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Nano-PLA Denture Base Composites for Customizing Prosthetic Solutions in Oral Cancer Patients

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Abstract

This review explores the potential of nano-poly lactic acid (nano-PLA) composites in customizing prosthetic solutions for oral cancer patients. Oral cancer often requires surgical resection, radiation therapy, or chemotherapy, which lead to significant oral deformities. Traditional prosthetic materials like polymethyl methacrylate (PMMA) may not fully address the specific needs of these patients. Nano-PLA composites, with their biocompatibility, mechanical strength, and antimicrobial properties, present an innovative solution. This review assesses the material properties of nano-PLA composites, their application in maxillofacial prosthodontics, and their integration with 3D printing technologies for the customization of prosthetic devices in oral cancer rehabilitation.

Keywords: Nano-PLA composites, oral cancer, prosthetic customization, maxillofacial prosthodontics, biocompatibility, 3D printing

Introduction

Oral cancer, one of the most prevalent malignancies worldwide, is associated with high rates of morbidity and mortality. Standard treatments, including surgical resection, radiation therapy, and chemotherapy, often result in significant structural and functional impairments in the oral and maxillofacial region[1]. The rehabilitation of these patients through prosthetic devices is crucial to restore speech, mastication, and aesthetics. Traditional materials such as PMMA have long been used for these prosthetics but present limitations, particularly in complex post-surgical cases.

The emergence of nano-poly lactic acid (nano-PLA) composites offers a promising alternative for prosthetic solutions[2]. Nano-PLA is a biodegradable, biocompatible material that can be enhanced with nanoparticles to improve its mechanical properties and antimicrobial capabilities[3]. Integrating PLA into denture resins enhances biodegradability, mechanical strength, and dimensional stability. Additionally, incorporating ZnO nanofillers into PLA-based resins offers further benefits such as increased antibacterial properties and improved durability against breakage and abrasion. When combined with digital technologies like 3D printing, nano-PLA allows for highly customized prostheses tailored to the unique anatomical changes in oral cancer patients. In terms of the cost of processing as opposing its competitive material, PLA aexhibits extraordinary physio mechanical properties (e.g., high strength, high modulus, good barrier and clarity properties). This makes it a potential candidate, to replace some important petroleum-based polymers such as polystyrene (PS). This review evaluates the current literature on the use of nano-PLA composites in prosthodontics, particularly in the context of oral cancer rehabilitation[4].

Material Properties of Nano-PLA Composites

Biocompatibility

ASTM International Standardization Organization (standard #D-5488-94d) defines 'biodegradable' as 'capable of undergoing decomposition into carbon dioxide, methane, water, inorganic compounds, and biomass5. Biomedical systems can be divided into two groups mainly permanent and temporary. PLA is widely recognized for its biocompatibility, having been used in various medical applications, including drug delivery systems and tissue engineering[6]. The incorporation of nanoparticles (e.g., zinc oxide or titanium dioxide) into PLA enhances its properties, making it more suitable for oral prostheses. Nano-PLA composites are non-toxic, and their degradation products (lactic acid) are naturally metabolized by the body. The primary mechanism by which PLA is degraded inside the body is hydrolysis of the ester-bond backbone, The degradation products can be either monomeric LA or oligomers of LA. The hydrolytic degradation is then further catalysed by the newly-formed carboxylic groups at the terminal ends of the cleaved PLA chains[7,8].This characteristic is particularly important for oral cancer patients, who often have compromised oral tissues due to surgery or radiation therapy. Custom made scaffold design can be produced according to the anatomical data of the specific patient. PLA is one of the most common biodegradable polymers used for 3D scaffold printing. Which can bear an edge of advantage towards rehabilitation in cancer affected individuals. Studies suggest that nano- PLA composites support cell adhesion and proliferation, making them ideal for oral prosthetic applications.

Mechanical Properties

The inclusion of nanoparticles in PLA increases its mechanical strength, toughness, and durability, which are essential for prosthetic devices that undergo constant stress during chewing and speaking. PLA offers a itself as a promising thermoplastic aliphatic polyester with relatively high mechanical strength (flexural strength up to 140 MPa, Young’s modulus 5–10 GPa), with excellent optical properties, good processing ability (with low shrinkage not causing product deformation) and complete biodegradation[9-13]. Currently, various methods of PLA modification are used. Mixing PLA with additives is usually a practical way to improve the properties and cost reduction of this polymer .In the case of powder particles used in medical applications, the most frequently added to the PLA basis are: silver, magnesium, iron and steel, silicon, boron nitrile, hydroxyapatite and more both in the micro and nano-scale [14-18]. Dimensional stability is also critical for denture resins, as conventional acrylic resins often experience size alterations over time, potentially affecting the fit and comfort of dentures. Injection-molding methods and the integration of nanofillers have been explored to address these issues, providing enhanced dimensional precision and stability. Furthermore, researchers have evaluated the mechanical properties of various thermoplastic denture base polymers and found positive outcomes for those reinforced with nanomaterials[19]. Nano-PLA composites have been shown to possess superior tensile strength and flexural modulus compared to conventional materials like PMMA. These enhanced mechanical properties make nano-PLA suitable for maxillofacial prostheses, which must withstand complex biomechanical forces.

Antimicrobial Properties

Oral cancer patients are at an increased risk of oral infections due to the immunosuppressive effects of chemotherapy and radiation therapy. Nano-PLA composites can be engineered to incorporate antimicrobial nanoparticles, such as zinc oxide (ZnO), which have been demonstrated to reduce bacterial colonization on prosthetic surfaces. Zinc oxide nanoparticles (ZnO NPs) attracted more attention due to their multifaceted properties, such as stability, a high surface-to-volume ratio, chemical reactivity, electrical and magnetic properties, non-cytotoxicity, biosafety, and biocompatibility, and are barely prone to bacterial resistance20. This antimicrobial effect is particularly beneficial in preventing infections around the surgical site and maintaining oral hygiene in patients with compromised immune systems. In PLA-based denture resins, ZnO nanoparticles significantly inhibit bacterial growth and prevent biofilm formation by inducing reactive oxygen species (ROS), which damage microbial cell membranes and cause cell death, efficiently targeting pathogens such as Candida albicans and Streptococcus mutans[21,22].The goal of incorporating ZnO nanofillers with PLA is to leverage the advantages of both materials, creating a composite that is strong, durable, and resistant to microbial colonization and biofilm formation.

Integration of Nano-PLA with 3D Printing Technology

3-D printing technologies, such as fused filament fabrication (FFF), stereolithography (SLA), and selective laser sintering (SLS), have been well established for personal, educational and professional uses. In particular, FFF 3D printing attracts tremendous interest for manufacturing thermoplastics due to its low cost, easy-to-use, and large availability[23,24].

Precision in Prosthetic Customization

One of the key advantages of nano-PLA is its compatibility with 3D printing technologies, particularly VAT photopolymerization and fused deposition modeling (FDM). In some studies the results showed that FDM 3D printing can achieve an accuracy of, for example, 0.1128 mm in roundness tolerance, emphasizing that the orientation of the printed part and support material are important factors affecting the geometric accuracy of 3D-printed parts[25]. Within this context, the printed pieces are composed of two characteristic zones: the contour and infill26. Digital impressions and 3D scanning allow for precise customization of prostheses, ensuring an accurate fit that is essential for both function and comfort. For oral cancer patients, whose anatomy may have been significantly altered, this ability to produce personalized prostheses is invaluable.

Nano-PLA's printability also means that intricate designs, such as maxillofacial prostheses for large defects or obturators for patients with palatal defects, can be created with high accuracy. Traditional methods often rely on manual molding, which may not capture the precise anatomy needed for these complex cases.

Cost and Time Efficiency

The use of nano-PLA composites with 3D printing can reduce both the time and cost associated with fabricating prostheses. Conventional methods of producing custom prosthetics are labor-intensive, require multiple adjustments, and can be costly[27]. In contrast, 3D printing offers a more streamlined and cost-effective process, allowing for rapid prototyping and production of prosthetic devices tailored to the specific needs of each oral cancer patient [28].

Clinical Applications in Oral Cancer Rehabilitation

Maxillofacial Prosthetics

Patients who undergo partial or complete maxillectomy, mandibulectomy, or other extensive surgeries often require maxillofacial prostheses to restore both function and appearance. Polylactic acid has been known into multiple biomedical applications due to its biocompatibility and bioresorbability and with the human tissues. Scaffolding, drug delivery, medical implants, suturing, membrane covering, derma, cosmetics, etc., are some of the major fields of biomedical, as depicted in where the role of PLA has been appreciable in the last decade28 .Nano-PLA composites have shown potential in creating robust and lightweight prostheses that can withstand the forces exerted during chewing while providing a natural appearance. Additionally, their biocompatibility ensures that they do not cause irritation or allergic reactions in patients who may already have compromised oral tissues due to cancer treatment.

Dentures and Obturators

For patients with smaller defects or those undergoing palatal resection, nano-PLA-based obturators and dentures offer an effective solution. Traditional denture base materials like PMMA can cause discomfort or ill-fitting prostheses in such patients. Nano-PLA's flexibility and superior fit allow for better retention, patient comfort, and enhanced speech and mastication, leading to improved quality of life for patients recovering from oral cancer[29]

Infection Control

In oral cancer patients, maintaining a clean oral environment is crucial, especially in post-surgical and post-radiation therapy cases. Nano-PLA composites, enhanced with antimicrobial nanoparticles, offer an additional layer of protection against bacterial infections[30-32]. This feature can significantly reduce post-prosthetic complications such as stomatitis and mucositis, which are common in immunocompromised patients.

Future Directions and Challenges

Although nano-PLA composites have demonstrated promising results in preliminary studies, further research is needed to optimize their properties for long-term use in oral cancer rehabilitation. Some areas that necessitate further investigation include:

While nano-PLA composites have shown superior mechanical properties in vitro, their long-term performance in vivo, particularly in high-stress areas such as the oral cavity, needs further exploration.

As a biodegradable material, nano-PLA may degrade over time. Understanding its degradation profile in the oral cavity and how it affects the prosthesis's functional life will be essential. However, in terms of the previous literature, various properties, optical, impact of processing temperature, interfacial energy, environment, and storage (aging) on the properties of PLA have not been fully evaluated yet. Therefore, a lot of work is still to be done to make PLA viable as a permanent, cost-effective, and safe solution for its implementation as a biomaterial in the human body.

While 3D printing offers cost advantages in prosthetic fabrication, widespread adoption of nano-PLA composite prosthetics will depend on making this technology accessible to dental clinics worldwide, particularly in low-resource settings.

Conclusion

Nano-PLA denture base composites represent a significant advancement in the customization of prosthetic solutions for oral cancer patients. Their biocompatibility, enhanced mechanical strength, and antimicrobial properties make them ideal for use in complex maxillofacial prosthetics. Poly lactic acid has been proved to be a versatile polymer, which gives it an added advantage of being tailored into different forms such as nano fiber, micro capsules, nano particles, and hydrogels. By incorporation of various fibers in PLA, a significant improvement in strength can be achieved that in near future can replace metallic material in bone implants. The properties enhancement of PLA by blending it with various copolymers is playing a crucial part in expanding its scope in the biomedical domain (Scaffolding, drug delivery, tissue engineering, medical implants, membranes covering, derma, cosmetics, medical surgeries, and human implants)[33]. When combined with 3D printing, nano-PLA allows for precise customization and cost-effective solutions that improve the quality of life for oral cancer survivors. As research into nano-PLA composites progresses, it is likely that this material will become an integral part of oral cancer rehabilitation protocols, offering patients better prosthetic outcomes and fewer complications.

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