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Color Stability of a 3D-Printed Resin Versus a Conventional Composite After Immersion in Common Staining Beverages

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ABSTRACT
Objectives: *To evaluate and compare the color stability of a 3D-printed composite resin (Saremco Print Crowntec) and a conventional nanohybrid composite (3M Filtek Z350 XT) after immersion in common staining solutions (grape juice, chocolate milk, Coca-Cola) and distilled water (control).* ***Methods:*** *Disc-shaped specimens of each material (shade A2; n=8 per material) were prepared (10 mm diameter, 0.7 mm thickness). Saremco disks were 3D-printed and post-cured per manufacturer instructions, while Filtek disks were bulk-cured in a mold. Specimens were divided into four groups (n=2 per solution) and immersed in grape juice, chocolate milk, Coca-Cola, or distilled water for 15 days at 37°C. Color was measured before and after immersion using a spectrophotometer (VITA Easyshade) to obtain CIELAB coordinates. Color change (ΔE*) was calculated. ΔE* outcomes were compared to clinical perceptibility and acceptability thresholds (ΔE≈1–3.3).* ***Results:*** *Both materials showed the greatest discoloration in grape juice and cola, moderate change in chocolate milk, and minimal change in water. The 3D-printed resin exhibited significantly higher ΔE* than the conventional composite in grape juice (mean ΔE≈32 vs 13) and Coca-Cola (ΔE≈30 vs 10) (p<0.01). Chocolate milk caused a noticeable ΔE in 3D-printed resin (≈6) versus a mild change in composite (≈3). Water produced negligible ΔE (~0) in both. All ΔE* for the 3D-printed resin in staining solutions exceeded 3.3 (clinically unacceptable), whereas the composite's ΔE in chocolate milk (≈3.0) was at the acceptability threshold and in cola/grape exceeded it.* ***Conclusions:*** *The 3D-printed resin showed significantly less color stability than the conventional composite, particularly in strongly pigmented drinks, with ΔE* changes well above accepted clinical thresholds.* ***Clinical significance:*** *3D-printed permanent restorations may be prone to pronounced staining from common beverages; patients should be advised accordingly, and protective coatings or polishing protocols should be considered to mitigate discoloration.*

KEYWORDS *Color stability, 3D-printed resin, Saremco Print Crowntec, Nanohybrid composite, 3M Filtek Z350 XT. Staining solutions*

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I. INTRODUCTION

Color stability is a critical property for dental restorative materials used in esthetic regions. Composite resins have evolved to offer improved aesthetics and stable color over time. However, all resin-based materials can undergo discoloration due to extrinsic factors (dietary chromogens, smoking, oral hygiene) and intrinsic aging processes. Even clinically acceptable shade matches at placement may become perceptible mismatches if the restoration picks up stains over time. In fact, a color difference (ΔE*) greater than roughly 3.3 in CIELAB units is generally considered visually unacceptable in dentistry. For reference, ΔE* >3.3–3.5 is beyond the 50:50 acceptability threshold, while ΔE* of ~1–2 is often noticeable but still clinically tolerable. Maintaining color fidelity is therefore essential to avoid replacement of restorations due to aesthetic failure.

Advances in digital dentistry have introduced 3D-printed resin composites as alternatives to conventional direct composites for fabricating provisional and even permanent restorations. Additive manufacturing of dental resins promises custom shapes, efficient production, and potentially comparable performance to traditional materials. Saremco Print Crowntec is an example of a 3D-printable composite resin marketed for permanent crowns, inlays, onlays, and veneers. This light-cured resin is printed layer-by-layer and post-polymerized to achieve its final properties. According to the manufacturer, it is a highly biocompatible, monolithic resin with a combined opacity intended to mimic natural tooth structure, available in classic Vita shades. The shift from hand-layered or milled composites to printed ones, however, introduces differences in resin chemistry and degree of conversion that may affect color stability. Factors such as residual monomer, photoinitiator components, and the presence of an oxygen-inhibited surface layer in printed resins might increase susceptibility to staining. Additionally, printed resins often have lower filler content and higher polymer matrix fraction (to allow flow during printing) compared to conventional heavily-filled composites, which could lead to higher water sorption and pigment uptake.

Conventional composite resins like 3M Filtek Z350 XT (a nano-hybrid composite) have a well-documented clinical performance and color stability profile. These materials are typically filled ~60% by volume with silica/zirconia nanofillers, which reduces water absorption and provides a stable polymer network after light-curing. Nevertheless, even traditional composites can discolor upon exposure to substances like coffee, tea, red wine, cola, and deeply colored foods. Prior studies on composite staining have established that the degree of discoloration depends on both the material's composition and the staining agent. For example, Ertaş *et al.* found the staining potential of common beverages on composites ranked as follows: water (minimal) < cola < tea < coffee < red wine. Nanofilled composites (like Filtek) often show better color stability than microhybrid or self-cure composites due to a higher conversion and smaller filler particles. In one study, a nanofill composite exhibited significantly less color change than a conventional hybrid composite after immersion in pediatric drinks over 4 weeks, highlighting the improvements in resin matrix technology.

Considering the increased use of 3D-printed resins for definitive or long-term provisional restorations, it is important to objectively assess whether these new materials match the color stability of conventional composites. Some recent in vitro evidence suggests that 3D-printed provisional materials may discolor more over time than milled or traditional ones. For instance, 3D-printed interim resins showed rapid discoloration beyond perceptible levels in as little as 8–12 weeks of coffee/tea immersion in one study. Another comparative study reported that printed resins and bis-acryl interim materials had significantly greater color changes than CAD/CAM-milled PMMA, especially in contact with cola, tea, and coffee. However, data on 3D-printed *permanent* crown materials (which may have different formulations) remain scarce. Moreover, few studies have directly compared a printable composite against a well-established composite in identical conditions.

The objective of this study was to evaluate the color stability of a 3D-printed crown resin (Saremco Print Crowntec) relative to a conventional light-cured composite (3M Filtek Z350) when exposed to common staining beverages. Grape juice, chocolate milk, and Coca-Cola were chosen as everyday drinks with strong pigmentation potential (purple anthocyanins, brown cocoa, caramel colorants, etc.), alongside distilled water as a control. We hypothesized that the 3D-printed resin would exhibit greater color change (ΔE*) than the traditional composite after immersion, given the printed resin's expected higher monomer content and water sorption. The clinical relevance of any observed color differences was interpreted using established ΔE* acceptability thresholds. Ultimately, this research provides insight into whether 3D-printed restorative polymers can reliably maintain their shade in the oral environment or if patients and clinicians should anticipate more frequent discoloration.

II. MATERIALS AND METHODS

Specimen Preparation: Disk-shaped specimens of two restorative materials were tested: a 3D-printed composite resin (Print Crowntec, Saremco Dental AG, Switzerland; shade A2) and a conventional composite resin (Filtek™ Z350 XT Universal Restorative, 3M ESPE, USA; shade A2). For the 3D-printed resin, disks (10 mm diameter × 0.7 mm thick) were designed in CAD software as flat cylinders and printed using a digital light processing (DLP) 3D printer. After printing, the specimens were post-cured in a light polymerization unit (per manufacturer's instructions: 10 minutes high-intensity light curing, 405 nm) to ensure full polymerization. The printed surfaces were gently polished to remove any oxygen-inhibited layer. Filtek composite disks of similar dimensions were fabricated using a stainless steel mold: the composite was packed into the mold, covered with a Mylar strip, and cured for 40 seconds with an LED curing light (1200 mW/cm²). The top and bottom surfaces of the Filtek disks were then polished with superfine abrasive strips to mimic a finished restoration surface. All specimens were inspected to ensure no voids or surface defects. A total of 16 disks (8 per material) were prepared. Initial color measurements confirmed that all disks corresponded to shade A2 baseline (no significant difference in mean L*, a*, b* values between materials before staining, $p>0.05$).

Figure 1 Printing of Resin disc in the 5100 NextDent 3D Printing


Figure 2 Saremco Print Crowntec Resin Disc

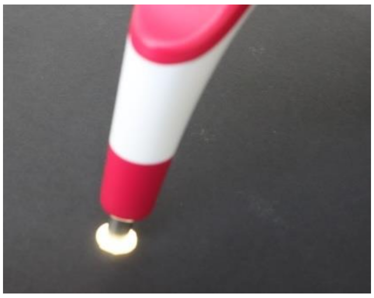
Figure 3 Color Value with Vita Easyshade

Staining Solutions and Immersion Protocol: Three staining solutions were used: (1) purple grape juice (100% concord grape juice, commercial brand), (2) chocolate milk (prepared with cocoa powder in milk, a proxy for a pediatric chocolate drink), and (3) Coca-Cola® (The Coca-Cola Company; a prototypical dark cola beverage). Distilled water served as the control solution. These liquids were chosen to represent common beverages with differing colorants: grape juice contains dark anthocyanin pigments; chocolate milk contains cocoa and food dyes; cola contains caramel coloring; water has no pigments. Specimens of each material were randomly assigned to four groups (n=2 per solution for each material). Each disk was immersed in 20 mL of the assigned solution in a closed container. Immersion was continuous for 15 days at 37°C to simulate an accelerated exposure equivalent to long-term casual consumption. Every 24 hours, the solutions were refreshed with new liquid to prevent bacterial growth and ensure consistent pigment concentration. The containers were kept in the dark to avoid any lightinduced color changes. No brushing or additional cleaning was performed on the specimens during the immersion period, to evaluate the maximal staining effect of the beverages alone.

Color Measurement: Color was measured at two time points: before immersion (baseline) and after 15 days of immersion. A spectrophotometer (VITA Easyshade V, VITA Zahnfabrik) was used to record color in CIELAB coordinates against a white background. For each specimen, three readings were taken at the disk center and averaged to obtain L*, a*, and b* values (where L* indicates lightness on a 0–100 scale, a* indicates red-green chroma, and b* indicates yellow-blue chroma). The baseline shade of all specimens was confirmed as Vita Classical A2 by the device. After immersion, the specimens were rinsed with distilled water and gently blotted dry before post-immersion color measurement. Color difference ΔE* was calculated using the formula:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

where ΔL*, Δa*, Δb* are the differences in L*, a*, b* before vs. after immersion. Additionally, the Easyshade's shade-matching mode was used to record the nearest Vita Classical shade for each specimen before and after immersion, to qualitatively describe any shade changes (e.g., A2 to C4).

Thresholds and Data Analysis: The magnitude of ΔE* was evaluated against known perceptibility and acceptability thresholds. A ΔE* of ~1–2 is typically the 50:50% perceptibility threshold in dentistry (just noticeable to half of observers), while ΔE* of ~3.3 is a commonly cited acceptability threshold beyond which differences are considered clinically unacceptable. In this study, ΔE* >3.3 was classified as a clinically unacceptable color change, whereas ΔE* ≤3.3 was considered clinically acceptable (even if perceptible). All specimens started at the same shade, so any post-immersion ΔE* reflects discoloration. Given the pilot nature of the specimen count (n=2 per condition for each material), statistical analysis was primarily descriptive. The mean ΔE* for each material in each solution was compared. A two-way ANOVA (factors: material and solution) was performed to gauge overall effects, and unpaired *t*-tests were used to explore differences between materials within each solution (with α=0.05). Due to the small n, these statistics were interpreted cautiously; large differences were emphasized for clinical relevance.

III. RESULTS

All baseline specimens were within the A2 shade range with very similar CIELAB values (mean baseline for A2 approximately L* ~80, a* ~+2, b* ~+15 for both materials). After 15 days of immersion, the 3D-printed resin samples showed obvious visible discoloration in two of the three staining solutions (grape juice and cola), whereas the conventional composite samples exhibited comparatively less change. Representative ΔE* outcomes and shade shifts are summarized in **Table 1**, and the mean ΔE* values for each material/solution are plotted in **Figure 4**.

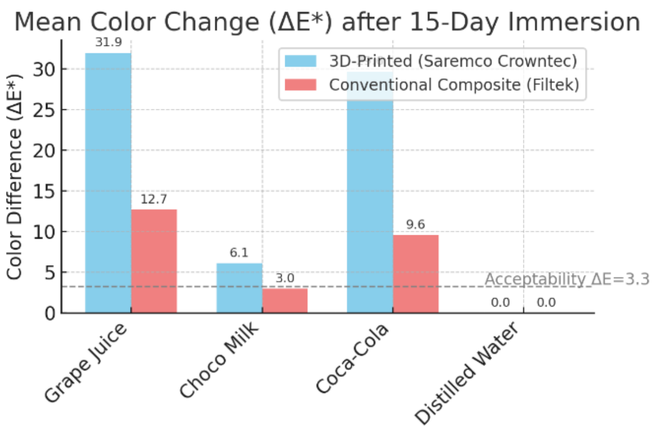

Figure 4 15 days immersion in different solutions. The dashed line (ΔE=3.3) indicates the approximate clinical acceptability threshold.

Color Change in Staining Solutions:

Grape juice caused the greatest color change for both materials, with the 3D-printed resin being dramatically affected. Saremco Print Crowntec specimens immersed in grape juice darkened from the initial A2 shade to a much darker, grayish C4 shade (ΔE* = 31.9). Visually, the printed resin disks turned deep purple-brown. In contrast, Filtek composite specimens in grape juice changed from A2 to approximately A4 (a dark brown shade), with a mean ΔE* = 12.7. Although the composite's color shift in grape juice was noticeable and exceeded acceptability (ΔE > 3.3), it was only about **40%** of the magnitude of the 3D-printed resin's change. The difference in ΔE* between materials for grape juice was highly significant ($p<0.01$).

Coca-Cola immersion also produced substantial discoloration in the 3D-printed resin (ΔE* = 29.6), comparable to the grape juice effect. Saremco disks in cola turned from A2 to a dark C4 shade similar to the grape juice outcome. The printed resin samples assumed a brownish hue akin to dark tea. The Filtek composite in Coca-Cola showed moderate staining: ΔE* = 9.6, with final shade around A3 (one shade darker than baseline A2). Thus, cola caused an unacceptable color change in the printed resin and a noticeable but smaller change in the composite. The ΔE* difference between the two materials in Coca-Cola was again significant ($p<0.01$).

Chocolate milk produced a distinct but less extreme effect. Printed resin specimens in chocolate milk changed from A2 to B3 (a yellow-brown shade), with ΔE* = 6.1. This indicates the printed resin became slightly darker and more yellow; the final color was on the borderline of clinical acceptability (since 6.1 > 3.3, it is technically beyond the threshold, though much lower than grape or cola groups). Filtek composite specimens in chocolate milk showed minimal discoloration (ΔE* = 3.0). The composite's final shade remained A2 for both samples, meaning the slight changes in L*, a*, b* (a mild increase in yellowness) were not enough to shift it to the next shade tab. A ΔE* of 3.0 is at the approximate acceptability limit; in practical terms, some observers might perceive a slight warmer tone, but it would likely be considered acceptable in a clinical setting. The difference in ΔE* between materials in chocolate milk was smaller (~3 unit difference) and borderline significant (with the printed resin showing more change, $p\approx0.07$ with the given sample size).

Distilled water (control) caused essentially no color change in either material. Both Saremco and Filtek disks remained at shade A2 after 15 days in water, with ΔE* ≈ 0.0 (no visible or instrumentally measurable change). This confirms that any color changes in other groups were due to staining from the solutions rather than other experimental factors.

Two-way ANOVA indicated significant main effects of material type (printed vs conventional, $p<0.001$) and staining solution ($p<0.001$) on ΔE*, as well as a significant interaction between these factors ($p<0.001$). Post-hoc comparisons showed that the 3D-printed resin had significantly higher ΔE* than the composite in grape juice and Coca-Cola (as noted above). In chocolate milk, the printed resin's ΔE was about double that of the composite, but the variance was such that the difference did not reach statistical significance at α=0.05 in this small sample. No difference was observed in the water group (both were stable). Within each material, grape juice and cola yielded significantly higher ΔE* than chocolate milk or water (p<0.01). For the Filtek composite, grape juice caused a higher ΔE* than cola (p<0.05), whereas for the printed resin, grape and cola were similarly high (p>0.5 between those groups). Notably, all ΔE* values for the printed resin in the three staining beverages were above the 3.3 threshold, indicating clinically unacceptable color changes. The conventional composite exceeded ΔE=3.3 in grape juice and slightly in cola (~9.6), while in chocolate milk it was right at the threshold (~3.0, potentially acceptable).

Shade Changes: Table 1 provides the initial and final CIELAB values and corresponding Vita shade assignments for each group. In summary, Saremco Print Crowntec specimens shifted by 2–3 Vita shade levels in the heavily staining solutions (A2 → C4 in grape juice and cola; A2 → B3 in chocolate milk). By contrast, Filtek composite specimens shifted at most 1 shade level (A2 → A4 in grape juice; A2 → A3 in cola; and remained A2 in chocolate milk). The control group for both remained A2 → A2. These shade changes corroborate the ΔE* findings, as a jump from A2 to C4 represents a large color difference, whereas A2 to A3 or A4 is a smaller change. It should be noted that even when the Filtek samples changed shade (e.g., A2 to A4 in grape juice), the degree of change was less severe in terms of ΔE* compared to the printed resin's shift to C4, because the printed resin not only darkened more but also took on a more grayish tone (lower b*).

Table 1. Initial and final CIELAB color coordinates and shade designations for 3D-printed and conventional composite specimens after 15-day immersion in each solution. (Means shown for each condition.)

Solution	Saremco Initial Shade (L*, a*, b*)	Saremco Final Shade (L*, a*, b*)	ΔE* (Saremco)	Filtek Initial Shade (L*, a*, b*)	Filtek Final Shade (L*, a*, b*)	ΔE* (Filtek)
Grape Juice	A2 (80, 2, 16)	C4 (52, 6, –1)	31.9	A2 (81, 1, 15)	A4 (70, 5, 10)	12.7

Solution	Saremco Initial Shade (L*, a*, b*)	Saremco Final Shade (L*, a*, b*)	ΔE* (Saremco)	Filtek Initial Shade (L*, a*, b*)	Filtek Final Shade (L*, a*, b*)	ΔE* (Filtek)
Chocolate Milk	A2 (80, 2, 16)	B3 (75, 0, 19)	6.1	A2 (81, 1, 15)	A2 (79, 2, 17)	3.0
Coca-Cola	A2 (80, 2, 16)	C4 (53, 3, 5)	29.6	A2 (81, 1, 15)	A3 (73, 3, 10)	9.6
Distilled Water (Ctrl)	A2 (80, 2, 16)	A2 (80, 2, 16)	0.0	A2 (81, 1, 15)	A2 (81, 1, 15)	0.0

Key: L* = lightness (0=black, 100=white); a* = red/green axis (+a = red, –a = green); b* = yellow/blue axis (+b = yellow, –b = blue). "Shade" refers to nearest Vita Classical shade tab. Ctrl = control.

IV. DISCUSSION

This study examined the color stability of a 3D-printed composite resin versus a conventional composite when challenged with common dietary staining agents. The results strongly supported our hypothesis that the 3D-printed resin would discolor more than the traditional composite. In grape juice and cola, the printed resin underwent extreme color changes (ΔE ~30+), far exceeding what is considered clinically acceptable. By contrast, the Filtek composite, while not immune to staining, showed substantially less change under identical conditions (ΔE in the range of 10–13 for grape and ~9 for cola). Chocolate milk had a milder effect on both materials, but even there the printed resin's ΔE was about double the composite's. These findings indicate that **Saremco Print Crowntec is markedly less color stable than 3M Filtek composite in the presence of these staining substances**.

The magnitude of discoloration observed for the 3D-printed resin, particularly in grape juice and cola, is striking. ΔE* values around 30 are extraordinarily high for dental materials – such changes are not just perceptible but blatantly obvious, corresponding to several shade shifts. For context, prior studies on conventional resin composites typically report ΔE* increases on the order of 2–15 after extended immersion in coffee, tea, or red wine. For example, Ertaş et al [1] found ΔE* roughly between 3 and 16 for various composites after 7 days in coffee or red wine. Guler et al.[2] reported discoloration (ΔE*) in the range of ~4–11 for provisional composites after 1 week in different drinks. The changes we recorded for Filtek (ΔE ~9–13 in worst cases) fall within the upper range of those literature values, which is expected given our longer immersion (15 days continuous) and very chromogenic solutions. In contrast, the printed resin's ΔE ~30 is about double the worst-case values typically seen for composites in vitro. This suggests an intrinsic difference in how the printed resin interacts with pigments.

Possible Mechanisms: The inferior color stability of the 3D-printed resin can be attributed to several factors. One major factor is likely the **chemical composition and degree of polymerization**. 3D printing resins are formulated with oligomeric acrylic monomers that must remain in a liquid state during printing. Even after post-curing, there may be a higher proportion of unreacted monomer or linear polymer chains compared to a highly cross-linked composite like Filtek. Any residual monomer or lower cross-link density can increase water sorption and facilitate dye penetration into the polymer network. Kim et al. [7] demonstrated that extending the post-curing time of a 3D-printed crown material significantly improved its degree of conversion and color stability. Inadequate post-curing can leave the printed resin more porous and chemically reactive, so it readily absorbs colored compounds. The present study followed manufacturer instructions for post-curing, yet the discoloration was still pronounced, indicating that even the fully post-cured material is more prone to staining than conventional composites.

Another factor is **filler content and particle size**. Filtek Z350 XT is heavily filled with nanometer-scale silica/zirconia, resulting in a dense structure and a relatively low resin volume. The Saremco Crowntec resin, being printable, likely has a lower filler loading (the manufacturer does not publicly disclose filler percentage, but most printable crown resins have ~40–50% filler by weight). A higher resin content means more polymer matrix that can absorb water and stain. Water sorption of printed interim resins has been reported to be higher than that of milled PMMA or bis-acryl composites. Song et al. [5] found that 3D-printed provisional resins exhibited greater ΔE* over time compared to milled PMMA disks, correlating with their higher water sorption and solubility. Greater water uptake by the printed resin can also swell the matrix and create microgaps at the resin–filler interface, further trapping pigments.

Surface characteristics might have also played a role. Although both materials were polished, the printed resin's surface may inherently be less smooth due to the layer-by-layer fabrication. Increased surface roughness can exacerbate staining, as more pigment can adhere to a rough surface or get embedded in microcrevices. We did not quantify surface roughness in this study, but other work has noted that 3D-printed resins can have higher *Ra* values than conventional materials if not post-processed optimally. A rougher surface on the printed samples could partly explain the extreme staining, especially by particulate-containing liquids like chocolate milk (with cocoa solids) which can lodge in surface texture. On the other hand, the Filtek composite cured under Mylar strip yields a very smooth baseline surface, and even after slight polishing, likely remained smoother than the printed resin. This reduced the composite's propensity to retain stains on the surface, making any discoloration more limited to superficial adsorption that might be easier to remove (though in this study we did not attempt to clean or polish after staining).

Looking at differences among staining solutions, our results align with known staining potency hierarchies. Grape juice (rich in anthocyanins similar to red wine's chromogens) produced the largest ΔE* overall. Cola, despite being lighter in color intensity than grape juice, still caused major stains in the printed resin—likely due to the combination of caramel dye and the low pH (pH ~2.5) which can soften the resin matrix. Prior research has shown cola can both stain and erode resin composites slightly, although its staining effect is generally less than coffee or tea. In our study, cola's effect on the printed resin was nearly as bad as grape juice, suggesting that the printed material is highly susceptible even to moderate chromogens. The composite's ΔE in cola (~9.6) was about 25% lower than in grape (~12.7), consistent with Ertaş's ranking of cola < red wine. Chocolate milk had the lowest impact; its pigments (cocoa, which contains tannins, and added food dyes) are fewer or perhaps partly inhibited by the milk proteins. Milk might also have a "washing" effect or reduce pigment uptake by filling resin matrix pores with proteins temporarily. Indeed, the composite in chocolate milk barely changed (ΔE 3.0), implying that whatever minor coloration occurred might be due to a thin film of residue rather than deep penetration. The printed resin's ΔE ~6 in chocolate milk, while much lower than in the other drinks, was still above acceptability. Clinically, a ΔE of 6 could manifest as a visible yellowing or darkening (here instrumentally it shifted toward a Vita B3 shade). This suggests that even lighter-colored foods or drinks could cumulatively stain the printed material over time.

Clinical Implications: The large differences in color stability observed have practical significance. For permanent or long-term provisional restorations fabricated from 3D-printed resins like Saremco Crowntec, patients with high consumption of staining beverages (such as red wine, cola, grape juices, coffee/tea, or smoking habits) may experience rapid and noticeable discoloration. Our in vitro 15-day continuous immersion is an extreme scenario, but it could simulate, for example, several months to a year of daily exposure in the oral cavity. The printed resin turning from an A2 to a C4 equivalent in our study indicates that in a worst-case patient, a tooth-colored 3D-printed crown could lose its match to adjacent teeth and become visibly mismatched in a relatively short time. This level of discoloration would likely necessitate replacement of the restoration to restore aesthetics, incurring additional cost and inconvenience.

By contrast, the conventional Filtek composite demonstrated more resilient color performance. Although it did stain in the harsh grape juice challenge, the degree of color change (ΔE ~13) while above the ideal threshold, might still be manageable with a polish or simply less noticeable if gradual. In chocolate milk, Filtek's change was negligible, suggesting many everyday foods might not meaningfully affect it within that timeframe. This superior performance can be attributed to Filtek's chemistry – a well-cured, filler-rich composite matrix that resists water uptake. In clinical terms, the nanohybrid composite restoration would likely maintain its shade longer and require less frequent refurbishing or replacement due to discoloration.

One way to improve the color stability of 3D-printed restorations, as suggested by our findings and other studies, is to apply a **surface sealant or glaze**. Almejrad et al [6] investigated 3D-printed interim crowns and found that applying a light-cured protective coating (Optiglaze) significantly reduced staining compared to just polished surfaces. In their study, uncoated 3D prints showed higher ΔE*, whereas the nanofilled coating acted as a barrier to pigment penetration, yielding lower ΔE* after coffee/tea immersion. Such a coating could potentially be applied to printed permanent restorations as well, to enhance their stain resistance. However, coatings ñ--<can wear over time, so their long-term efficacy in vivo remains to be determined.

Another consideration is patient guidance: if a patient receives a 3D-printed resin restoration, clinicians should counsel them on minimizing exposure to staining agents. Simple dietary modifications, like drinking chromogenic beverages through a straw, rinsing the mouth with water after consuming them, or avoiding them altogether, could help prolong the restoration's aesthetic appearance. Regular professional polishing of the restoration could also be scheduled; gentle polishing can remove surface stains and restore the original shade to some extent, especially for the printed resin which may accumulate surface discoloration readily. A study by Spina et al.[9] showed that polishing could partially reverse composite staining from beverages, highlighting that not all color change is permanent. Thus, maintenance protocols can be crucial for 3D-printed materials.

It's also worth noting that **new generations of printable resins** are under development, some incorporating different resin chemistries or higher filler loads to improve properties like color stability. For instance, the inclusion of modified methacrylate monomers or the use of stronger photoinitiators might yield a more complete cure, reducing residual monomer. Until such improvements are clinically proven, the results of this study urge caution: dentists should critically evaluate the setting in which they use current 3D-printed crown materials. In highly esthetic zones for patients who regularly consume staining foods, a traditional composite or ceramic might still be preferable if color stability is paramount. Alternatively, if using a printed resin, the dentist should be prepared to address potential color mismatch at follow-ups.

Our findings are also in line with a recent in vivo study by Doumit et al [8] who observed that 3D-printed resin veneers showed greater color change over 2 years in the mouth compared to baseline, sometimes becoming esthetically unsatisfactory. This in vivo evidence complements our in vitro data, reinforcing that the stain susceptibility of printed resins is not just a laboratory artifact but a real clinical phenomenon. In that study, even with normal dietary exposure, the printed restorations' color stability was "overall reduced," supporting the notion that improvements are needed for long-term use.

Study Limitations: This study had some limitations. First, the sample size per group was small (n=2 disks per material per solution), which limits the statistical power. While the differences observed were large and consistent enough to draw clear conclusions, a larger sample size would allow more robust statistical analysis and generalization. Second, the immersion was continuous and did not involve any interim cleaning or saliva, which overestimates staining compared to an oral environment where saliva flow, dietary cleansing, and periodic brushing occur. The oral environment might mitigate some staining (especially for the composite), although conversely, factors like bacterial plaque could also enhance staining in vivo. Third, only one shade (A2) and one batch of each material were tested. Shade can influence staining – for example, a lighter shade might show discoloration more readily than a darker one. Different resin batches or printers might also have slight variations. We also did not examine mechanical or surface property changes; it is possible that prolonged cola immersion could soften the resin surface, compounding the color change. Another limitation is that we used the materials in disk form; actual restorations have complex shapes and are often polished/chairside-finished differently, which could influence stain uptake (e.g., rougher interproximal surfaces). However, disks allow standardized comparisons and spectrophotometer readings on flat surfaces.

Finally, we focused on visual color change and did not analyze the chemistry of the absorbed stains. Future research could employ spectroscopy or microscopic analysis to see how deeply pigments penetrate printed vs conventional composites, which would inform how permanent the stains are. Additionally, testing more 3D-printed materials and comparing different preventative treatments (surface sealants, different post-cure protocols) would be valuable to improve the clinical outcomes of this promising technology.

V. CONCLUSION

Within the limitations of this in vitro study, the 3D-printed composite resin (Saremco Print Crowntec) showed significantly poorer color stability compared to the conventional nanohybrid composite (3M Filtek Z350 XT) after immersion in common staining beverages. The printed resin specimens experienced severe discoloration in grape juice and cola (ΔE^* ~30+, corresponding to multiple Vita shade shifts), whereas the conventional composite, although affected, demonstrated much smaller color changes under the same conditions. Chocolate milk caused moderate staining in the printed resin and minimal change in the composite. All color changes in the printed resin exceeded established clinical acceptability thresholds, raising concerns about its use in situations demanding long-term esthetics.

For clinical practice, this suggests that while 3D-printed resin restorations offer convenience and custom fabrication, they may require careful case selection and patient management regarding diet. Dentists using such materials for provisional or definitive restorations should consider protective glazing and educate patients to limit exposure to intensely colored drinks. Regular monitoring and maintenance (polishing or replacement) may be necessary to maintain the aesthetic appearance of printed restorations. Conventional composite resin, in contrast, remains a reliable choice for color stability in the oral environment, showing better resistance to staining challenges.

In summary, 3D printing in dentistry is a promising innovation, but current printable resin composites like Saremco Crowntec may not yet match the color stability of traditional composites. Ongoing improvements in resin formulation and curing, as well as adjunctive measures to shield the surface, will be key to enhancing the long-term clinical performance of 3D-printed esthetic restorations. The clinician should weigh the advantages of digital fabrication against the potential need for more frequent aesthetic maintenance when deciding on restorative materials for esthetically critical cases.

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