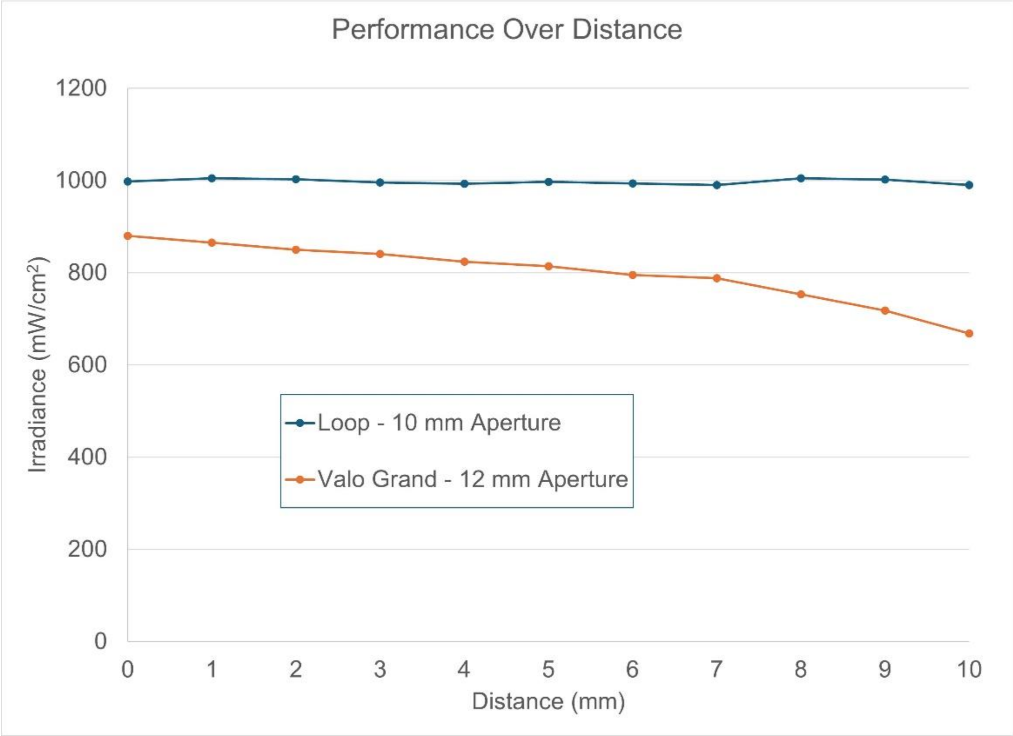
Figure 7 – MARC Light Collector



The Closed-Loop feedback mechanism was enabled and the tip of the Loop centered at 0 mm distance. It was powered on and immediately adjusted to the corresponding distance, demonstrating its ability to maintain consistent irradiance at the sensor surface up to a 10 mm distance.

The Valo Grand also performs very well over distance, with significantly less intensity loss at clinically relevant distances compared to many other LCUs. Figure 8 illustrates the performance over distance for both the Valo Grand and the Loop.

Figure 8 – Performance over distance with Closed-Loop control engaged.

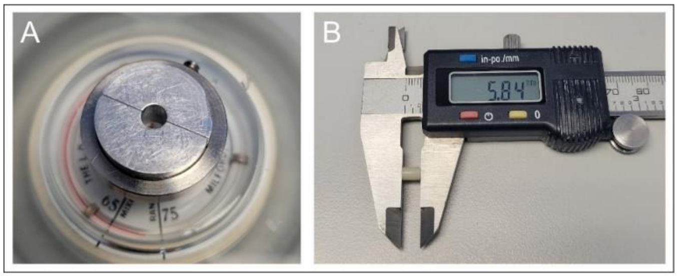


Depth of Cure (DOC)

The ISO 4049:2019 Depth of Cure (DOC) test was originally developed to evaluate the performance of materials, but it can also be used to compare the effectiveness of LCUs. While this test is standardized with the LCU tip positioned at 0 mm distance, incorporating varying distances can make the results more clinically relevant.

The DOC method involves packing light cured composite into a 4 mm diameter cavity within a cylindrical steel mold, as shown in Figure 9A. After curing, the composite specimen is removed, and any remaining uncured material is scraped away using a plastic spatula. The height of the specimen is then measured and divided by two, as depicted in Figure 9B. Three specimens are prepared for each condition.

Figure 9A - 9B – Stainless steel mold with a 4 mm diameter cavity.



The Valo Grand and Loop were tested at distances of 2, 4, 6, and 8 mm in their standard mode with a 10-second curing cycle. For the 4, 6, and 8 mm distances, the LCUs were initially positioned at 2 mm and then immediately moved to each corresponding distance to demonstrate the benefit of the Loop feedback feature.

Figure 10 illustrates how the Loop feedback mechanism maintains consistent irradiance as the distance increases, resulting in an enhanced DOC compared to the Valo Grand. Table 2 provides the means and standard deviations for each condition.

Figure 10 – DOC at distance.

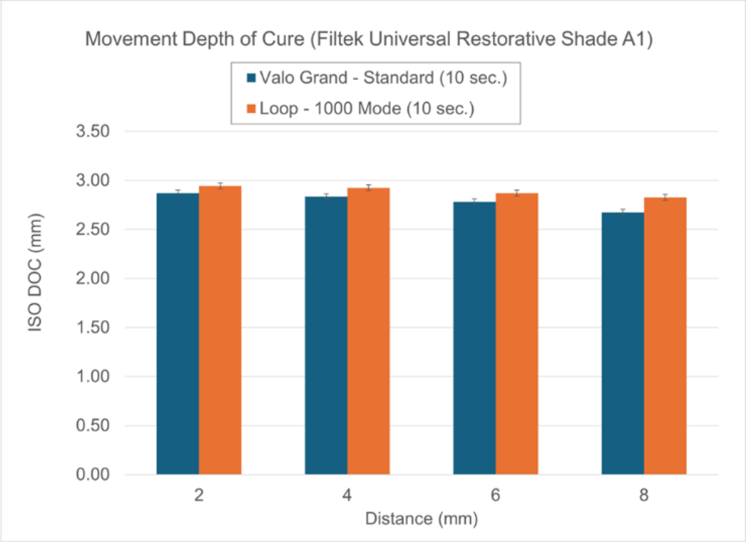


Table 2 – DOC at distance

Distance (mm)	Valo Grand - Standard (10 sec.)	Loop - 1000 Mode (10 sec.)
2	2.87 ± 0.02 mm	2.94 ± 0.03 mm
4	2.83 ± 0.02 mm	2.93 ± 0.02 mm
6	2.78 ± 0.03 mm	2.87 ± 0.02 mm
8	2.67 ± 0.02 mm	2.83 ± 0.02 mm

Safety – Soft Tissue, Under-Curing, & Accidental Exposure

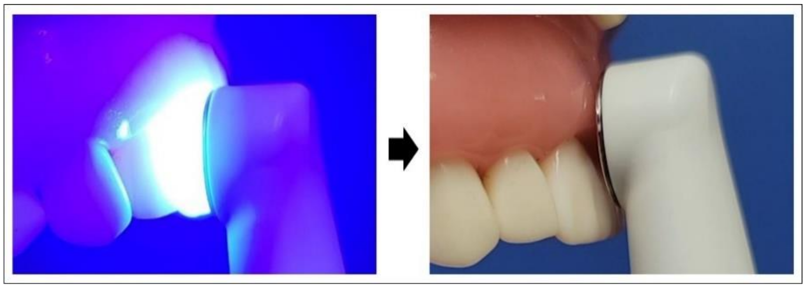
Soft Tissue

Modern LCUs are significantly more powerful than those of the past, making it important to be aware of the heat they can generate. A simple test, such as running a curing cycle on the back of your hand, can help demonstrate the need for caution in certain situations.

Restorations near the gingival tissue have been identified as a potential risk area, as LCUs can cause burns to sensitive tissues.

The Loop addresses this risk with its feedback function, which automatically shuts off the power if the LCU tip is positioned or accidentally moved over the gingival tissue. Figure 11 illustrates this feature: when the Loop tip begins to move over the gingival soft tissue, the power is turned off to prevent potential damage to the tissue.

Figure 11 – Loop feedback function identifies when over soft tissue and turns off.



Under-Curing

The Loop feedback function will also pause the curing cycle for up to three seconds at a time if the LCU operator slides off the tooth or if the distance from the tooth surface exceeds 10 millimeters. If the LCU tip position is corrected within this time frame, the curing cycle will resume and compensate for any lost time to ensure the intended energy delivery. For example, if a curing cycle pauses for 2 seconds during a 20 second cycle, the active cycle will continue to 22 seconds. However, if the position is not corrected, the display will indicate a failure to deliver the intended energy, and a new cycle will need to be initiated.

Accidental Exposure

Accidentally pressing the power button can pose a risk to both the patient's and clinical staff's eyes. With the Loop feedback function enabled, the curing cycle will not engage until the LCU tip is positioned within 3 mm of the surface to be light cured, helping to prevent accidental exposure.

LCU Maintenance – Barriers, Tip Debris/Damage, & Sources Degradation

Barriers

Many commercially available LCUs require single-use infection control barriers. These barriers are effective at preventing material from sticking to the tip, which can save time and prevent damage to the tip. However, some barriers can reduce LCU output by more than 30%, potentially affecting the light delivery to materials. [13] The Loop includes specially designed barriers along with compensation for this reduction, ensuring that the expected light intensity is maintained during the curing process.

Debris & Damage

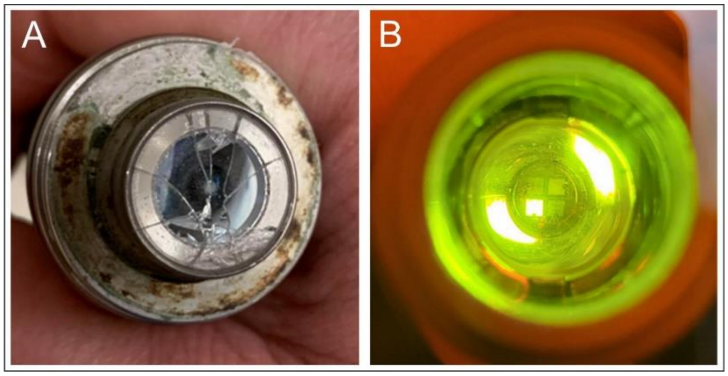
A recent study published in 2024 [14] assessed over a thousand LCUs from 544 dental clinics in the United States and Canada. The study found that 74% of LCUs had some degree of damage or debris on the tip. These issues can significantly affect performance if not addressed. The Loop conveniently detects any minor debris or damage to the tip once it is placed in its charging base, as seen in Figure 12, ensuring optimal performance.

Figure 12 – Loop daily cleaning check indicator.

Source Degradation

In the same study, only one in four LCUs were found to produce outputs within 20% of the manufacturer's stated specifications, as required in the ISO10650:2018 standard. Figures 13 A/B show examples of LCUs that appeared to be functioning, but both contained damage. LCUs are classified as Class II medical devices in the United States, regulated by the FDA under the General Radiological Health Requirements. Radiation-producing devices are considered defective if they fail to meet design specifications related to the emission of electronic product radiation.

Figures 13A – LCU that was dropped and the internal components broken, significantly reducing output. **13B** - LCU the experienced 3 of 4 LED chips burning out, significantly reducing output.



The use of such defective devices could lead to liability if patients experience any harm. Despite this, many dental offices still do not regularly test their LCU equipment. LCUs can be dropped or subjected to wear and still produce some light, giving the false impression that they are in good working order. However, they can lose a significant amount of intensity before completely failing.

The Loop's ability to monitor its output and self-calibrate to the manufacturer's stated specifications provides significant value in maintaining the reliability of medical devices used in patient treatment. Like all medical devices, LCUs require routine testing and maintenance to ensure optimal performance over time. Relying solely on patient feedback to identify issues can lead to inefficiencies and additional costs. The Loop is designed to help maintain consistent performance, reducing the likelihood of potential issues and supporting compliance with industry best practices. Figure 14 shows the Loop in its monthly full calibration position, with a display confirming that the equipment is functioning within expected parameters.

Figure 14 – Loop completing monthly full calibration function

Summary

This White Paper presents a comparison between the Loop, with its advanced smart technology activated, and the Valo Grand across several key metrics. The analysis highlights critical insights into their overall performance and safety features.

- The Loop provides significant advancements in smart technology that:
    - Protects soft tissue from exposure
    - Prevents user technique errors leading to under-curing
    - Safeguards against accidental eye exposure
    - Eliminates the need for manual functionality testing by automatically self-assessing and self-correcting, establishing itself as the most advanced LCU on the market today
- The Loop's closed loop algorithm provides consistent irradiance up to 10 mm
- The Valo Grand offers a larger active area, but the Loop compensates with a wider beam at distance, effectively bridging the gap in coverage
- Both the Valo Grand and Loop feature low-profile tips, ensuring excellent intra-oral access

Conclusion

LCUs are integral to over 50% of procedures performed by general practitioners daily. However, like any device, LCUs have a finite lifespan, and their failure can result in disrupted procedures, increased stress for patients and clinical staff, and financial losses for the practice. As technology evolves, smarter devices continue to enhance our lives, offering innovative solutions to longstanding challenges. The Loop represents more than just another LCU—it marks a groundbreaking advancement in smart curing technology. By addressing critical issues, saving valuable time, and elevating patient care, the Loop delivers exceptional value that justifies its investment.

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