In Vitro Physical Properties of 3D-Fabricated Provisional Crowns with Polylactic Acid *

Propiedades físicas *in vitro* de coronas provisionales confeccionadas en 3D con ácido poliláctico

Propriedades físicas in vitro de coroas provisórias fabricadas em 3D com ácido polilático

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ABSTRACT

Background: The evolution of digital technology in dentistry has enabled the fabrication of restorations using subtractive or additive methods. Polylactic acid (PLA), derived from renewable resources such as sugarcane, is being considered as an alternative to fast-curing acrylic for the fabrication of provisional prostheses using three-dimensional printing. **Purpose**: To determine the thermal properties of provisional crowns fabricated three-dimensionally with PLA in vitro. **Methods**: A quasi-experimental *in vitro* study was conducted. Thirty preparations were made on natural teeth, scanned with a MEDIT i500, and designed in EXOCAD. The crowns were printed with a 135° deposition angle of the PLA filament and divided into two groups: one exposed to heat by immersion in a water bath between 60 °C and 95 °C for 1 to 5 minutes, and the other was exposed to cold by immersion in ice water at 2 °C for the same time. **Results**: Measurements taken before and after thermal testing showed a constant mean of 1200 µm in the mesiodistal direction across the 30 crowns analyzed. **Conclusion**: The PLA-printed crowns did not exhibit dimensional changes due to contraction or expansion under the evaluated thermal conditions. This suggests that it is stable and potentially viable as a provisional material for dental restorations.
Keywords: cold; dental materials; dentistry; heat; polylactic acid copolymer; three-dimensional printing; *Saccharum*; technology

RESUMEN

Antecedentes: La evolución de la tecnología digital en Odontología ha permitido fabricar restauraciones mediante métodos sustractivos o aditivos. El ácido poliláctico (PLA), derivado de recursos renovables como la caña de azúcar, se plantea como alternativa al acrílico rápido en la confección de prótesis provisionales mediante impresión tridimensional. **Objetivo:** Determinar las propiedades térmicas de coronas provisionales confeccionadas tridimensionalmente con PLA *in vitro*. **Métodos:** Se desarrolló un estudio cuasiexperimental *in vitro*. Se realizaron 30 preparaciones en dientes naturales, escaneadas con MEDIT i500 y diseñadas en EXOCAD. Las coronas se imprimieron con un ángulo de 135° de deposición del filamento de PLA y se dividieron en dos grupos: uno expuesto al calor mediante inmersión en baño María entre 60 °C y 95 °C durante 1 a 5 minutos, y otro al frío mediante inmersión en agua con hielo a 2 °C durante el mismo rango de tiempo. **Resultados:** Las mediciones realizadas antes y después de las pruebas térmicas mostraron una media constante de 1200 µm en sentido mesiodistal en las 30 coronas analizadas. **Conclusión:** Las coronas impresas en PLA no presentaron cambios dimensionales

por contracción o dilatación bajo las condiciones térmicas evaluadas. Ello sugiere que es estable y potencialmente viable como material provisional en restauraciones dentales.
Palabras clave: calor; copolímero de ácido poliláctico; frío; impresión tridimensional; materiales dentales; odontología; *Saccharum*; tecnología

RESUMO

Antecedentes: A evolução da tecnologia digital na odontologia possibilitou a fabricação de restaurações utilizando métodos subtrativos ou aditivos. O ácido polilático (PLA), derivado de recursos renováveis como a cana-de-açúcar, está sendo considerado uma alternativa à resina acrílica de cura rápida para a fabricação de próteses provisórias por meio de impressão tridimensional. **Objetivo**: Determinar as propriedades térmicas de coroas provisórias fabricadas tridimensionalmente com PLA in vitro. **Métodos**: Foi realizado um estudo quase-experimental *in vitro*. Trinta preparos foram feitos em dentes naturais, escaneados com um equipamento MEDIT i500 e desenhados no software EXOCAD. As coroas foram impressas com um ângulo de deposição de filamento de PLA de 135° e divididas em dois grupos: um exposto ao calor por imersão em banho-maria entre 60 °C e 95 °C por 1 a 5 minutos, e o outro ao frio por imersão em água com gelo a 2 °C pelo mesmo período. **Resultados**: As medições realizadas antes e depois do teste térmico mostraram uma média constante de 1200 µm na direção mesiodistal nas 30 coroas analisadas. **Conclusão**: As coroas impressas em PLA não apresentaram alterações dimensionais devido à contração ou expansão sob as condições térmicas avaliadas. Isso sugere que o material é estável e potencialmente viável como material provisório para restaurações dentárias.
Palavras-chave: calor; copolímero de ácido polilático; frio; impressão tridimensional; materiais odontológicos; odontologia; *Saccharum*; tecnologia

INTRODUCTION

Provisional crowns are an important step in various restorative dentistry procedures, such as fixed partial dentures, single crowns, and inlays, and they influence the success or failure of the treatment (1). For this reason, they must be designed with well-defined, smooth, and polished margins, which ensures adequate removal of bacterial plaque and prevents a localized inflammatory response (2). Likewise, the fit of the provisional crown influences the contour of the gingival margin, as it provides a guide and a stop that prevents gingival overgrowth (3). Techniques for fabricating provisional crowns can be direct, indirect, or hybrid (4). The choice of a specific technique depends on the type of material, its cost, working time, setting time, and the dentist's preference (5).

Computer-aided design and manufacturing (CAD/CAM) systems stand out in modern dentistry for their efficacy. They offer numerous advantages. This technology allows for dental restorations to be made using three-dimensional (3D) printing. The methods can be subtractive or additive. These systems replace analog workflows, such as taking impressions with elastomeric materials, plaster casting, polymer preparation, and the handcrafted fabrication of restorations or prostheses, among other procedures (1,6).

In the field of materials, 3D printing allows the use of biodegradable copolymers such as PLA. This is a thermoplastic polyester belonging to the α-hydroxy acids. In its natural form, it is a colorless, moisture-resistant polymer. It has barrier properties against taste and odor. Its use is widely documented in the medical field, with numerous reports on its biocompatibility (7,8). In dentistry, it can replace self-curing acrylic resins for temporary restorations, eliminating problems such as strong odor, volumetric shrinkage, and tissue irritation (9). PLA is obtained from complex carbohydrates such as corn starch, tapioca roots, or sugarcane (10). It is biodegradable, does not emit harmful gases, and exhibits good scratch and wear resistance (11). Its degradation in the environment can vary between 6 months and 2 years, depending on the size, shape, isomer ratio, and temperature (12).

PLA is the most widely used material for 3D printing in general. When processed using the fused deposition modeling (FDM) technique, PLA is easy to print at low temperatures (170 °C) without deformation. It has extremely low shrinkage, a good finish, and allows for post-printing treatments. Temporary crowns are prostheses for temporary use. They provide a chewing surface and protect the prepared tooth. Furthermore, they must meet aesthetic requirements according to the size, shape, and color of the adjacent teeth (13).

Although biopolymers represent a sustainable and potentially safer alternative to conventional materials, their behavior under the functional and aesthetic demands of the oral environment is not fully characterized. This uncertainty limits their widespread clinical application. They could cause degradation, deformation, or inflammatory responses during the provisional period, affecting treatment quality and patient satisfaction. Therefore, it was considered necessary to investigate how the PLA biopolymer behaves under the specific conditions of the oral cavity. This aims to ensure its efficacy and safety in the 3D printing of provisional crowns. This research considered that PLA could replace self-curing acrylic resins. However, there are no recent studies analyzing physical properties, such as the dimensional change of PLA, when subjected to in vitro temperature variations. This motivated the present study, which evaluates it as an alternative material for the fabrication of provisional restorations.

MATERIALS AND METHODS

A quasi-experimental *in vitro* study was conducted. A non-probabilistic convenience sampling method was used, including 30 preparations on natural teeth, following the central limit theorem, that is, seeking an approximation to the normal distribution of sample means. The study protocol was developed by the research team. The dental preparations of the individual crowns were performed with a simple chamfer finish line for metal-ceramic restorations.

Direct observation was the technique used to collect the information, which was recorded on a form designed by the research team. The study variable was the mesiodistal diameter of the crown, measured in micrometers. The full crowns printed in PLA that were selected did not exhibit filament interference with the measurement process. Once the preparations were completed, they were scanned with the MEDIT i500 intraoral scanner, following the manufacturer's specified protocol. Subsequently, the tooth preparation was verified using the "preparation review" tool included in the software. This feature identified the areas of the tooth that required further reduction for the final restoration.

The scanned information was sent in STL format to the Flashforge Guider 3D printer, which uses the FDM system. This equipment allowed for the production of provisional crowns with the specific anatomical characteristics of each natural tooth. A printing angle of 135° was used, in accordance with a recent study that identified this angle as the most suitable for crown fabrication (14), considering the deposition of the PLA filament (Figure 1). The filament used was Steren® white PLA, with a diameter of 1.75 mm (Figures 2 and 3). The intraoral scanner was calibrated using Calibration Wizard and the tool's dial. The 3D printer, for its part, has an automatic bed calibration tool for the filament extrusion area. Furthermore, the operators were trained following the protocol established by each manufacturer. Both the tooth preparations and the scans were performed by a single operator.

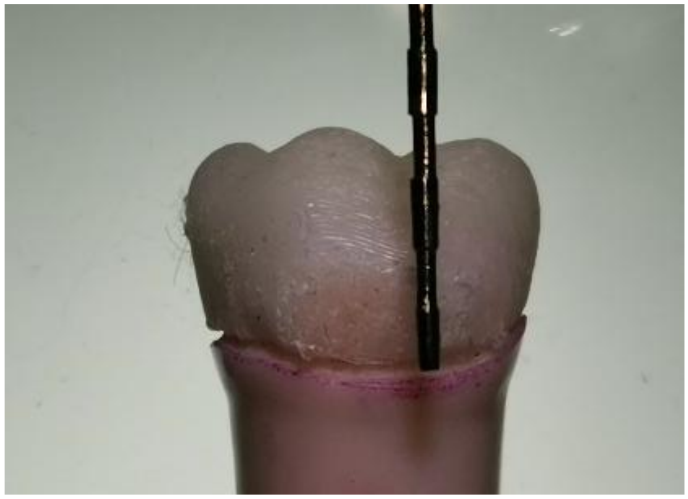

FIGURE 1
Mesiodistal and buccolingual diameter of provisional crowns printed with digital vernier caliper
Source: the authors.

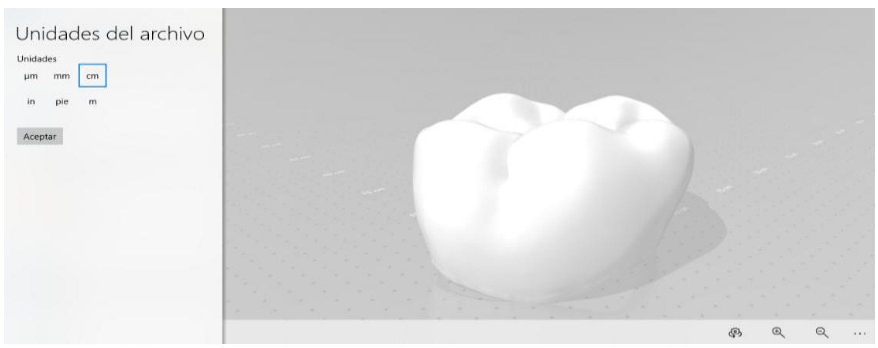

FIGURE 2
STL (Standard Tessellation Language) file of a temporary crown designed in EXOCAD®
Source: the authors.

FIGURE 3
Flashforge Guider 3D printer
Source: the authors.

For thermal testing, the provisional crowns were divided into two groups: 15 PLA crowns for heat testing and 15 PLA crowns for cold testing. Heat testing was performed using a Biobase water bath and a Taylor 9840N thermometer with a measurement range of −40 °C to 150 °C. The crowns were immersed for 1 to 5 minutes, starting from an initial temperature of 60 °C and reaching 95 °C. Dimensional changes were measured at each interval using a digital Vernier caliper. Elevated temperatures were considered, including those commonly encountered in everyday activities such as consuming coffee, tea, or soup, where a temperature of 60 °C is tolerable without causing esophageal injury (15). For cold testing, the crowns were immersed in a beaker of ice water for 1 to 5 minutes, reaching a temperature of 2 °C.

Descriptive statistics and Microsoft Excel version 16 were used to organize and analyze the data. It is important noting that this quasi-experimental study was reviewed by the Institutional Ethics Committee of the Evangelical University of El Salvador, as per minutes No. 335, dated February 2023.

RESULTS

Table 1 shows the results of the thermal tests. For the cold test group, temperatures between 1 °C and 5 °C were analyzed, with immersion times of 1 to 5 minutes. The PLA crowns showed no dimensional changes (contraction or expansion), maintaining a mesiodistal and buccolingual diameter of 1200 µm, measured using a digital Vernier caliper before and after each test. The measurement was reconfirmed with several readings of the same tooth to validate the results (Figure 4). Figure 5 presents a diagram illustrating the process and behavior of the crowns during the thermal tests.

TABLE1
Descriptive statistics of heat and cold tests

Type of thermal test	**Average**	**Median**	**Estándar deviation**	**Lower**	**Higher**
Heat test	1.20 °C	1.20 °C	0.053	1.10 °C	1.30 °C
Cold test	1.20 °C	1.20 °C	0.038	1.10 °C	1.30 °C

Source: the study.

FIGURE 4
Mesiodistal and buccolingual diameter of provisional crowns printed with digital vernier caliper
Source: the study.

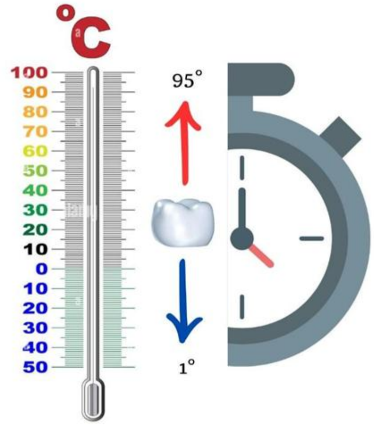

FIGURE 6
Schematic of thermal behavior of PLA crowns
Source: the study.

In this study, mesiodistal measurements of test specimens showed that polylactic acid-etched crowns did not undergo dimensional changes when subjected to temperatures between 1 °C and 95 °C. The crowns retained their initial dimensions in all evaluated diameters. Furthermore, the insertion axis of the crowns in relation to the tooth preparations was verified. No deformations were observed, allowing for proper seating.

DISCUSSION

In the present study, PLA was subjected to thermal testing between 2 °C and 95 °C. The measurements of the provisional crowns were not affected within this temperature range, possibly due to their high extrusion temperature. The temperatures used were based on studies indicating that hot beverages should not exceed 65 °C to avoid esophageal damage (15). The properties observed in the PLA-printed crowns demonstrate that they would have dimensional stability in the oral environment when consuming commonly consumed hot and cold beverages or foods, such as coffee, tea, soup, or iced soft drinks. In a study by Charasseangpaisarn et al. (16), samples of PLA and polymethyl methacrylate (PMMA) were exposed to low temperatures to evaluate their flexural modulus. The authors found that FDM-printed PLA exhibited lower flexural strength than PMMA.

The direct application of the exothermic reaction and chemical substances in acrylic resins can negatively affect the dentin-pulp system. Furthermore, PMMA requires relining the margins of the provisional restoration due to polymerization shrinkage. Unlike PMMA, PLA does not shrink after processing (17). Even when subjected to temperature variations, its dimensions remain stable. This allows it to seat properly on the tooth preparation, as found in this study.

Bis-acrylic resins offer better mechanical stability, are biocompatible, and generate minimal exothermic reactions during polymerization. Therefore, they do not cause pulpal or periodontal irritation. However, they are a considerably more expensive alternative to acrylic resins, which do generate exothermic reactions, shrink during polymerization, and release a large amount of monomer waste (18). This creates a need to find more cost-effective alternatives with a smaller environmental footprint, such as PLA, for use in provisional crowns. Furthermore, the digital workflow can be leveraged, offering lower, more predictable costs and faster turnaround times (19).

PLA has sufficient thermal stability to delay degradation and maintain molecular weight and performance. At temperatures above 200 °C, PLA undergoes hydrolysis, lactic acid recombination, oxidative cleavage of the backbone, and intermolecular or intramolecular transesterification (20). However, these temperatures are unlikely to occur in everyday life.

Tahayeri A, et al. (21) suggest that a 3D-printable provisional restorative material possesses sufficient mechanical properties for intraoral use, despite the limited precision of the chosen 3D printing system. Some studies mention that the mechanical performance of biopolymers such as PLA, as well as their flowability and surface roughness, must be improved for their use in medical implants, due to the way the printer extrudes filaments layer by layer to form an object. PLA is considered a leading biomaterial for various medical applications and can replace conventional petroleum-derived polymers. However, its clinical use in dentistry is still limited. Some publications mention the practicality of printing provisional restorations (crowns, bridges, surgical guides, etc.) in this material and using them for short treatment periods, thanks to its biodegradability properties (22).

Limitations of the study

PLA, being a relatively unexplored material in dentistry, presents specific challenges. The use of more suitable instruments to verify certain variables, as well as other devices to measure coronal diameter, a simulated scenario to better record thermal tests, and the use of a high-tech thermometer, are factors that were not considered in this study.

CONCLUSIONS

No dimensional changes (contraction or expansion) were observed in the printed crowns at the temperatures applied during this study.

The PLA objects exhibited sufficient thermal properties to be considered in future research, as they remained dimensionally stable at temperatures typical of hot (up to 65 °C) and cold (down to 0 °C) beverages, which correspond to common ranges in the daily diet.

RECOMMENDATIONS

Further research on the use of PLA in dentistry is suggested, focusing on physical, thermal, and optical testing. These studies will allow for a more precise determination of its properties and facilitate a second phase of clinical trials in patients.

It is recommended that specific research be conducted on the degradation processes of PLA. As a biodegradable polymer, its study could confirm its potential as an environmentally friendly material compared to other materials used in dentistry.

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* Original research.

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