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Evaluation of fluorescence of 5 types of 3D-Printed Hybrid Resins – comparison with a natural tooth: an *in vitro* study

Diogo Cabecinha Viegas [a,*], Mariana de Jesus Morgado [b], Margarida Chambel Correia [b], Panaghiotis Bazos [c], Tatiana Cursino Pereira [d], João Tiago Mourão [a], Guilherme De Siqueira Ferreira Anzaloni Saavedra [e]

[a] *Department of Fixed Prosthodontics and Oral Rehabilitation, Faculdade de Medicina Dentária, Universidade de Lisboa (FMDUL), Lisboa, Portugal*
[b] *Dental Medicine, Faculdade de Medicina Dentária, Universidade de Lisboa (FMDUL), Lisboa, Portugal*
[c] *RCS Edin, Bio-Emulation, Aigio, Greece*
[d] *Department of Dental Materials and Prosthodontics, Postgraduate Program in Applied Oral Health Sciences, Universidade Estadual Paulista (UNESP), Instituto de Ciência e Tecnologia de São José dos Campos, São Paulo, Brazil*
[e] *Department of Dental Materials and Prosthodontics, Universidade Estadual Paulista (UNESP), Instituto de Ciência e Tecnologia de São José dos Campos, São José dos Campos, São Paulo, Brazil*

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ABSTRACT

Objective: This study evaluated the fluorescence of five types of printed hybrid resins, comparing them with the fluorescence of natural teeth.
Methods: Two hundred hybrid resin specimens were produced and divided into five groups of 40 specimens each, according to the following brands: FREEPRINT® Crown, Saremco® print CROWNTEC, VarseoSmile® TriniQ®, VarseoSmile® Crownplus, and V-print C&B Temp. All samples were fabricated using a 3D printer. After printing, the specimens were washed, light-cured, polished, and photographed. After determining the L*a*b* values of the selected natural tooth and all the specimens, Delta E was calculated for each sample in relation to the natural tooth. The data were analyzed using SPSS software, and the results were compared using parametric tests.
Results: Significant differences were observed in the Delta E values of all the resins, except between the FREEPRINT® Crown and VarseoSmile® Crownplus groups. The FREEPRINT® Crown and VarseoSmile® Crownplus resins had the lowest ΔE values (4.93 and 5.6395, respectively). On the other hand, the V-print C&B Temp and Saremco® print CROWNTEC resins had the highest ΔE values (19.74 and 22.85, respectively). Therefore, the FREEPRINT® Crown resin showed a lower Delta E, followed by VarseoSmile® Crownplus, VarseoSmile® TriniQ®, V-Print C&B Temp, and finally Saremco® print CROWNTEC.
Conclusions: FREEPRINT® Crown and VarseoSmile® Crownplus showed the lowest ΔE values, being the closest to natural tooth fluorescence, though still far from ideal.

1. Introduction

The natural optical properties of dental tissues have attracted increasing interest from professionals in the field of oral health. The increased demand for esthetics due to different social factors highlights the relevance and challenge of mimicking the natural appearance of teeth through aesthetic restorations in clinical situations. Therefore, restorative materials that exhibit fluorescence properties similar to those naturally present in the oral cavity have clear aesthetic advantages over other materials [1,2].

Photoluminescence refers to the ability of a substrate to emit visible light after absorbing energy. It is subdivided into fluorescence and phosphorescence, and it can be observed when light is emitted after the absorption of photons that excite electrons within these materials [3].

Experiments carried out by Benedict in 1928 demonstrated that hard dental tissues are naturally fluorescent when exposed to ultraviolet radiation [1,4]. According to the literature, teeth emit visible light when the ultraviolet light is absorbed in the range of 350–450 nm, resulting in

* Corresponding author.
E-mail addresses: dviegas@edu.ulisboa.pt (D.C. Viegas), mariana.brj.morgado@gmail.com (M.J. Morgado), margaridaccorreia@edu.ulisboa.pt (M.C. Correia), tatiana.pereira@unesp.br (T.C. Pereira), jmourao@campus.ul.pt (J.T. Mourão), guilherme.saavedra@unesp.br (G.D.S.F.A. Saavedra).

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a bluish-white appearance; as a result, teeth have whiter and brighter appearances when exposed to natural light [3,5–12]. Dentin is primarily responsible for dental fluorescence; this phenomenon is mainly due to the presence of large amounts of organic material within dentin. [11–16]. Furthermore, dental fluorescence differs across teeth; in fact, the cervical area of the teeth often contains more organic components, and the fluorescence of this area is slightly greater than that in the incisal area [11,15,17,18].

According to the literature, several factors influence dental fluorescence, including the mineral composition and macroscopic structure of the tissues. In addition, age, environmental factors, and dietary habits can contribute to variations in the amount of dental fluorescence across dental tissues [5,15,19–21].

Furthermore, fluorescence makes natural teeth whiter and brighter in daylight, giving them an appearance suggesting vitality and naturalness. However, in environments such as nightclubs, dental fluorescence is particularly noticeable, as the use of ultraviolet light is common in such environments. Thus, in these environments, individuals may notice greater differences in coloration between their natural teeth and restorations, as restorations emit different levels of fluorescence than natural teeth do [5,22].

Long-lasting provisional restorative materials are essential in fixed rehabilitations, as these types of restorations are indicated for use for more extended periods throughout treatment; consequently, they must meet numerous criteria, including biological, mechanical, and aesthetic factors. [9,23–25]. To improve the aesthetics of resins under various lighting conditions, manufacturers have included compounds such as rare earth oxides (europium, cerium, and ytterbium, among others), as these are well-known fluorescent compounds and are the gold standard regarding fluorescent additives [5,26].

At the end of the 20th century, the Commission Internationale de l'Eclairage (CIE) developed a new system - CIELab* that, for the first time, made it possible to express color in numerical form and thus calculate the difference between two colors. In this system, color is expressed in three coordinates (L*, a*, b*), where L* corresponds to the brightness of the object, a* represents the red/green axis, and b* represents the yellow/blue axis. This system is currently the most widely used in scientific projects because of its ease of use and standardized properties. Recently, the b* value has been used in the literature to express the level of fluorescence [27–30].

As shown in the literature, fluorescence quantification can be performed using different methods and technologies. The most widely used techniques are advanced spectroscopy and digital imaging techniques, with spectrophotometry being the most frequently employed method [1,2,5,31,32]. Thus, although different fluorescence quantification methods have been developed, particularly for use in in vitro studies, no established fluorescence quantification protocol serves as the gold standard as of today. This methodological fragmentation underscores a critical research gap: while several studies have investigated fluorescence in conventional resin materials, very few have focused on hybrid 3D-printed resins. Consequently, the absence of standardized fluorescence quantification methods, combined with the limited exploration of hybrid 3D-printed resins, highlights an underexplored yet essential area for future research, representing an urgent research gap.

This study presents a mimetic characterization of dental restorations through evaluations of the fluorescence of five types of resin materials. By examining fluorescent properties and seeking to establish a standardized fluorescence quantification protocol, this study could promote more adequate reproduction of the natural optical characteristics of teeth by clinicians. Therefore, this study aimed to evaluate the fluorescence properties of different 3D-printed hybrid resins, with the fluorescence of a natural tooth used as a reference.

Thus, the following hypotheses were formulated:

Null Hypothesis (H0): There are no statistically significant differences in fluorescence (ΔE in relation to the natural tooth) among the five hybrid resins evaluated.

Alternative Hypothesis (H1): There are statistically significant differences in fluorescence (ΔE in relation to the natural tooth) among the five hybrid resins evaluated.

2. Materials and methods

2.1. Materials

In this study, five commercial brands of hybrid resins for 3D printing were used, all with the same color (A1). In total, 200 specimens were manufactured and divided equally into five groups of 40 samples each. Information on the compositions, manufacturers, and batches of the samples is provided in Table 1.

2.2. Sample calculation

The sample size was calculated using a power analysis [33] and G*Power software [34]. An effect size f of 0.25, an average test power (1-β) of 0.8, and a significance level α of 0.05 were used. The results indicated that a minimum of 40 specimens per group would be sufficient.

2.3. Sample acquisition

The specimens were produced using a 3D printer (ASIGA UV Max; Asiga, Alexandria, New South Wales, Australia). After printing the specimens were washed and light-cured according to the manufacturer's instructions.

The natural tooth selected as the reference was obtained from a previously extracted right central incisor for reasons unrelated to the study. The tooth appeared without previous restorations or caries lesions, which was stored in a 5 % thymol solution.

Each specimen was fabricated using an STL file obtained from a mold based on the dental anatomy of the upper right central incisor. The mold was acquired by duplicating the tooth with an elastomeric condensation silicone (Elite Double 22, Zhermack), which was then poured with dental gypsum (Fujirock white, GC, Europe). The resulting model was scanned using an intraoral scanner (3Shape, Trios 3, Copenhagen, Denmark).

After polymerization, all the specimens were prepared as follows:

The specimens were subjected to a blasting process using an Eco basic sandblaster (Renfert, Hilzingen, Germany) and steam (Steam Cleaner Wasi-Steam Classic II - WASSERMANN; Hamburg, Germany), to guarantee the removal of residual particles formed during the printing and curing stages.

Polishing was carried out using the Diapol Twist polishing system (EVE Ernst Vetter GmbH, Pforzheim, Germany) with three abrasive rubbers with progressive granulations in the following sequence: blue rubber, pink rubber, and grey rubber. Finally, a goat hair brush (Leickert Dental, Lübeck, Germany) was used.

2.4. Camera settings

A Nikon D7000 camera and a fluorescent filter (Fluor eyes; Bio-Emulation, Germany) were used to obtain the specimens' photos. The following parameters were used: f = 22, t = 1/125, and ISO = 400. Images were taken at a ratio of 1:1.2. The distance between the camera and the specimen was fixed at 45 cm, and the position of the camera was maintained during the entire study.

2.5. Use of a reference card

A reference card was then used to calibrate each image (Figs. 1 and 2). A small sample of BracePaste® composite resin (American Orthodontics, Wisconsin, USA) served as a reference and was placed on the reference card to calibrate the images (Fig. 3). Images were imported

Table 1
Brand, manufacturers, and batches of the materials used.

Brand	Manufacturer Batch	Composition	Colour	Form of Acquisition	Expiry date
VarseoSmile® Crown^{plus}	BEGO Lot: 600885	Bis-EMA resin matrix + silanized glass filler; TPO photoinitiator	A1 - Dentin	Own resources	2025-09-29
VarseoSmile® TriniQ®	BEGO Lot: 601436	Methacrylate-based matrix + silanized glass filler; TPO photoinitiator	A1-Dentin	Own resources	2026-12-11
V- Print c&b temp	VOCO Lot: 2407211	Acrylate-based resin + silanized ceramic filler; TPO photoinitiator	A1	Own resources	2025-07-14
Saremco® print CROWNTEC	SAREMCO Lot: E645	BisEMA + aromatic urea dimethacrylate matrix + boron-aluminum-barium glass filler; TPO photoinitiator	A1	Own resources	2027-01-31
FREEPRINT® Crown	DETAX Lot: 260301	Urethane dimethacrylate matrix + silanized ceramic filler; TPO photoinitiator	A1	Own resources	2025–03

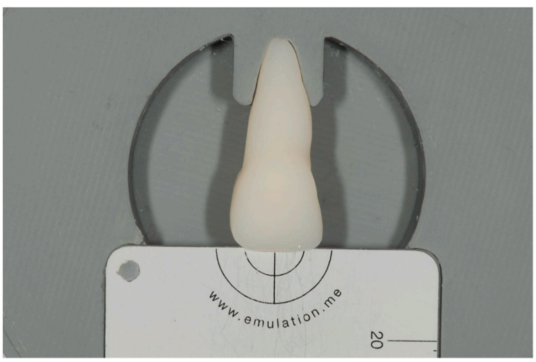

Fig. 1. Representative images of the resin sample with white balance cards.

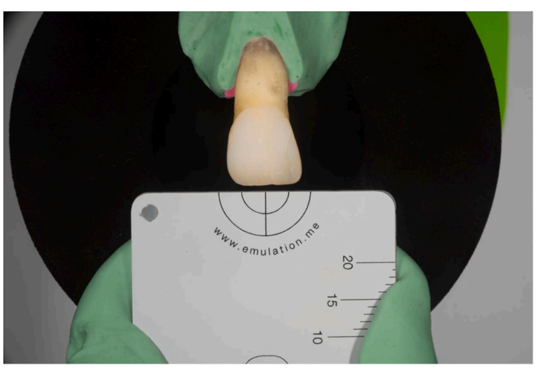

Fig. 2. Representative images of the resin sample with an white balance card.

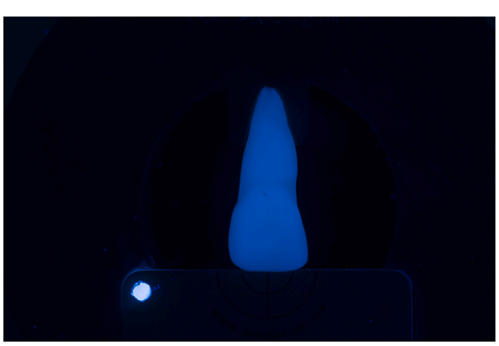

Fig. 3. Photograph of the sample with the reference marker and fluorescence filter.

into Adobe Lightroom Classic (ver. 14.3.1), and we proceeded to calibrate the images based on the L* reference value of 85 (BracePaste®).

The CIELab* coordinates (L*, a*, and b*) of the region corresponding to the transition of the cervical 1/3 and the mesial 1/3 of the specimens were determined subsequently.

After all the images were calibrated and the coordinates were obtained, the ΔE value was calculated using the CIEDE2000 color-difference formula [35].

2.6. Statistical analysis

The mean values and standard deviations were calculated for each group in each test. The normality of the data was assessed using the Shapiro–Wilk test. ANOVA test was used to evaluate if there were significant differences among the five groups ($p < 0.001$).

The Games–Howell post-hoc test was used for multiple comparisons between groups. The statistical data were analyzed using the IBM SPSS Statistics 30 system (SPSS Inc., Chicago, IL, USA).

3. Results

The mean values and standard deviations of the differences in fluorescence (ΔE) between the five types of resin samples and the natural tooth specimen were calculated; the mean differences ranged from 4.93 to 22.95 (Fig. 4).

Compared with the natural tooth specimen, the FREEPRINT® Crown resin sample had the lowest ΔE, followed by the VarseoSmile® Crownplus, VarseoSmile® TriniQ®, V-Print C&B Temp, and Saremco® print CROWNTEC specimens.

To test for normality, the Shapiro–Wilk test was used; the results indicated that the distribution of the results was normal in all groups. Therefore, we used a parametric test (ANOVA; Table 2) and carried out multiple comparisons using the Games–Howell post hoc test.

Considering the results presented above (Tables 2 and 3), significant ($p < 0{,}05$) differences were observed between the ΔE values of all the resins, except between the FREEPRINT® Crown and VarseoSmile® Crownplus groups (p value = 0,087). The FREEPRINT® Crown resin had the lowest ΔE value with the natural tooth sample, followed by the VarseoSmile® Crownplus, VarseoSmile® TriniQ®, V-Print C&B Temp,

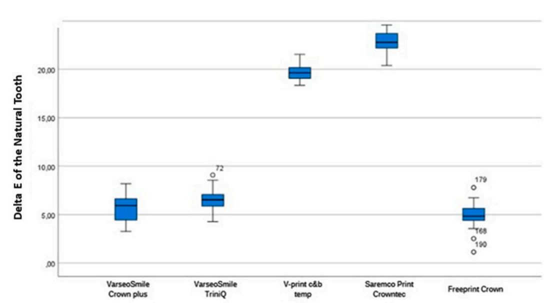

Fig. 4. Box plot of color difference (ΔE) between various 3D-printed resins and natural teeth.

Table 2
ANOVA results.

ΔE between the resin samples and natural tooth sample	ANOVA				
	Sum of Squares	df	Mean Square	Z	p value
Between groups	11910.002	4	2977.501	2654.175	<0.001
Within groups	218.754	195	1.122		

and finally Saremco® print CROWNTEC samples (Fig. 5).

4. Discussion

The results indicate statistically significant differences between at least two of the resin groups analyzed, allowing us to reject the null hypothesis, which stated that there are no significant differences in fluorescence between the groups.

This study aimed to assess the fluorescence of different materials by comparing the fluorescence of five types of 3D-printed hybrid resins using the ΔE value (color difference) between each of the resins and a natural tooth as a reference. The results of the present study revealed that the FREEPRINT® Crown and VarseoSmile® Crownplus resins had the lowest ΔE values (4.93 and 5.6395, respectively). On the other hand, the V-print C&B Temp and Saremco® print CROWNTEC resins had the highest ΔE values (19.74 and 22.85, respectively), revealing statistically significant differences for at least two of the resins analyzed; thus, we rejected the hypothesis that there were no differences in fluorescence between the samples. Moreover, significant differences in fluorescence were observed among almost all the resin groups. These differences in fluorescence represent a limitation when trying to mimic dental structures through restorative treatments.

The addition of different components, such as rare earth oxides including europium, cerium and ytterbium, is a common practice to generate fluorescence in other materials; however, the exact details regarding the composition and ratios of components in different brands are often proprietary and not publicly disclosed, which makes it difficult to truly analyze the contribution of each substance to the fluorescence phenomenon [5–7,22,26,36]. This highlights the need for more studies to establish a solid correlation between material composition and fluorescent properties [6,7,9,22,36].

The results of this study are consistent with those of previous investigations that also demonstrated differences in fluorescence intensity between different types and brands of resins and between the resins and the natural teeth. *Meller* et al. found that the fluorescence intensity also differs between brands, indicating that the formulation and components of resins directly impact their fluorescence [7]. However, in contrast to the present study, most studies compared the properties of composite resins used for direct restorations [1,2,6,9,21,22,30–32].

Several techniques and methods have been developed to quantify the fluorescence of restorative materials; however, spectrophotometers have been used to perform fluorescence analysis in most previous studies [1,37–39]. However, some techniques involving digital images have been used to analyze fluorescence intensity. For instance, Brokos et al. [32] concluded that fluorescence analysis carried out based on digital images obtained using photographic filters provided color coordinates very close to those obtained via spectrophotometry. Moreover, the use of digital photos represents a more economical and widely available alternative in most dental offices, making the protocol employed in this study easily replicable in any clinic, even those with limited resources.

In addition, the key properties of restorative materials have been related to their fluorescence in previous studies. In particular, restorative materials with higher fluorescence tend to have higher luminosity

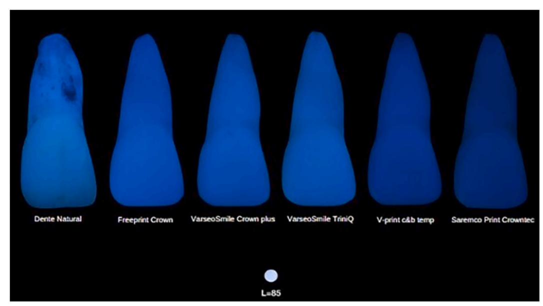

Fig. 5. Fluorescence of natural teeth and the different 3D-printed resin materials. Image captured using standardized conditions (L = 85).

Table 3
Multiple comparison results using the Games–Howell post-hoc test, with ΔE between the resin and natural tooth samples as the dependent variable.

Multiple comparisons						
Resin (i)	Resin (j)	Average difference (I-J)	Standard Error	p value [Ed2]	95 % confidence interval (Lower limit)	95 % confidence interval (Upper limit)
VarseoSmile® Crown^{plus}	VarseoSmile® TriniQ®	−0.90200*	0.25359	0.006	−1.6116	−0.1924
	V-print C&B Temp	−14.09575*	0.24303	<0.0001	−14.7771	−13.4144
	Saremco® print CROWNTEC	−17.20875*	0.25497	<0.0001	−17.9221	−16.4954
	FREEPRINT® Crown	0.71050	0.27714	0.087	−0.0636	1.4846
VarseoSmile® TriniQ®	VarseoSmile® Crown^{plus}	0.90200*	0.25359	0.006	0.1924	1.6116
	V-print C&B Temp	−13.19375*	0.20016	<0.0001	−13.7529	−12.6346
	Saremco® print CROWNTEC	−16.30675*	0.21450	<0.0001	−16.9058	−15.7077
	FREEPRINT® Crown	1.61250*	0.24044	<0.0001	0.9403	2.2847
V-print C&B Temp	VarseoSmile® Crown^{plus}	14.09575*	0.24303	<0.0001	13.4144	14.7771
	VarseoSmile® TriniQ®	13.19375*	0.20016	<0.0001	12.6346	13.7529
	Saremco® print CROWNTEC	−3.11300*	0.20190	<0.0001	−3.6771	−2.5489
	FREEPRINT® Crown	14.80625*	0.22927	<0.0001	14.1643	15.4482
Saremco® print CROWNTEC	VarseoSmile® Crown^{plus}	17.20875*	0.25497	<0.0001	16.4954	17.9221
	VarseoSmile® TriniQ®	16.30675*	0.21450	<0.0001	15.7077	16.9058
	V-print C&B Temp	3.11300*	0.20190	<0.0001	2.5489	3.6771
	FREEPRINT® Crown	17.91925*	0.24189	<0.0001	17.2431	18.5954
FREEPRINT® Crown	VarseoSmile® Crown^{plus}	−0.71050	0.27714	0.087	−1.4846	0.0636
	VarseoSmile® TriniQ®	−1.61250*	0.24044	<0.0001	−2.2847	−0.9403
	Saremco® print CROWNTEC	−14.80625*	0.22927	<0.0001	−15.4482	−14.1643
	V-print C&B Temp	−17.91925*	0.24189	<0.0001	−18.5954	−17.2431

(L*), and more recently, the b* value has been related to fluorescence levels [14,30]. Although studying these relationships was not the main aim of this study, we did confirm the positive relationship between fluorescence and luminosity (L*) or brightness. Moreover, we verified the negative correlation between luminosity (L*) and the yellow/blue axis value (b*); the more negative the b* value was, the greater the tendency to move towards the blue portion of the axis [40]. According to our results, the brighter the material is, the greater the L* value, and the bluer the fluorescence. This finding indicates a future research direction to elucidate the relationship between fluorescence and the parameters used for colorimetric quantification.

Another essential aspect in the process of color matching and fluorescence is the perceptibility and acceptability of color. Perceivability refers to the color difference that the human eye can distinguish, while acceptability refers to the clinically tolerable color difference. The difference between the perceptibility and acceptability thresholds is called Industry Tolerance. It indicates the extent to which the color of two objects can differ while still maintaining an acceptable match [41,42]. Since both perceptibility and acceptability depend on human perception, these values are subjective and therefore difficult to define precisely. The lack of agreement in the literature regarding acceptability and perceptibility thresholds is due mainly to the fact that most of the existing studies were carried out under in vitro conditions and do not satisfactorily reproduce the variables of a real clinical environment, where factors such as the presence of saliva, ambient light, and observation angles vary constantly [42].

Despite its relevance, this study has several limitations. First, one of them is that the clinical significance of the results cannot be definitely determined, as there is no consensus regarding acceptability thresholds, and the acceptability thresholds obtained in most studies were acquired through evaluation of color difference, not considering the difference in fluorescence. However, as we discussed previously, there is a relation between fluorescence and L*ab values; therefore, according to the different values reported by Paravina et al. (2019), the present results would fall outside the limits of acceptability established in most of the previous studies, which indicates that this variation in fluorescence would most likely have clinical implications [42].

Also, since only one natural tooth sample (maxillary central incisor) was included in our analysis, dental fluorescence can vary significantly among individuals due to several factors, such as the age of the patient, which affects the degree of dentin deposition and enamel wear, the type of tooth, and its location in the dental arch. In addition, the fluorescence of individual teeth is not uniform, and the cervical zone is more fluorescent than the incisal edge [1,10–12,14–21]. To increase the representativeness of the results, a greater sample of natural tooth specimens, with different characteristics, should be included in the analysis in future research. Thus, the sample used in this study is not sufficient to draw broad conclusions between resin fluorescence and general dental fluorescence, restricting the conclusions to comparisons among resins.

Thus, this study highlights the importance of standardizing test protocols and evaluating the long-term performance of materials, reinforcing the need for continuous research and innovation in the development of composite resins with fluorescence similar to that of natural teeth. It is important to note that the reliance on an in vitro setup and the lack of patient-based validation represent limitations that should be emphasized, and future studies should address these aspects to enhance clinical relevance.

By exploring new additives and new manufacturing techniques, researchers can develop composite resins with optimal fluorescent characteristics, resulting in more natural and realistic dental restorations. In summary, this study, despite its limitations, improves the understanding of dental professionals, thus positively impacting their decision-making regarding the materials used in oral rehabilitation, particularly long-lasting temporary restorations. This study contributes to the understanding and development of restorative materials with properties increasingly similar to those observed in the oral cavity. By considering these results and the study limitations, new research in this area can be performed.

5. Conclusions

Considering the study limitations and objectives, we concluded that there are significant differences in fluorescence (resin ΔE compared with natural teeth) among the five resins (FREEPRINT® Crown, Saremco® print CROWNTEC, VarseoSmile® TriniQ®, VarseoSmile® Crownplus, and V-print C&B Temp), as at least one between-group comparison is statistically significant.

Significant differences were observed among the ΔE values of all resins, except between the FREEPRINT® Crown and VarseoSmile® Crownplus materials.

FREEPRINT® Crown resin had the lowest ΔE value, followed by VarseoSmile® Crownplus, VarseoSmile® TriniQ®, V-Print C&B Temp, and finally Saremco® print CROWNTEC. However, it is essential to note that none of the materials fell within the reference ΔE thresholds. Although these thresholds are primarily established for color differences, considering the strong relationship between color and fluorescence, and if these acceptability and perceptibility limits are extrapolated, all materials could likely have clinical implications due to being outside the recommended limits, which, from an aesthetic point of view, is still suboptimal.

CRediT authorship contribution statement

Diogo Cabecinha Viegas: Supervision, Methodology, Formal analysis, Conceptualization. **Mariana de Jesus Morgado:** Writing – review & editing, Writing – original draft, Investigation, Data curation. **Margarida Chambel Correia:** Writing – review & editing, Data curation. **Panaghiotis Bazos:** Formal analysis. **Tatiana Cursino Pereira:** Formal analysis. **João Tiago Mourão:** Formal analysis. **Guilherme De Siqueira Ferreira Anzaloni Saavedra:** Formal analysis.

Patient consent

This study did not involve any human participants or patient data so patient consent is not required.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Glossary

%	Percentage
°	Degree
®	Trademark
µm	Micrometer
3D	Three-dimensional
CIE	Commission Internationale de l'Eclairage
cm	Centimetre
ISO	International Organization for Standardization
mm	Millimetre
n	Cardinal numeral quantifier
nm	Nanometre
ns	Nanosecond
p	p-value
Rpm	Number of revolutions per minute (unit of rotational speed)
STL	Standard Tessellation Language
UV	Ultraviolet
α	Statistical significance level
ΔE	Delta E

f Maximum lens aperture
t Aperture time
DSLR Digital Single-Lens

Data availability

Data will be made available on request.

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