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Polylactic Acid in Dentistry – A Sustainable Biomaterial for Oral Health

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Abstract

Introduction and Objective: Polylactic acid (PLA) is a biodegradable, biocompatible polymer derived from renewable sources. In light of the growing importance of environmental sustainability, health promotion, and digital innovation, PLA has gained relevance in medical and dental sciences. The objective of this review is to explore PLA's applications in dentistry while highlighting its potential role in patient safety, and the development of sustainable health solutions.

Brief Description of the State of Knowledge: PLA is increasingly utilized in dental procedures due to its safety profile and compatibility with digital manufacturing technologies, including 3D printing. In surgery and periodontology, PLA-based membranes are used in guided bone and tissue regeneration (GBR/GTR). In prosthodontics, PLA supports the production of temporary crowns, bridges, and denture bases. In orthodontics, it is applied in palatal plates and aligners. Its biodegradable nature and absence of toxic residues make PLA a valuable alternative in preventive and environmentally conscious dental care.

Summary: Although PLA shows strong potential, its mechanical limitations require further improvement. Research into composites and material modifications is ongoing. PLA represents a promising direction in dentistry, offering opportunities for innovation in clinical practice, sustainability, and the education of future healthcare professionals.

Keywords: polylactic acid, biopolymer, periodontology, prosthodontics, orthodontics

Introduction

In recent decades, with the advancement of science and technology, biomedicine has undergone rapid development, particularly in the field of biomedical materials. Low toxicity and good biocompatibility have always been key objectives in the development and application of biomedical materials [1]. Traditional plastics, made from non-biodegradable substances, have gained popularity due to their affordability and strong mechanical properties. However, their mass production has contributed to environmental pollution and health concerns [2]. In response to these challenges, interest has grown in biodegradable materials, such as polylactic acid (PLA), which is derived from renewable resources and naturally hydrolytically degrades into water and carbon dioxide [3].

Polylactic acid is one of the most well-known biopolymers and is considered a promising alternative for multiple applications due to its properties, such as flexibility, stiffness, thermoplastic behavior, biocompatibility, and excellent moldability [4]. In the 1970s, PLA-based products were approved by the U.S. Food and Drug Administration (FDA) for direct contact with biological fluids [5]. Its first medical application involved the treatment of mandibular fractures in dogs [6]. Since then, PLA has been successfully used in numerous medical fields, including craniofacial implants, drug delivery systems, and scaffolds supporting bone and cartilage regeneration. With its wide range of applications and the ability to customize its mechanical properties, PLA remains one of the most promising biomaterials not only in medicine but also in dentistry. The use of PLA in dentistry has been presented in Fig. 1.

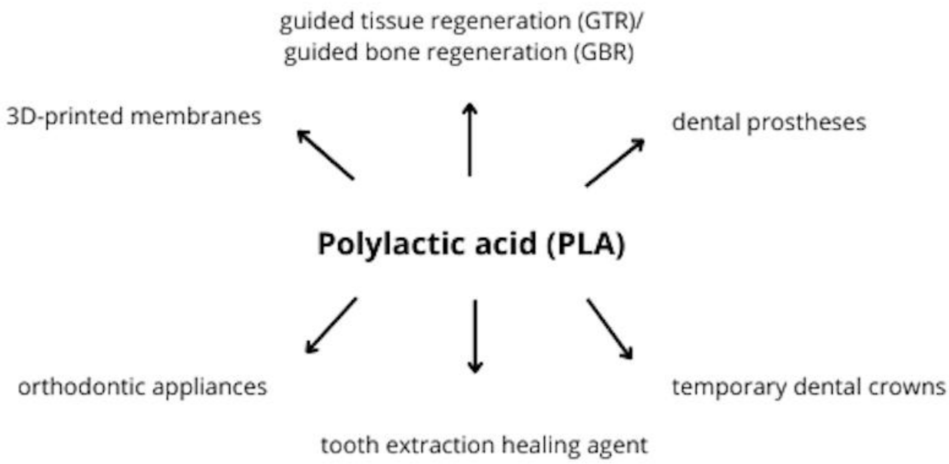

Fig. 1. The use of PLA in dentistry

Synthesis of PLA

Lactic acid (LA, 2-hydroxypropionic acid, $CH_3CHOHCOOH$) is a naturally occurring organic acid that exists in two enantiomeric forms, L- and D-LA. It was discovered in the 18th century in sour milk by the Swedish chemist Carl Scheele [7]. Due to the presence of carboxyl and hydroxyl groups, it is used as a monomer for chemical conversions and the production of substances such as acrylic acid, propylene glycol, and acetaldehyde [8]. Although LA can be synthesized through chemical processes, nearly 90% of the global LA production is obtained through bacterial fermentation, while the remaining portion is produced synthetically through the hydrolysis of lactonitrile [9]. Most commercial lactic acid is derived from bacterial fermentation of carbohydrates by homofermentative Lactobacillus species, which produce LA exclusively without additional byproducts, making the process more economical [10].

LA serves as a fundamental building block for synthesizing PLA, a biodegradable polymer widely used in the production of packaging materials and containers due to its processability and transparency [11]. Moreover, it has attracted significant interest for medical applications due to its biocompatibility and biodegradability [12]. The synthesis of PLA begins with the production of LA and ends with its polymerization, with an intermediate step involving the formation of lactide. PLA is primarily synthesized through three stages. The first stage involves the microbial fermentation of LA. In the second stage, LA is purified, followed by the preparation of its cyclic dimer (lactide). The third and final stage consists of polycondensation of LA or ring-opening polymerization (ROP) of lactides [13]. The synthesis of PLA is shown in FIG. 2.

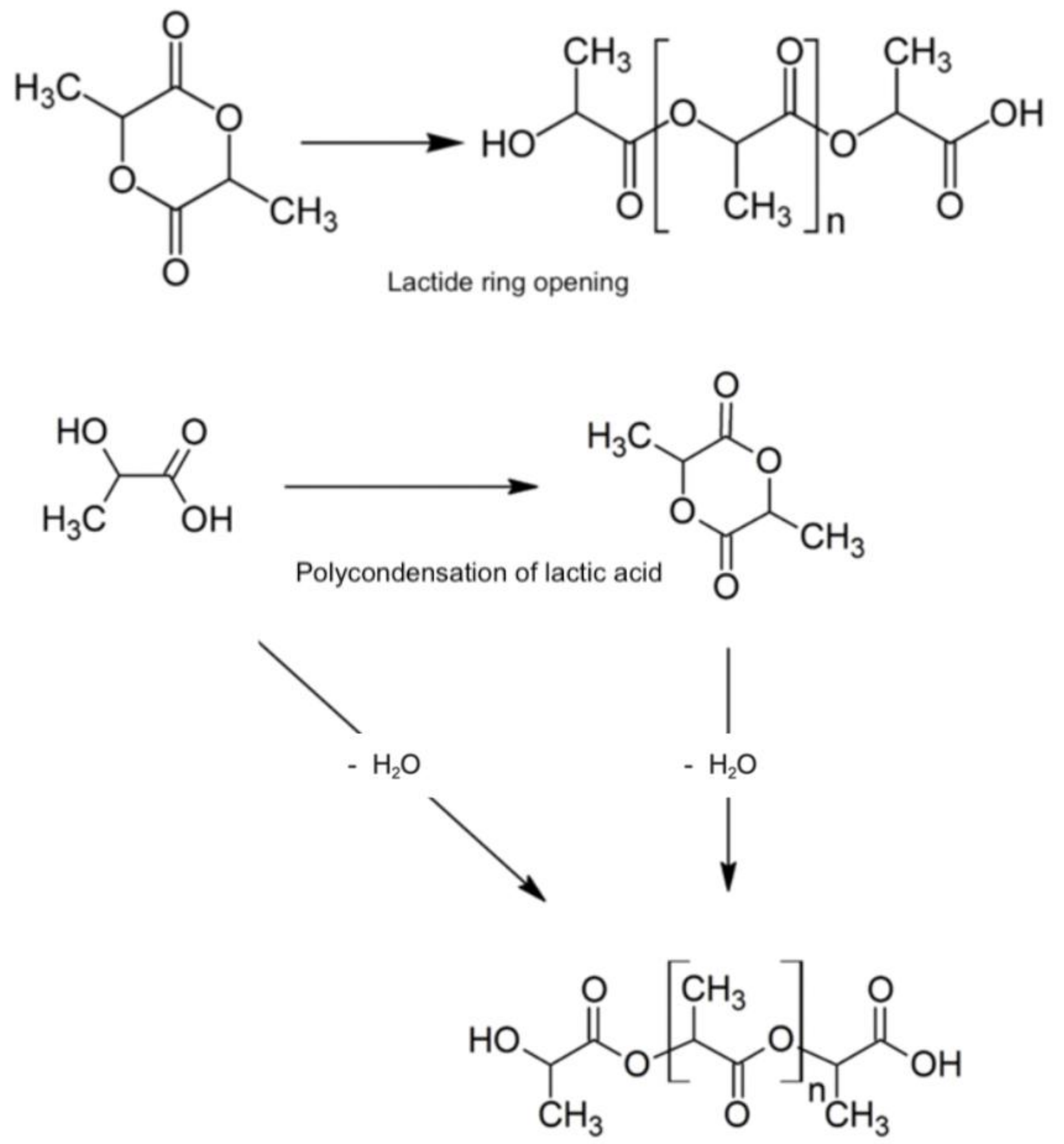

Fig. 2. PLA synthesis

Application of PLA in Medicine

Polylactic acid (PLA) plays a crucial role in contemporary medicine, being used in a wide range of medical procedures and technologies. One of its most important applications is in tissue engineering, where PLA is being used as a material for producing biodegradable scaffolds that support the regeneration of damaged tissues, including bone and cartilage. Due to its biodegradability and biocompatibility, PLA gradually disintegrates in the body, allowing the implanted material to be naturally replaced by newly formed tissues. It is particularly used in the form of fibers, membranes, and three-dimensional structures created through 3D printing technology, offering precise customization to meet the unique needs of patients [5].

In orthopedics and maxillofacial surgery, PLA is commonly used in the production of resorbable plates, screws, sutures, and wires for stabilizing fractures and reconstructing bone following trauma. Its advantage over traditional metal structures is degradation in the body, eliminating the need for additional surgery to remove the implanted material [14]. Moreover, studies have shown that PLA-based structures support the proliferation, growth and spread of various cell types, including osteoblasts, osteoblast-like cells, and human umbilical vein endothelial cells (HUVECs) [15].

Another significant applications of PLA are controlled drug delivery systems. PLA can encapsulate active substances such as antibiotics, anticancer drugs, and hormones, enabling their gradual release at the site

of action [5]. PLA-based micro- and nanoparticles have been successfully used in oncology, enabling drug transport to cancer cells, increasing treatment effectiveness, and minimizing side effects. Furthermore, PLA is utilized in vaccines, ensuring the sustained release of antigens and enhancing the immune response [16,17].

Recently, PLA has also gained attention in plastic surgery and regenerative medicine, where it is used in the production of dermal fillers and implants for soft tissue reconstruction [5,18]. Its applications also extend to the production of biodegradable vascular stents, which maintain blood vessel patency and gradually degrade, eliminating complications associated with the long-term presence of foreign materials and the need for surgical removal [19].

Due to its distinctive properties, PLA is widely used in medicine as a next-generation biomaterial. Ongoing research focuses on further modifications to improve its mechanical properties, degradation rate, and interaction with tissues, opening new prospects for its application in an even broader range of medical procedures [5].

PLA in Periodontology, Oral Surgery, and Implantology

Periodontitis, which leads to the destruction of structures supporting the teeth, is one of the most common chronic diseases. It causes gingival recession, periodontal ligament destruction, and alveolar bone loss [20,21]. Studies indicate that over 47% of adults aged 30 and older exhibit different stages of periodontal disease [22]. With the advancement of tissue engineering and nanotechnology, new technologies and biomaterials have been developed to recreate the microenvironment of the natural extracellular matrix for periodontal tissue regeneration [23]. Biomaterial-based approaches are widely used to support periodontal tissue regeneration [24]. Guided tissue regeneration/guided bone regeneration (GTR/GBR) techniques use polymeric materials as physical barriers, preventing connective and epithelial tissue growth into the defect area and promote periodontal tissue regeneration [25]. The effectiveness of the GTR/GBR method has been confirmed for vertical alveolar bone defects but not for horizontal bone loss. Currently available GTR/GBR membranes lack tissue-regenerative properties and must be used with grafts to improve tissue regeneration [26]. Other significant limitations of natural biomaterials include variability and poor mechanical properties of produced consecutive batches. To overcome these drawbacks, several synthetic biodegradable polymers have been developed for resorbable GTR/GBR membranes, including polylactic acid (PLA), polyglycolic acid, polyethylene glycol membranes, polycaprolactone, and copolymers of lactic and glycolic acid, with their modifications [21].

Polylactic acid polymers are extensively studied for their applications in guided bone regeneration, often in combination with bioceramics such as hydroxyapatite (HAp) and fluorapatite (FAp). Research carried out by Takayama et al. [27] demonstrated that these materials exhibit significant osteointegration and stimulate osteoblast proliferation, supporting bone tissue mineralization and regeneration. It has been proven that hydroxyapatite combined with UV-treated PLA (UV-HAp/PLLA) and bioresorbable hydroxyapatite combined with PLA (PLGA/HAp) induce higher osteogenesis compared to conventional materials such as titanium.

A study conducted by Jang et al. [28] evaluated the use of polylactide (PLA) membranes containing graphene oxide (GO) in GBR. These membranes, fabricated using 3D printing, exhibited improved biological properties compared to traditional materials. It was found that GO increased surface hydrophilicity, promoting adhesion, proliferation, and differentiation of preosteoblasts. The study demonstrated that GO-PLA membranes accelerated bone regeneration and showed better mineralization and integration with bone tissue than PLA membranes alone. The results suggest that GO-PLA membranes could serve as an effective alternative to conventional GBR barriers, enhancing bone healing and regeneration.

In another study, by Zhang et al. [29], the properties of 3D-printed polylactic acid membranes were compared with conventionally manufactured membranes. The study assessed the impact of different pore sizes (large – 479 µm, small – 273 µm, and no pores) on their mechanical and biological properties. The analysis revealed that 3D-printed membranes had superior mechanical strength compared to those produced using traditional methods. Preosteoblast proliferation studies showed no significant differences in cell growth among the groups, suggesting that the manufacturing method and pore size had little influence on adhesion and proliferation. The findings confirmed that 3D printing is a promising technique for producing personalized membranes for guided bone and tissue regeneration (GBR/GTR).

PLA in Prosthodontics

PLA is also used as a material for temporary prosthetic restorations, offering biocompatibility and biodegradability. Studies conducted by Crenn et al. [30] demonstrated that PLA obtained via 3D printing using fused deposition modeling (FDM) exhibits mechanical properties comparable to certain traditional resins, such as Unifast® (GC, Tokyo, Japan). PLA has low porosity, which enhances its mechanical properties, but its microhardness is lower than that of other temporary materials. A significant advantage of PLA is the absence of residual monomers, which in conventional materials may exhibit cytotoxic and allergenic effects.

Additionally, studies suggest that PLA dentures printed using FDM technology meet the requirements for precise intraoral adaptation, indicating their potential application in prosthodontics as a cost-effective and efficient alternative to traditional denture fabrication methods. When used with CAD software for prosthetic production, PLA can replace conventional approaches and improve the functionality of prostheses [31].

PLA has also been studied for its use in temporary crown fabrication with CAD/CAM technology [32,33]. In a study by Benli et al. [32], PLA was compared with conventionally used polymethyl methacrylate (PMMA) and polyetheretherketone (PEEK) in terms of marginal and internal fit as well as fracture resistance. The results showed that PLA achieved fit values similar to PMMA but exhibited lower mechanical strength than PEEK. Despite its lower fracture resistance, PLA is an environmentally friendly and biocompatible alternative to conventional temporary materials. Similarly, in a study by Molinero-Mourelle et al. [33], the marginal fit of crowns made from PLA using FDM technology was compared to PMMA crowns. The results indicated that the marginal fit of PLA was within a clinically acceptable range and comparable to PMMA. Both studies suggest promising outcomes for the application of PLA in 3D printing technology in terms of efficiency and sustainability in prosthetic production.

PLA in Orthodontics

Polylactic acid is also used in orthodontics, supporting bone healing and regeneration after tooth extraction. Studies conducted by Huang et al. [34] demonstrated that oligodeoxynucleotides loaded with polylactic-co-glycolic acid nanospheres (PLGA-NfD), targeting the nuclear transcription factor kappa B (NF-κB), reduce alveolar bone resorption during orthodontic tooth movement. The use of these nanoparticles at the extraction site was found to promote bone structure restoration by increasing trabecular bone density and reducing trabecular spacing. Additionally, NF-κB inhibition reduces inflammation and decreases the expression of bone resorption markers, such as tartrate-resistant acid phosphatase, tumor necrosis factor-α, and interleukin-1β, while simultaneously promoting periodontal regeneration by increasing the expression of alkaline phosphatase, transforming growth factor-β1, osteopontin, and fibroblast growth factor-2. As a result, osteoblast activity and osteocalcin levels increase. This therapy can effectively support orthodontic treatment by reducing the risk of unwanted changes in the alveolar bone and improving the stability of orthodontic treatment outcomes.

Polylactic acid is also used in orthodontics as an alternative to traditional materials like polymethyl methacrylate (PMMA). Research conducted by Naveed et al. [35] introduced PLA modified with sesame oil as a material for palatal plates in orthodontic appliances. The use of 3D printing technology allows for precise and reproducible manufacturing of these components, eliminating issues related to inconsistent thickness and structure found in conventional PMMA plates. The addition of sesame oil improves the mechanical properties of PLA, reducing its fragility and moisture absorption, which enhances patient comfort. Tests have shown that PLA has better load resistance and durability in the oral environment compared to conventional materials. Furthermore, PLA is biodegradable, making it more environmentally friendly than PMMA, which does not naturally degrade. Modern technologies, such as 3D printing and material modifications, allow for further improvement of PLA properties, which may contribute to its wider application in orthodontics as an alternative to traditional materials.

Conclusions

Polylactic acid is playing an increasingly significant role in dentistry, with applications in bone and tissue regeneration, prosthodontics, and orthodontics. Its biodegradability and biocompatibility make it a valuable material for the production of membranes supporting tissue regeneration, temporary crowns, and orthodontic appliances. While current studies confirm its effectiveness, further research is needed to enhance its mechanical properties. In the future, with advancements in biomaterial engineering, PLA may play an even greater role in modern dentistry, contributing to the development of more efficient, less invasive, and safer treatment methods.

Disclosure

Authors contribution

Conceptualisation: Wiktoria Musyt

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References

1. Li G, Zhao M, Xu F, Yang B, Li X, Meng X, et al. Synthesis and Biological Application of Polylactic Acid. Molecules. 2020;25(21):5023.

2. Siracusa V, Rocculi P, Romani S, Rosa MD. Biodegradable polymers for food packaging: a review. Trends Food Sci Technol. 2008;19(12):634–43.

3. Singhvi M, Joshi D, Adsul M, Varma A, Gokhale D. D-(−)-Lactic acid production from cellobiose and cellulose by Lactobacillus lactis mutant RM2-24. Green Chem. 2010;(12):1106–9.

4. Bussa M, Eisen A, Zollfrank C, Röder H. Life cycle assessment of microalgae products: State of the art and their potential for the production of polylactid acid. J Clean Prod. 2019;213:1299–312.

5. Singhvi MS, Zinjarde SS, Gokhale DV. Polylactic acid: synthesis and biomedical applications. J Appl Microbiol. 2019;127(6):1612–26.

6. Tan L, Yu X, Wan P, Yang K. Biodegradable Materials for Bone Repairs: A Review. J Mater Sci Technol. 2013;29(6):503–13.

7. John RP, Nampoothiri KM, Pandey A. Fermentative production of lactic acid from biomass: an overview on process developments and future perspectives. Appl Microbiol Biotechnol. 2007;74(3):524–34.

8. Fan Y, Zhou C, Zhu X. Selective Catalysis of Lactic Acid to Produce Commodity Chemicals. Catal Rev. 2009;51(3):293–324.

9. Zhou S, Shanmugam KT, Yomano LP, Grabar TB, Ingram LO. Fermentation of 12% (w/v) glucose to 1.2 M lactate by Escherichia coli strain SZ194 using mineral salts medium. Biotechnol Lett. 2006;28(9):663–70.

10. Datta R, Henry M. Lactic acid: recent advances in products, processes and technologies — a review. J of Chemical Tech & Biotech. 2006;81(7):1119–29.

11. Auras R, Harte B, Selke S. An Overview of Polylactides as Packaging Materials. Macromol Biosci. 2004;4(9):835–64.

12. Tokiwa Y, Calabia BP. Biodegradability and biodegradation of poly(lactide). Appl Microbiol Biotechnol. 2006;72(2):244–51.

13. Singhvi M, Gokhale D. Biomass to biodegradable polymer (PLA). RSC Adv. 2013;3(33):13558.

14. Roseti L, Parisi V, Petretta M, Cavallo C, Desando G, Bartolotti I, et al. Scaffolds for Bone Tissue Engineering: State of the art and new perspectives. Mater Sci Eng C Mater Biol Appl. 2017;78:1246–62.

15. Yan Y, Chen H, Zhang H, Guo C, Yang K, Chen K, et al. Vascularized 3D printed scaffolds for promoting bone regeneration. Biomaterials. 2019;190–191:97–110.

16. Siafaka PI, Barmbalexis P, Bikiaris DN. Novel electrospun nanofibrous matrices prepared from poly(lactic acid)/poly(butylene adipate) blends for controlled release formulations of an anti-rheumatoid agent. Eur J Pharm Sci. 2016;88:12–25.

17. Oerlemans C, Bult W, Bos M, Storm G, Nijsen JFW, Hennink WE. Polymeric micelles in anticancer therapy: targeting, imaging and triggered release. Pharm Res. 2010;27(12):2569–89.

18. Kanno T, Sukegawa S, Furuki Y, Nariai Y, Sekine J. Overview of innovative advances in bioresorbable plate systems for oral and maxillofacial surgery. Jpn Dent Sci Rev. 2018;54(3):127–38.

19. Ormiston JA, Serruys PWS. Bioabsorbable coronary stents. Circ Cardiovasc Interv. 2009;2(3):255–60.

20. Eke PI, Dye BA, Wei L, Slade GD, Thornton-Evans GO, Borgnakke WS, et al. Update on Prevalence of Periodontitis in Adults in the United States: NHANES 2009 to 2012. J Periodontol. 2015;86(5):611–22.

21. Deng Y, Liang Y, Liu X. Biomaterials for Periodontal Regeneration. Dent Clin North Am. 2022;66(4):659–72.

22. Kim J, Amar S. Periodontal disease and systemic conditions: a bidirectional relationship. Odontology. 2006;94(1):10–21.

23. Elgali I, Omar O, Dahlin C, Thomsen P. Guided bone regeneration: materials and biological mechanisms revisited. Eur J Oral Sci. 2017;125(5):315–37.

24. Chang B, Ahuja N, Ma C, Liu X. Injectable scaffolds: Preparation and application in dental and craniofacial regeneration. Mater Sci Eng R Rep. 2017;111:1–26.

25. Bottino MC, Thomas V, Schmidt G, Vohra YK, Chu TMG, Kowolik MJ, et al. Recent advances in the development of GTR/GBR membranes for periodontal regeneration–a materials perspective. Dent Mater. 2012;28(7):703–21.

26. Sam G, Pillai BRM. Evolution of Barrier Membranes in Periodontal Regeneration-"Are the third Generation Membranes really here?". J Clin Diagn Res. 2014;8(12):14–7.

27. Takayama A, Moroi A, Saito Y, Yoshizawa K, Nishida T, Ueki K. Evaluation of Space-Maintaining Sinus Membrane Using the Absorbable Screws in Sinus Lifting Bone Augmentation. Implant Dent. 2019;28(1):28–38.

28. Jang HJ, Kang MS, Kim WH, Jo HJ, Lee SH, Hahm EJ, et al. 3D printed membranes of polylactic acid and graphene oxide for guided bone regeneration. Nanoscale Adv. 2023;5(14):3619–28.

29. Zhang HY, Jiang HB, Ryu JH, Kang H, Kim KM, Kwon JS. Comparing Properties of Variable Pore-Sized 3D-Printed PLA Membrane with Conventional PLA Membrane for Guided Bone/Tissue Regeneration. Materials (Basel). 2019;12(10):1718.

30. Crenn MJ, Rohman G, Fromentin O, Benoit A. Polylactic acid as a biocompatible polymer for three-dimensional printing of interim prosthesis: Mechanical characterization. Dent Mater J. 2022;41(1):110–6.

31. Deng K, Chen H, Zhao Y, Zhou Y, Wang Y, Sun Y. Evaluation of adaptation of the polylactic acid pattern of maxillary complete dentures fabricated by fused deposition modelling technology: A pilot study. PLoS One. 2018;13(8):e0201777.

32. Benli M, Eker-Gümüş B, Kahraman Y, Huck O, Özcan M. Can polylactic acid be a CAD/CAM material for provisional crown restorations in terms of fit and fracture strength? Dent Mater J. 2021;40(3):772–80.

33. Molinero-Mourelle P, Canals S, Gómez-Polo M, Solá-Ruiz MF, Del Río Highsmith J, Viñuela AC. Polylactic Acid as a Material for Three-Dimensional Printing of Provisional Restorations. Int J Prosthodont. 2018;31(4):349–50.

34. Huang ACS, Ishida Y, Hatano-Sato K, Oishi S, Hosomichi J, Usumi-Fujita R, et al. NF-κB Decoy Oligodeoxynucleotide-Loaded Poly Lactic-co-glycolic Acid Nanospheres Facilitate Socket Healing in Orthodontic Tooth Movement. Int J Mol Sci. 2024;25(10):5223.

35. Naveed N, Dutta K, Balamurugan D, Haveri AV, Sabapathy K. Oil-Incorporated Poly(Lactic Acid) as an Alternative Material for Orthodontic Base Plate: A 3D Printing Approach. Tijing LD, editor. Adv Polym Technol. 2022;2022:1–16.