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Optimizing dental resin polymerization: the impact of multiple wavelength light-curing units

Otimização da polimerização de resinas dentárias: o impacto das unidades de fotopolimerização com múltiplos comprimentos de onda

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ABSTRACT

Objective: This study aims to evaluate the influence of variable wavelengths on the polymerization and degradation of microhybrid dental composites with different photoinitiator systems. **Material and Methods:** Three types of resin were analyzed: EMPRESS DIRECT TRANS 30 (IVOCLAR) (ED) with an alternative photoinitiator, VITTRA APS (FGM) (VA) utilizing an APS system and Z100 (3M) (Z) containing only camphorquinone. Vickers microhardness (DV), compressive strength (RC), and solubility (S) tests were conducted, creating the following groups with 10 samples per group: A1: ED light-cured by monowave, A2: ED light-cured by biwave, B1: VA light-cured by monowave, B2: VA light-cured by biwave, C1: Z light-cured by monowave, C2: Z light-cured by biwave. **Results:** RC (Mpa): A1: 249.88 (36.73), A2: 174.31 (19.68), B1: 240.78 (26.17), B2: 207.7 (35.6), C1: 268.74 (31.15), C2: 202.77 (31.56). S: A1: 0.0005, A2: 0.0001, B1: 0.0005, B2: 0.0005, C1: 0.0004, C2: 0.0002. DV (HV): A1: 35.59 (4.88), A2: 37.97 (4.27), B1: 70.33 (12.75), B2: 73.64 (9.7), C1: 129.59 (12.85), C2: 128.33 (18.91). Groups A and E showed significantly higher compressive strength than B and (A/B; P=0.0007, E/F; P=0.0035, ANOVA followed by Tukey test). No significant difference was detected between groups C and D. **Conclusion:** The correct association between wavelength and photoinitiator is important for compressive strength. The APS system showed compatibility with both types of LCUs.

KEYWORDS

Chemical Waste Degradation; Composite resin; Compressive strength; Dental Curing Lights; Hardness.

RESUMO

Objetivo: Apesar do amplo uso das resinas compostas, é essencial verificar se os fotopolimerizadores (LCUs) com um ou mais comprimentos de onda polimerizam eficientemente qualquer tipo de resina. Este trabalho foi avaliou a influência de comprimentos de onda na polimerização e degradação de compósitos dentais microhíbridos com diferentes iniciadores. **Material e Métodos:** Foram analisadas: EMPRESS DIRECT TRANS 30 (IVOCLAR) (ED) com fotoiniciador alternativo, VITTRA APS (FGM) (VA) utilizando sistema APS e Z100 (3M) (Z) contendo apenas canforoquinona. Os testes de microdureza Vickers (DV), resistência à compressão (RC) e solubilidade (S) foram realizados com os seguintes grupos com 10 amostras por grupo: A1: ED fotopolimerizada por monowave, A2: ED fotopolimerizada por biwave, B1: VA fotopolimerizada por monowave, B2: VA fotopolimerizada por biwave, C1: Z fotopolimerizada por monowave, C2: Z fotopolimerizada por biwave. **Resultados:** RC (Mpa): A1: 249,88 (36,73), A2: 174,31 (19,68), B1: 240,78 (26,17), B2: 207,7 (35,6), C1: 268,74 (31,15), C2: 202,77 (31,56). S: A1: 0,0005, A2: 0,0001, B1: 0,0005, B2: 0,0005, C1: 0,0004, C2: 0,0002. DV (HV): A1: 35,59 (4,88), A2: 37,97 (4,27), B1: 70,33 (12,75), B2: 73,64 (9,7), C1: 129,59 (12,85), C2: 128,33 (18,91). Os grupos A e E apresentaram valores significativamente maiores de resistência à compressão do que B e F (A/B; P=0,0007, E/F;

P=0,0035, ANOVA seguido pelo teste de Tukey). Não foi detectada diferença significativa entre os grupos C e D. **Conclusão:** A correta associação entre comprimento de onda e fotoiniciador é importante para a resistência à compressão. O sistema APS mostrou compatibilidade com os LCUs testados.

PALAVRAS-CHAVE

Degradação de Resíduos Químicos; Resina composta; Resistência à compressão; Lâmpadas de Polimerização Dentária; Dureza.

INTRODUCTION

Given the widespread use of composite resins in the daily practice of dental surgeons, understanding the factors that influence the degradation of restorations when different wavelengths are used, is essential in the search for a higher-quality dental restoration. Understanding these phenomena supports improvements in restoration techniques, thereby increasing the lifespan of direct dental restorations.

Photoactivated composite resins are used in dentistry as a restorative material due to their advantages over other restorative materials. The benefits of these materials include their aesthetic appeal, adhesiveness, biocompatibility, and the potential for offering less invasive treatments [1]. The wide range of opacities and colors available in composite resins allows for the precise imitation of the lost tooth structure, thus promoting the preservation of said structure, as the preparation required to receive these materials is more conservative [2]. For proper polymerization to occur, certain elements are employed to ensure the curing and maintenance of the materials' mechanical efficiency, such as increasing translucency, the addition of new methacrylate-based monomers, and alternative reaction initiators such as Lucerin TPO and BAPO [3-5].

Despite the extensive discussion surrounding these new initiators and the advances in the development of these biomaterials, the existing literature on their clinical performance remains scarce, and composite resins still present shortcomings, especially in terms of their degradation. One factor that contributes to this early deterioration of the restorative material is inadequate polymerization [6]. The longevity and clinical success of restorations depend directly on correct photoactivation. The variety of light-curing units on the dental market has given rise to many concerns among professionals, especially regarding their application and effectiveness in the polymerization process of composite resins. There are several types of these units, including monowave, which emits only blue light, and polywave, which emits two or more lights of different wavelengths, including violet. The conventional photoinitiator - camphorquinone (CQ) - exhibits maximum absorption at the wavelength of blue light. The alternative photoinitiators currently in use have their peak at the wavelength of violet light [7]. Faria-e-Silva et al. (2017) [8] point out that the failure rate in subsequent restorations is low, around 2%. However, in anterior restorations, these failures rise to around 4%.

This may be related to inadequate curing, especially since these specific types of restorations require lighter-colored composites. They therefore use initiators other than CQ. Insufficient photoactivation results in lower conversion rates of monomers into polymers, leading to mechanical and physical deterioration, which directly impacts the longevity and quality of the restorations [9,10]. Camphorquinone, the most commonly used photoinitiator in composite resins, is an alpha-diketone that absorbs light with a wavelength between 460-480 nanometers (nm).

However, its yellowish color makes it difficult to incorporate, as it interferes with the coloration of lighter resins or those that require a high degree of translucency. For this reason, some photoinitiating substances are being used as replacements or complements to CQ [11,12]. Among the photoinitiator systems used, we can highlight 1-phenyl-1;2-propanedione (PPD), mono-acyl phosphinic oxide (MAPO or Lucirin TPO), bisakyl-phosphinic oxide (BAPO or Irgacure 819), benzoyl germanium (Ivocerin), diphenyliodonium hexafluorophosphate (DPIHFP), 1,3-benzodioxole (BDO), piperonyl alcohol (AP), 1,3-diethyl-2-thiobarbiturate (TBA), and the System APS (Advanced Polymerization System), about which there is little data available in the literature. These substances absorb light at wavelengths below 410 nm and are less responsive to the 450 to 468 nm light range emitted by monowave LED units [13].

Until their second generation, LED devices emitted a single peak of light (blue) in the 450 to 468 nm range. However, as newer initiating substances were developed, this led to a mismatch. To address this issue, third-generation LEDs, also called polywaves or biwaves, were introduced. These LED units also emit violet-colored light and reach a broader wavelength spectrum. This broad spectral wavelength range, with emission peaks at ~405 nm and at ~455 nm, theoretically coincides with the range that activates both CQ and alternative photoinitiators [14]. However, they present heterogeneity in the light beam emitted, which can lead to false benefits due to heterogeneous curing of the material, premature failure and low resistance to degradation [15].

The deterioration of the oral environment over time can lead to the fracturing or discoloration of composite resin restorations. In addition, surface properties such as hardness, wear resistance, and solubility may be altered, compromising the longevity of the restoration [16]. Therefore, this research could serve as a tool to elucidate the impact of light-curing units with different lights on different photoinitiators on these mechanical properties, thereby advancing the understanding of the indications and enhancing the clinical performance of resin composites. Thus, the aim of this study is to analyze, through solubility, microhardness, and compressive strength, the degradation of composites with CQ alone, as well as that of composites with other initiators, when using LED light-curing units with only one, two, or more wavelengths.

MATERIAL AND METHODS

DenteMed's Prime Led and Schuster's Emitter Now Duo light-curing devices were used to produce the specimens, with irradiances of 803.33 W/m^2 and 970 W/m^2, respectively.

Three types of composite resins were used for the solubility, compressive strength, and microhardness tests, as shown below:

a. Z100 - manufactured by 3M, has only camphorquinone (CQ) as an initiator, rendering it compatible with blue light.

b. Vittra APS - manufactured by FGM, is comprised of a combination of primers called the APS System. It is unclear which alternative photoinitiators are present, but it is known that this resin contains a low concentration of CQ.

c. IPS Empress Direct (ED) - manufactured by Ivoclar Vivadent, its photoinitiator is Ivocerin, developed by the brand. There is no indication specified by the manufacturer. However, its curing would be more complete with violet light.

The samples used for the study were separated into groups:

Group A1: Empress Direct light-cured by monowave

Group A2: Empress Direct light-cured by biwave

Group B1: Vittra light-cured by monowave

Group B2: Vittra light-cured by biwave

Group C1: Z100 light-cured by monowave

Group C2: Z100 light-cured by biwave

Compressive strength

Twenty samples of each resin were prepared for the compression test. Ten of them were photoactivated using a biwave device, while the remaining ten were photoactivated using a monowave, both of which were manufactured by Schuster. The samples were prepared within a metal washer measuring 6 mm in diameter and 2 mm in thickness. The resins were light-cured in accordance with the manufacturer' instructions. Prior to photoactivation, pressure was applied to both sides of the specimen with the use of glass plates and polyester strips on both sides of the test specimen, which served to flatten and remove excess material.

The test was carried out at the Applied Biotechnology Laboratory (Laboratório de Biotecnologia Aplicada - LABA), using the EMIC machine (universal testing machine) at 1mm/sec, as recommended by ISO 4049 [17].

Solubility

The same resins were used for the solubility test, following the same standards and methods employed in preparing the compression test specimens. Each specimen was placed inside a plastic container containing 5 ml of distilled and deionized water. Following preparation, the specimens were placed in an oven at 37°C. On each day, the samples were removed from the containers and reweighed until the weight stabilized, which took an average of 14 days. The solubility and disintegration of the studied resin corresponds to the loss of mass after the removal of water and storage in an oven at 37°. The tests were carried out in the Biomaterials Laboratory of the Faculty of Dentistry of Universidade Federal Fluminense (Faculdade de Odontologia - FO-UFF).

Vickers hardness

The hardness tests were carried out on the INSIZE/ISH-TDV1000 durometer with the same resins, and following the same standards and methods used in preparing the specimens in the previous tests. After producing the samples, we attached a metal washer to a stabilizing piece so that the material would not move during the test. At the end of all the tests, the results with the monowave and biwave LCUs were compared, considering their respective indications. The results were analyzed using Past software, with ANOVA calculations and Tukey's test ($\alpha = 5\%$), which determines which groups show a statistical difference from each other.

Statistical treatment

The data was tabulated in Microsoft Office Excel® software and exported to GraphPad Prism 9.5.1 for statistical analysis. Kolmogrov-Smirnov and Shapiro-Wilk tests were used to test data normality, showing a normal distribution for the variables tested, such as the graph for compressive strength.

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

RESULTS

Characterization of light-curing units

The light-curing units were measured on the MSC15-W spectroradiometer (Gigahertz-Ultradent) five times to determine their average powers. The active tips were measured with a digital caliper with an accuracy of 0.01 mm. The MSC15-W measures the total power and the power of each wavelength corresponding to the blue and violet colors. With this power and the area of the light-curing unit, we can calculate the average irradiance of each device.

Emitter now duo

As shown in Table I, this light-curing unit exhibited a total average radiating power of 440 mW and an irradiance of 862 mW/cm^2, given that the active tip is 8.1 mm in diameter. This result represents the average of 5 measurements in MSC15-W.

Despite its classification as a biwave unit, the observed power output in the violet light range (385-425 nm) was significantly lower than expected, averaging only 3.8 mW - less than 1% of the device's total average power. As illustrated in Figure 1A, the device exhibited a minor peak of violet light at a wavelength of 419 nm.

Prime LED

The total average radiant power of this LCU was determined to be 321 mW, with an irradiance of 730 mW/cm^2, based on the measurement of the active tip diameter, which is 7.5 mm. Despite its designation as a device that emits only blue light,

Table I - Characterization of the Emitter Now Duo and Prime LED light-curing unit. Standart deviation in parentheses

Light Curing unit	Diameter	Total Power (mW)	Blue Light Power (mW)	Violet Light Power (mW)	Irradiance (mW/cm^2)
Emitter	8.1	440.82 (16.2)	436.36 (16.1)	3.85 (0.11)	862
Prime	7.5	321.64 (10.8)	319.48 (10.6)	1.76 (0.07)	730

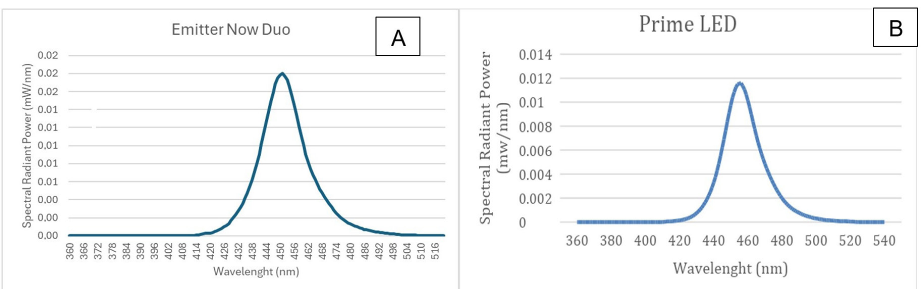

Figure 1 - A) Spectrum of the Emitter Now Duo light-curing unit. It presents a small peak at 419 nm wavelength, a violet light region, and a maximum peak at 451 nm wavelength, a blue light region. B) Spectrum of the Prime LED light-curing unit.

it exhibited small power output in the violet light range of 420-490 nm, with a measured value of approximately 1.76 mW, or approximately 0.5% of the total average power, as shown in Table I. Nevertheless, the device did not exhibit any peak in this range, as illustrated in the graph in Figure 1B.

Compressive strength (CS)

The statistical differences were between groups A1 and A2, and C1 and C2. In other words, the average compressive strength of Z100 resin, when light-cured using the monowave, was significantly higher than when light-cured using the biwave. In turn, when light-cured using the biwave, the average compressive strength of Empress Direct was also significantly higher than when it was light-cured using the monowave. Furthermore, it also presented a lower standard deviation, which indicates greater predictability (Table II).

The APS system proved to be compatible with both light-curing units, as it generated positive results which were not significantly altered by changing the appliance. However, with regard to compressive strength, it showed greater predictability with the monowave, as evidenced by a lower standard deviation.

The comparative analysis of the groups was conducted using ANOVA, followed by the Tukey test for multiple comparisons. The analysis was carried out with seven sampling units per group, and the test power was calculated post-hoc, showing 99% power (G*Power 3.1.9.7). The confidence interval adopted was of 95%, and $p<0.05$ (5%) was considered statistically significant.

The Kolmogorov-Smirnov and Shapiro-Wilk tests were employed to assess the normality of the data, revealing a normal distribution for the tested variables, as illustrated by the compressive strength graph (Figure 2).

Only the compressive strength test revealed a statistical difference between the groups. As illustrated in Figure 3, groups A and E had significantly higher compressive strength values than their peers B and F (A/B; p=0.0007, E/F; p=0.0035, ANOVA followed by Tukey test for multiple comparisons). No significant difference was detected between groups C and D.

Solubility (SL)

According to ISO 4049, the solubility considered ideal for the use of resins as a restorative material is up to 7.5 $\mu g/mm^3$ in 7 days of storage. Therefore, after the calculations, it can be concluded that all groups showed satisfactory solubility. Furthermore, no statistically significant differences were observed between the groups (Table III). The test was conducted for 14 days due to the need for weight stabilization; however, no solubility greater than the recommended value was recorded.

Table II - Average compressive strength of each group and their respective standard deviations

GROUP	RESINS/LCU	CS AVERAGE
A1 (a)	ED/MONOWAVE	249.88 (36.73)
A2 (b)	ED/BIWAVE	174.31 (19.68)
B1 (c)	VITTRA/MONOWAVE	240.78 (26.17)
B2 (c)	VITTRA/BIWAVE	207.7 (35.6)
C1 (a)	Z100/MONOWAVE	268.74 (31.15)
C2 (b)	Z100/BIWAVE	202.77 (31.56)

Equal letters denote statistical equality.

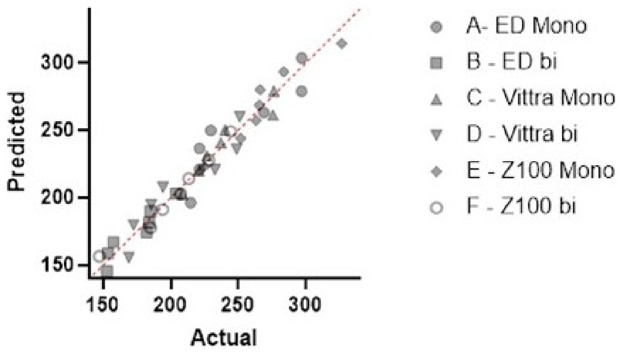

Figure 2 - Graph – QQ plot's compressive strength.

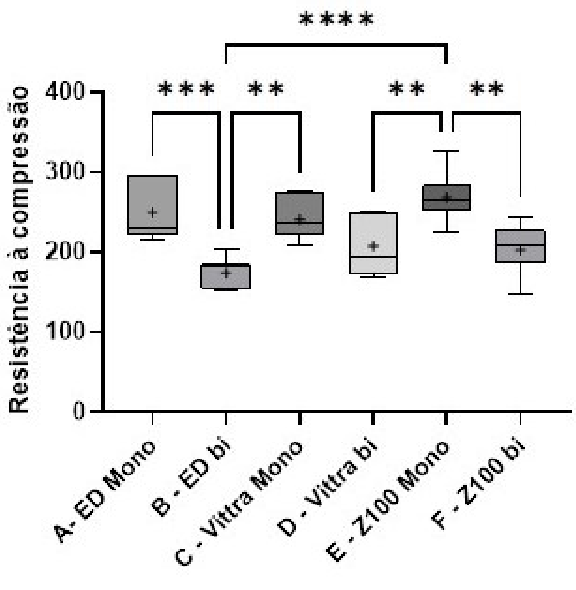

Figure 3 - Graph with average and standard deviation of compressive strength. (**= p0,01; ***= p0,001; ****=p0,0001).

Vickers hardness (HV)

There was no statistical difference in hardness between groups with the same resin light-cured by different LEDs (Table IV). However, considering the standard deviations, Vittra showed greater predictability when light-cured by biwave, as did Z100 when light-cured by monowave.

DISCUSSION

The result of the compression test corroborates the hypothesis that the lights' wavelengths can, in fact, influence the mechanical properties of the resins according to the photoinitiators that comprise/constitute them. The Ivocerin, ED's photoinitiator, has an absorption peak in the violet spectrum, similar to that of other alternative photoinitiators (380-420 nm), with a slight extension into the blue spectrum [18] (CONTRERAS et al., 2021). This factor may account for the greater efficiency of polywave.

However, the observation of statistical differences only in compressive strength draws attention to the influence of depth, given that the other tests in this study are more superficial in nature. Some studies, such as the one conducted by Gutierrez-Leiva & Pomacóndor-Hernández (2020) [19], indicated a lower degree of polywave light cure in depth, both in resins with only CQ and in those with alternative photoinitiators.

Table III - average solubility (g) of each group

GROUP	RESINS / LCU	SL AVERAGE
A1 (a)	ED / MONOWAVE	0.0005
A2 (a)	ED / BIWAVE	0.0001
B1 (a)	VITTRA / MONOWAVE	0.0005
B2 (a)	VITTRA / BIWAVE	0.0005
C1 (a)	Z100 / MONOWAVE	0.0004
C2 (a)	Z100 / BIWAVE	0.0002

Equal letters denote statistical equality.

Table IV - average hardness of each group and their respective standard deviations

Group	Resins / LCU	HV Average
A1 (a)	ED / MONOWAVE	35.59 (4.88)
A2 (a)	ED / BIWAVE	37.97 (4.27)
B1 (b)	VITTRA / MONOWAVE	70.33 (12.75)
B2 (b)	VITTRA / BIWAVE	73.64 (9.7)
C1 (c)	Z100 / MONOWAVE	129.59 (12.85)
C2 (c)	Z100 / BIWAVE	128.33 (18.91)

Equal letters denote statistical equality.

Since the result of the compressive strength of Empress Direct resin with the use of biwave was positive and even statistically superior to that using monowave, it is not possible to point out a generalized low performance of biwave in depth, at least when its thickness is up to 2 mm.

A study by Rocha et al. (2017) [20] indicated that the degree of polywave curing was higher when an alternative photoinitiator was used in conjunction with polywave up to a thickness of 2 mm. However, no notable difference was observed when the thickness exceeded 2.5 mm. On the other hand, the same article demonstrates that, for bulk-fill resin composites containing only CQ as a photoinitiator, the monowave and polywave LEDs exhibited equivalent efficiency. Additionally, for composites containing CQ associated with alternative photoinitiators, the polywave LED showed a greater depth of cure. These findings are consistent with the results obtained in the present study. According to the work conducted by Menees et al. (2015) [21] the inability of the polywave LCU to achieve greater depth of cure may be due to the higher absorbance exhibited by the alternative photoinitiators, which causes most of the violet light photons to be depleted in the upper layers of the composite. Further investigation of additional specimens of different sizes and thicknesses is necessary.

In line with the findings of this study, a systematic review by Lima et al. (2023) [22], which also refers to Ivocerin, shows that most of the studies available in databases show better results, in terms of mechanical properties, of resins with alternative photoinitiators when these are light-cured by biwaves or polywaves, except for flexural strength. On the other hand, there are not many studies that indicate significantly superior performance of monowave in resins with only CQ, although some differences are reported in this case. According to Contreras et al. (2021) [18], resins with only CQ demonstrate an elevated propensity for marginal failures when associated with the polywave light-curing unit. In addition, Gan et al. (2018) [23] mention that, in the case of bulk-fill resin composites with CQ as a photoinitiator, light curing with monowave may be more effective than with polywave, given that these resins indicate greater hardness.

Little is known about the APS system developed by FGM, of which no comparative studies with different LEDs can be found in the literature. However, in a study by Alharbi et al. (2024) [24], in which the Bluephase polywave was used, it was highlighted that the Vittra resin obtained acceptable values for surface hardness, surface gloss, and Vickers microhardness. Moreover, Tapety et al. (2023) [25] also showed that Vittra obtained satisfactory flexural strength, polymerization stress, degree of conversion, and Knoop hardness when using the Valo Cordless LED polywave, with the results for hardness and degree of light cure being attributed to the characteristics of the APS system. Therefore, we highlight the need for further study of this system given the versatility it has demonstrated so far. Finally, in view of the variety of alternative photoinitiators, light-curing units developed, depths and dimensions that can be used in resin increments, as well as the existence of minor discrepancies between studies, further investigation is essential to establish a consensus on the optimal parameters for light curing each type of resin and treatment.

The Z100 resin, manufactured by 3M, was chosen for this study due to its unique composition of camphorquinone (CQ) as a photoinitiator, making it compatible with blue light. Camphorquinone is a widely used photoinitiator in composite resins due to its ability to absorb light at wavelengths between 460-480 nanometers (nm), providing efficient polymerization. Furthermore, Z100 has been available on the market for a long time, which establishes it as a well-known resin that exclusively uses camphorquinone. Its long-standing presence in the market adds to its credibility and reliability for studies involving blue light polymerization. The choice of Z100 allows for a direct comparison with other resins that use alternative photoinitiators, such as the APS system and Ivocerin, which have absorption peaks at different wavelengths. This is essential for evaluating the influence of different wavelengths of light-curing units on the polymerization and degradation of composite resins. Therefore, the inclusion of Z100 in this study is crucial for understanding how blue light, emitted by monowave light-curing units, affects the polymerization of composite resins that use only CQ as a photoinitiator.

The observed results (Table II) corroborate the hypothesis that wavelengths of light can, in fact, influence the mechanical properties of the resins depending on the photoinitiators presenting them. We observed a considerably superior result generated by the monowave curing light on the resin with only CQ. Similarly, the biwave performed better on the one with only Ivocerin.

CONCLUSION

- The correct association between wavelength and photoinitiator indicated importance in terms of compression resistance.
- The APS system shows compatibility with both types of light curing units, although predictability varies depending on the mechanical property;
- Although it was observed that the type of light-curing unit influenced the results, both resins tested generated positive results for clinical indication.

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Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Author’s Contributions

LCS: Methodology. LCS: Writing – Original Draft Preparation. TRMF: Conceptualization. TRMF: Formal Analysis. TRMF: Investigation. TRMF: Resources. TRMF, LGM: Data Curation. TRMF, KMW: Writing – Review & Editing. TRMF, KMW: Supervision. JNSMDM: Validation. JNSMDM: Visualization.

Conflict of Interest

No conflicts of interest declared concerning the publication of this article.

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Regulatory Statement

This study does not involve human subjects or any parts of them and therefore does not require oversight by a human subjects committee.

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