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Color stability in 3D printed provisional dental restorations

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Abstract
Additive manufacturing of provisional dental restorations proves to be an alternative to create restorations with accuracy and precision. With a low cost and manufacturing time, compared to CAD CAM technology.
Aim: Conduct a literature review to review the main characteristics that influence color stability in 3D printed provisional restorations, analyzing information on additive manufacturing, types of printers, or any other factor that influences the manufacturing of 3D printed restorations. 3D.
Methodology: An electronic search was conducted through PubMed, SCOPUS and Google Scholar using the keywords: “3D provisionals” OR “digital dentistry”, “3D printing” OR “additive manufacturing” OR “PMMA”.Only full text articles in English have been considered. Complete articles in English were considered. We identified 103 results and used 39.
Results: Among the main factors that affect color stability, agents such as coffee and red wine were identified, which can affect the original appearance of the restorations.
Discussion: The research highlights the importance of surface treatment and the degree of curing of materials to ensure long-lasting aesthetic results. Manufacturing orientation parameters on color stability have a lot of impact.
Conclusion: It is important to highlight that there are few scientific articles related to the effects of manufacturing orientation parameters on color stability.

Keywords: 3D provisionals, digital dentistry, polymers, 3D printing, additive manufacturing

1. Introduction
Three-dimensional printing has revolutionized the healthcare sector by offering significant advantages, such as reduced wear time and the ability to create specific restorations with the necessary accuracy [1]. Compared to CAD CAM technology, additive manufacturing is presented as a promising and versatile alternative in dentistry, allowing the quick and easy production of high-quality prostheses [2]. The constant development of new materials has expanded the scope of 3D printing in dentistry, ranging from temporary crowns to inlays and veneers [3].
3D dental restoration printing technology has added a crucial element: satisfactory color reproduction. Color quality in 3D printed restorations is of utmost importance to meet patients' aesthetic expectations [4]. However, despite these advances, a problem arises that motivates this study: the lack of comprehensive research on color stability in 3D printed provisional restorations. This knowledge gap underlines the need to address the review on; additive manufacturing, types of printers available on the market, factors that affect the manufacturing of 3D printed restorations, and will focus especially on color stability in this type of temporary restorations.

2. Methodology
A search for articles published with emphasis on the last 5 years 2019-2023 was carried out using the PubMed, SCOPUS, Google Scholar database. and Mendeley. The quality of the articles was evaluated using guidelines such as identification, selection, inclusion and review.

The Booleans AND, OR and NOT were used. Keywords used for the search include: "3D provisionals" OR "digital dentistry" AND "polymers" OR "bionics" AND "3D printing" OR "additive manufacturing" OR "3D bio printing". Only full text articles in English have been considered. Complete articles in English were considered. We identified 103 results and used 32.

3. Results

3.1 Additive Manufacturing

Additive Manufacturing (AM), known as 3D printing, has evolved since its invention in the 1980s, giving rise to various 3D printers [5] In dentistry, 3D printing technology has facilitated the rapid manufacturing of dental restorations using protocols automated, standing out compared to conventional methods such as resin curing or CAD/CAM milling [1]. Research indicates that 3D printed resins may have greater strength compared to conventional ones, although strength may vary depending on composition and can be improved by adjustments to printing parameters [6, 7].

3D printing technology uses photocurable polymethylmethacrylate (PMMA) resins, and in search of improving their properties for biomedical applications they have incorporated nanomaterials such as graphene [8]. "Printability" in the context of bioprinting refers to the ability of the material to be fabricated in controlled layers to accommodate and maintain cell proliferation, with additional requirements such as nontoxicity, biodegradability, and adhesion to cells [9].

Despite advances, there is a lack of studies evaluating the negative microinfluences of restorations on intraoral tissues and applied after secondary processing [1]. 3D printing in dentistry allows for mass customization, an efficient digital workflow, and lower, more predictable costs compared to CAD/CAM technology. In addition, its advantage is highlighted in reducing the time of use, customization and minimization of waste [2].

AM has transformed dentistry by enabling rapid manufacturing and mass customization of dental restorations, prosthetics and implants. The incorporation of photocurable resins with nanomaterials offering improvements in biomedical properties. 3D bioprinting presents significant potential to develop artificial tissues and organs with natural-like properties, moving towards precise, reproducible, large-scale manufacturing of complex systems.

3.2 Types of printers

In the field of 3D printing for dental applications, there are various technologies with notable differences in terms of technology, resolution, precision and repeatability [10]. Light-cured 3D printing encompasses techniques such as stereolithography (SLA), digital light projection (DLP), liquid crystal display (LCD), multi-jet printing (MJP), continuous liquid interface production (CLIP), two-photon 3D printing (TPP) and holographic 3D printing technology, each with specific characteristics [11].

The SLA technique uses a laser beam of ultraviolet light to sequentially polymerize layers of liquid photopolymer resin, being capable of printing large-sized models, although its printing speed decreases with increasing size [5]. In comparison, DLP technology simultaneously polymerizes entire layers of photosensitive liquid resin using a UV light mask, notable for its high precision but limitation in print size due to technological constraints and the cost associated with Texas Instruments' dominance in this area [12].

LCD 3D printing uses a liquid crystal display as the imaging system, being more affordable but with a short lifespan and weak light intensity [13]. CLIP technology, an upgrade from DLP, shares similarities in light source and imaging system, but has specific viscosity requirements for materials, especially at high print speeds. MJP 3D printing has independence between image control and lamp source, allowing varied photopolymerization options, but is expensive and used in fields that require high precision, such as jewelry casting and precision medicine [14].

Inkjet bioprinting and laser-induced direct transfer (LIFT) are rapid methods, but require bioinks with specific viscosities. Inkjet bioprinting deposits small droplets of ink at predetermined locations, while LIFT uses a pulsed laser to induce jet formation on the substrate, requiring post-print cross-linking to improve mechanical integrity. However, both methods have limitations in terms of viscosity and cell retention [15].

In summary, the highlighted technologies are SLA and DLP, which allow the rapid and precise creation of complex structures tailored to specific requirements, while inkjet bioprinting and LIFT are methods that require specific viscosity considerations for bioinks.

3.3 Factors affecting the manufacturing of 3D printed restorations

In the manufacturing of 3D printed restorations with vat polymerization technologies, the process is divided into preprocessing and postprocessing. Preprocessing involves adjustments to layer thickness, support formation, and print direction.12 Postprocessing includes a rinse to remove residual resin and a post-curing process for final polymerization between layers. Methods such as SLA and DLP require these steps to achieve final polymerization, which can affect the accuracy of provisional prostheses [16].

The strength of 3D printed resins could be improved by factors such as the addition of filler or nanofiller, orientation, layer thickness, and postpolymerization time and temperature [17]. It is recommended to carry out more studies that combine these factors. Evaluations of provisional crowns according to angles, support thickness and construction orientation have been carried out by various studies [18].

Build orientation, especially at 45 °C, affects the marginal fit of three-unit resin prostheses produced by SLA 3D printing. Comparison of different layer thicknesses did not yield significant results, suggesting the need for further investigation [19]. The 0 degree print orientation is recommended to optimize the precision and flexural strength of crowns manufactured with SLA printer and resin ceramic material [20].

Factors such as printing speed and thickness of individual layers impact the mechanical properties of the product, being crucial from the perspective of materials used in medicine. Finite element simulations are useful to analyze this phenomenon [12]. The shape and thickness of the element can also significantly influence the results obtained during the curing process [2].

In summary, improving the strength of 3D printed resins involves considering factors such as filler addition, orientation, layer thickness, and postpolymerization parameters. Construction orientation and other specific factors have been evaluated in studies, highlighting the importance of these elements in optimizing the precision and strength of restorations.

3.4 Color stability in 3D printed provisional restorations

Color stability in 3D printed dental restorations is essential to preserve their original appearance over time, as exposure to coloring agents such as coffee and red wine can cause unsightly discoloration [21]. Color stability in these materials is crucial to ensure longevity and aesthetics, especially when considering different surface treatments [8].

In terms of color difference evaluation, when an observer views a 3D object, the viewing distance between his eyes to different locations of the 3D object varies. Effectively measuring the color of 3D objects and quantifying their color appearance difference is of great importance in various fields of science, medicine and technology. The evaluation of color difference is affected by many factors or viewing conditions, including sample shape, sample size, sample separation, texture, background, magnitude of color difference, etc., generally designated as parametric effects [22].

Literature identifies beverages such as coffee, red wine, orange juice, and burqa juice as agents that can affect the color of 3D printed materials [23]. Color change can also occur during use in the mouth due to factors such as temperature changes and brushing with pastes and brushes [24].

However, there is limited research on how surface preparation methods impact the color stability and geometry of printed objects [25]. Various guidelines have been proposed, such as covering the samples with glycerin, using resin, or increasing the temperature during polymerization in the light oven.

The research highlights the importance of surface treatment in color stability, noting that unpolished surfaces are more prone to staining, while varnish can protect the color, but with the risk of peeling over time. Polished surfaces offer better color stability, but proper polishing is crucial to avoid rougher areas that could absorb dyes [2].

The degree of curing of photopolymerizable materials can vary depending on the devices used, underscoring the need for more research on curing materials and equipment [17]. The results indicate that 3D printed materials should undergo thorough curing to minimize color change and ensure long-lasting aesthetic results [2]. In the case of provisional restorations, the use of a light polymerization protective layer and nanofiller is suggested to reduce discoloration caused by chromogenic beverages, being more effective against coffee [26].

Color stability is affected by many factors or viewing conditions is a critical aspect in 3D printed dental restorations, including sample shape, sample size, sample spacing, texture, background, the magnitude of the color difference, the orientation of the sample when printing, the duration of immersion, and the frequency of exposure to dye solutions are other factors that influence color stability and must be considered to maintain aesthetics throughout weather. Generally designated as parametric effects.

4. Conclusion

The research highlights the need to consider key factors in the manufacturing of 3D printed restorations, from the choice of technologies to the optimization of parameters. Color stability in 3D printed provisional restorations emerges as a crucial aspect, highlighting the importance of surface preparation methods and the degree of material curing to ensure long-lasting aesthetic results. The authors suggest conducting research associated with specific polymeric materials and exploring the impact on the color stability and stainability of these temporary restorations on manufacturing parameters in 3D printing. Studies are currently lacking. Altogether, this review article provides a comprehensive overview of the current advances and challenges in the use of 3D printing in dentistry, emphasizing its positive impact and the need for continued research to refine this technology.

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