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Original Research Article

Evaluation of degradation and performance of PLA-ZnO reinforced denture resins in artificial saliva for rehabilitation potential in geriatric population – An *in-vitro* study

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Abstract

Background: Enhancing the longevity and functionality of dental prostheses necessitates the development of robust and efficient denture-based polymers to pave itself for gerontology. Recent advancements have focused on incorporating zinc oxide (ZnO) and biodegradable polylactic acid (PLA) nanofillers to improve the properties of these resins under conditions that simulate the oral environment.

Aim: This study aims to evaluate the degradation rate of dental polymers infused with bio-based PLA nanofillers in the presence of artificial saliva, simulating the clinical performance of denture base materials, for rehabilitation potential in geriatric population.

Materials and Methods: Forty denture base resin samples were prepared using 10% polylactic acid (PLA) and 3% zinc oxide (ZnO) nanofillers in accordance with ISO 20795-1:2013 guidelines. The samples were incubated for 37 days at 37 ± 0.5°C and submerged in artificial saliva at pH 7 to replicate oral conditions. Evaluations included light transmittance, pH fluctuation, and dimensional accuracy. Post-incubation, direct microscopy assessed bacterial and fungal development. Statistical analysis was performed using IBM SPSS version 26.0.

Results: Dimensional accuracy tests showed no significant difference between the PLA-ZnO and control groups, with mean dimensional changes of 65.86 and 66.07, respectively ($p = 0.062$). pH measurements before and after incubation indicated no change due to PLA-ZnO nanofillers. The PLA-ZnO group exhibited greater water absorption, with a mean swelling degree of 1.57 compared to 1.43 in the control group ($p = 0.05$). Microbiological analysis showed no bacterial or fungal growth on the samples. Additionally, the PLA-ZnO group demonstrated a significant increase in light transmittance at 540 nm, with a mean intensity of 658.07 compared to 328.20 in the control group ($p = 0.05$).

Conclusion: PLA-ZnO composite resins exhibit enhanced antibacterial properties while maintaining light transmittance. However, they show altered optical characteristics and increased swelling, indicating the need for further optimization.

Keywords: Artificial saliva, Light transmittance, Denture resins, Dimensional accuracy, Mechanical properties, Nanofillers, Polylactic acid, Zinc oxide

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1. Introduction

The utilization of nanomaterials in dentistry has significantly advanced the development and efficacy of dental materials, particularly in enhancing the properties of denture resins. Recent research has focused on reinforcing these resins by incorporating biodegradable polylactic acid (PLA) and zinc oxide (ZnO) nanofillers to improve their mechanical, physicochemical, and antimicrobial characteristics. The incorporation of nanoparticles as biomaterials in dentistry is gaining substantial interest due to their superior performance compared to traditional materials. Nanoparticles like ZnO are noted for their high surface area-to-volume ratio and antimicrobial properties, making them ideal for dental applications. PLA, a biodegradable and biocompatible polymer, has been extensively studied in healthcare and dental fields for its ability to degrade into harmless lactic acid, making it suitable for medical implants and devices.

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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.[1-3]

Artificial saliva, which mimics the natural oral environment, is crucial for in vitro research on dental materials. Studies have shown that synthetic saliva made with mucin can influence the degradation rate and mechanical properties of polymers like polycaprolactone and polylactide.[4] Saliva pH is critical, as variations can significantly affect the durability and lifespan of denture bases. Research indicates that changes in saliva pH can impact the color retention and surface texture of dental resins, highlighting the importance of evaluating these factors when developing and testing new dental products.[5] Recent studies have demonstrated that ZnO nanoparticles can enhance the flexural strength and antimicrobial properties of polymethylmethacrylate (PMMA) denture base resins, adding value to dental materials.[6]

The goal of incorporating ZnO nanofillers with PLA in denture-based resins is to leverage the advantages of both materials, creating a composite that is strong, durable, and resistant to microbial colonization and biofilm formation. 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.[7]

Incorporating PLA and ZnO nanofillers into denture-base resins represents a significant advancement in dental material science. These composites are ideal for modern dental applications due to their improved mechanical properties, antibacterial activity, and biodegradability. In vitro experiments using artificial saliva provide valuable insights into the performance of these materials in environments similar to the oral cavity. The development of nanocomposite dental resins holds promise for improving patient outcomes by enhancing the quality and durability of dental prostheses as research progresses.

The rehabilitation of the geriatric 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.Improving the biocompatibility, and patient comfort of denture base resins remains a major challenge in prosthodontics. New strategies are needed to address issues related to material durability, degradation processes, biofilm formation, and overall advancement in denture base materials to better meet patient needs. Variations in saliva pH, along with the presence of bacteria and fungi, can make polymers susceptible to damage in the oral environment, leading to size alterations. This study aims to simulate the clinical performance of denture base materials by measuring the degradation rate of dental polymers infused with bio-based PLA under the influence of an artificial salivary substitute. The study also evaluates the dimensional accuracy of the materials, changes in saliva substitute pH levels before and after incubation, bacterial and fungal growth before and after saliva exposure, and light transmittance before and after saliva exposure. Limited research exists on using bio-based PLA and zinc oxide nanofillers in PMMA-based denture base materials, providing an opportunity to explore their potential impact in the oral environment for the geriatric population.

2. Materials and Methods

The study was conducted following the approval by Institutional review board of the institute and the sample size was estimated with 80% power was taken to be 40 with 95 % confidence interval as per previously reported studies.

2.1. Sample preparation

A total of 40 denture base resin samples were prepared in accordance with ISO 20795-1:2013 standards. The dimensions of sample were 64 ± 0.001 mm in length, 10 ± 0.01 mm in width, and 2.5 ± 0.01 mm in thickness. The samples consisted of heat-cure polymethyl methacrylate (PMMA) resin infused with 10% polylactic acid (PLA) and 3% zinc oxide (ZnO) nanofillers by weight. Duplication of samples ensured consistency across tests.(**Figure 1**)

2.2. Immersion and incubation

Before testing the samples were immersed in artificial saliva with a neutral pH of 7 and incubated at 37 ± 0.5°C for 37 days to simulate oral condition.

2.3. Dimensional accuracy

The Dimensional accuracy of the samples were estimated by following ISO 62:1999 standards for water sorption, swelling was measured by comparing wet and dry weights. Linear dimensional changes were evaluated using a digital vernier caliper with standard reference points. Salivary pH was measured using a pH meter with a glass electrode, capable of resolving to at least 0.01 pH units. Measurements were taken before and after incubation to detect any pH changes.(**Figure 2**)

2.4. pH variability

The variability in the salivary pH value was determined using a pH meter equipped with a glass electrode, which had a resolution of at least 0.01 pH units. This measurement was

taken both before and after the incubation period to assess any changes in pH.(**Figure 3**)

2.5. Light transmittance

Light transmittance was measured using a UV-vis reflectance spectrophotometer. The samples' color was assessed before and after incubation to detect changes in light transmittance.(**Figure 4**)

2.6. Microbial growth

Direct microscopy, following ICMR guidelines, was used to investigate bacterial and fungal growth on the PLA and PMMA samples after 56 days of incubation in microorganism-containing artificial saliva.(**Figure 5**)

The collected data were analyzed using IBM SPSS version 26.0. One-way ANOVA followed by post hoc Bonferroni tests were used to analyse dimensional accuracy and mechanical properties. Appropriate statistical methods were applied for pH variability and microbial growth analysis. Light transmittance data were analyzed by comparing pre- and post-immersion reflectance spectra.

3. Results

3.1. Dimensional accuracy of the material

The dimensional accuracy of PLA and ZnO nanofiller-reinforced denture base resins was evaluated. The results indicated no significant difference in dimensional changes between the PLA ZnO group and the control group. The PLA ZnO group had a mean dimensional change of 65.86 ± 0.51, while the control group had a mean of 66.07 ± 0.47 (**Table 1**). The p-value of 0.062 suggests that the addition of PLA and ZnO nanofillers did not significantly affect the dimensional stability of the resin.

3.2. pH variability

The pH fluctuation of the samples was assessed before and after incubation in artificial saliva. The investigation showed no significant variation in pH readings between pre- and post-incubation, indicating that the pH remained stable during the testing phase. This stability suggests that the PLA ZnO nanofillers did not alter the salivary pH environment.

3.3. Degree of swelling

A significant difference in the degree of swelling was observed between the PLA ZnO group and the control group. The PLA ZnO group had a mean swelling degree of 1.57 ± 0.45, while the control group had a mean of 1.43 ± 0.45 (**Table 2**). The PLA ZnO nanofiller-reinforced resin absorbed more water than the control group, as indicated by the p-value of 0.05.

3.4. Bacterial and fungal growth pre- and post salivary incubation

The samples were checked for bacterial and fungal growth before and after incubation. The bacterial culture broth showed no turbidity, and the post-incubation KOH mount revealed no evidence of fungal development. These findings suggest that the PLA ZnO composites possess strong antibacterial properties, preventing microbial growth even after prolonged exposure to artificial saliva.

3.5. Light transmittance pre- and post salivary incubation

Light transmittance was measured at a wavelength of 540 nm. There was a statistically significant difference (p-value of 0.05) between the PLA ZnO and control groups, according to an independent sample t-test. The PLA ZnO group had a mean absolute intensity of 658.07 ± 77.40, while the control group had a mean of 328.20 ± 71.80 (**Table 3**). The introduction of nanofillers appeared to improve the optical properties of the resin, potentially enhancing its aesthetic appeal in dental applications, as evidenced by the notable increase in light transmittance for the PLA ZnO group

Table 1: Intergroup comparison on dimensional changes between pre and post salivary incubation

S.No	Groups	Mean	S. D	p Value
1	Pre	66.07	0.47	0.062
2	Post	65.86	0.51	

Table 2: Intergroup comparison on degree of swelling between pre and post salivary incubation

S.No	Group	Mean	S.D	p Value
1	Pre	1.43	0.45	0.05*
2	Post	1.57	0.45	

Table 3: Intergroup light transmittance in the visible electromagnetic spectrum

S.No	Group	Mean	S.D	p Value
1	Pre	328.20	71.80	0.05*
2	Post	658.07	77.40	

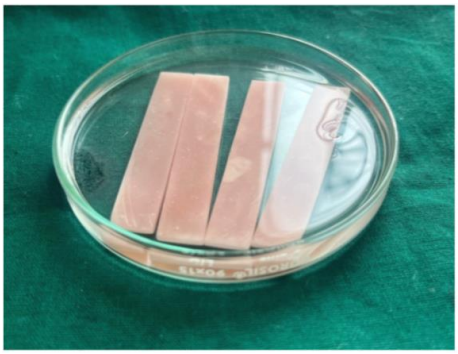

Figure 1: Modified Nanocomposite polymer samples in artificial saliva

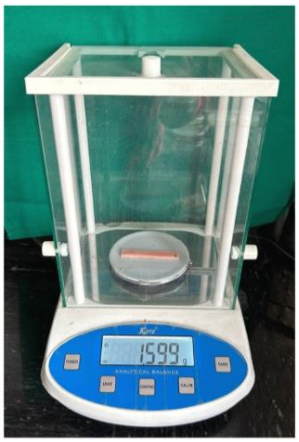

Figure 2: ISO 62:1999- standard for water sorption, dimensional change

Figure 3: Dimensional Change

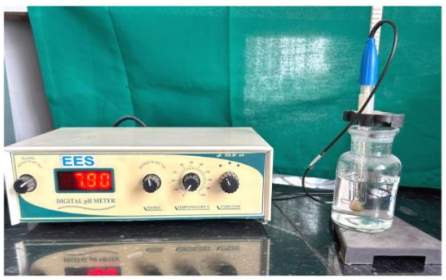

Figure 4: Ph Variability

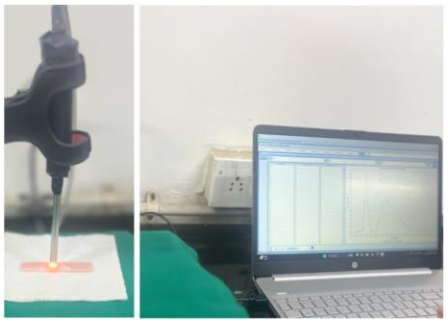

Figure 5: Light spectroscopy analysis

Figure 6: Fungal and bacterial count

4. Discussion

A rising geriatric population remains dentate and requires more dental care to maintain dental health and function. Numerous factors alter healing, host resistance, digestion and absorption, mastication, metabolic competency, renal and hepatic function, and excretory capability. Complex drug regimens further confuse clear diagnoses. Full consideration must be given these factors before treatment plans are formulated. Therefore this research has been done in terms of how well denture resins when added with biodegradable polylactic acid (PLA) and zinc oxide (ZnO) nanofillers perform under oral conditions by using artificial saliva for simulation. The emphasis is on examining how ZnO nanoparticles improve the mechanical strength, light transmittance, and antibacterial properties of the material, while also evaluating the impact of synthetic saliva on PLA degradation. Previous research has demonstrated that saliva composition can impact the degradation rate and mechanical stability of PLA, making artificial saliva essential for testing dental materials that mimic intraoral conditions.[4] This research confirms these results by showing that PLA-ZnO composites display regulated decomposition and sustained effectiveness when in contact with synthetic saliva. ZnO nanoparticles greatly improve the strength and antibacterial qualities of PLA-based polymers. ZnO is recognized for its two-fold function in dental use, offering antibacterial properties and strengthening the structure. Previous studies have demonstrated that ZnO nanoparticles enhance the toughness and longevity of dental products.[8] Likewise, the incorporation of ZnO nanoparticles into PMMA denture bases has led to significant enhancements in flexural strength and longevity.[9] The latest research validates these improvements, as PLA-ZnO composites exhibit better mechanical properties than traditional resins. This research complements earlier studies on epoxy composites and ZrO2-Al2O3 nanoparticles, showing comparable advantages in material performance.[10-13] The enhancements seen in PLA-ZnO mixtures align with these findings, demonstrating the effectiveness of ZnO nanoparticles in strengthening dental resins.[14,15]

This study is corroborated with few previous studies that has investigated different reinforcements for dental materials. The study showed that incorporating PLA-ZnO nanofillers in denture base resins resulted in enhanced mechanical and antibacterial characteristics while maintaining dimensional stability and pH levels. Comparable improvements in material performance have been documented using polyethylene and polypropylene fibers, titania nanotubes, and zirconia reinforcements, leading to enhanced impact strength and mechanical properties of dental resins.[16-19] Furthermore, research on zinc oxide strengthened epoxy composites has emphasized the improved mechanical characteristics of the material.[20] This research study further highlights the effectiveness of ZnO nanoparticles in enhancing dental resins, for the specific geriatric population, supporting the

findings of the current research. The research showed that PLA-ZnO composites retained their size accuracy, had steady pH levels, and improved light transmission. They also showed strong antibacterial abilities, a small decrease in bending strength, and increased swelling after being placed in artificial saliva.

4.1. Degradation behaviour

It is essential to the material's long-term performance that PLA interacts with artificial saliva in a way that shapes its degradation behavior. The effect of artificial oral circumstances on the speed at which PLA breaks down has been examined in earlier research.[21] In artificial saliva, PLA breaks down, but the addition of ZnO nanofillers prevents excessive breakdown and preserves the integrity of the material, according to the current study. This result is consistent with previous studies[22] on the kinetics of polymer breakdown and the time-temperature equivalency of that process. Through exposure to artificial saliva, PLA-ZnO composites are shown in this work to retain superior mechanical characteristics over traditional resins.

4.2. Dimensional accuracy

Ensuring the denture bases have accurate dimensions is essential for proper fit and functionality. Past studies on the impact of water soaking on denture base materials have demonstrated diverse outcomes. Miéssi et al. discovered notable alterations in size, especially in the back part of the palate, suggesting lack of stability in various acrylic resins over time.[23] On the other hand, Duymuş et al. found that different acrylic resins did not experience any noteworthy dimensional alterations while being immersed, indicating a state of stability.[24] Pitt et al. found that water immersion did not noticeably affect the size of denture bases made from poly (lactide), poly (caprolactone), and their copolymers, demonstrating the durability of the materials when exposed to hydrolytic conditions.[25] Goodkind et al. observed contraction in denture bases made with pour and cold-curing methods but observed no notable alterations in dimensional stability after six months submerged in water, suggesting enduring stability.[26] The current study assessed denture base resins reinforced with PLA-ZnO nanofiller, finding no notable difference in dimensional changes compared to the control group. The PLA-ZnO group displayed an average dimensional alteration of 65.86 (SD = 0.51), compared to the control group's average of 66.07 (SD = 0.47), yielding a p-value of 0.062. However, Miéssi et al. have indicated that it is important to keep track of localized dimensional changes, especially in the posterior palatal region. In general, the PLA-ZnO nanofillers uphold their dimensional stability, thus enabling their efficient clinical application.[23]

4.3. pH variability

Variations in pH levels play a crucial role in affecting the deterioration of dental materials in the constantly changing oral conditions. Lyu et al. investigated the breakdown speed of amorphous polylactide and discovered that although the rate showed a change at a certain molecular weight, it was not linked to the pH levels of the test solutions.[22] This means that alterations in pH did not have a significant impact on the rate of degradation or the physical characteristics of the polymer being analyzed. The study evaluated changes in pH of PLA-ZnO nanocomposites pre- and post-incubation in artificial saliva. The findings showed no notable difference in pH values before and after incubation, suggesting that the PLA-ZnO composites retained a consistent pH level during the entire testing period. This indicates that adding ZnO nanofillers does not change the pH of the environment where the materials are used, which helps maintain their stability in the various pH levels of the mouth. The results of the current research align with Lyu et al.'s observation that changes in pH had little effect on the degradation rate of the polymer. This research shows that PLA-ZnO composites have consistent pH performance, confirming that adding nanofillers does not impact pH sensitivity, guaranteeing material longevity in the oral environment. The lack of noticeable pH variations agrees with the steadiness seen in prior studies, enhancing the appropriateness of PLA-ZnO composites for medical uses that require pH stability [22].

4.4. Antimicrobial properties

The current research examined the antimicrobial effects of PLA-ZnO composites, showing no bacterial or fungal proliferation pre or post incubation in synthetic saliva. This shows that the composites have strong antibacterial qualities, stopping bacteria growth despite extended contact with saliva. Lin et al. showed that polyethylenimines (PEIs) and their derivatives have strong antibacterial effects against different bacteria, suggesting that altering the chemical structure can improve antimicrobial effectiveness.[29] In a similar manner, Tiller et al. demonstrated that poly(4-vinyl-N-alkylpyridinium bromide) surfaces were capable of eliminating as much as 94% of Staphylococcus aureus cells upon contact, highlighting the efficacy of polymeric coatings in managing bacteria.[30] The lack of bacteria growth on PLA-ZnO composites in our research confirms that these materials effectively resist bacterial contamination, in line with the strong antimicrobial properties seen in previous studies.

4.5. Light transmittance

Borucinska et al.[31] found a notable decrease in light transmission in PMMA bioreactor tubes over four years due to surface deterioration and build-up of biological residue, specifically impacting the crucial blue light spectrum (400-450 nm) for algae photosynthesis. This emphasizes the negative impact of material deterioration on the passage of light. On the other hand, the current research indicated a notable increase in light transmission at a wavelength of 540 nm in PLA ZnO resin because of incorporating zinc oxide nanoparticles. The mean intensity of the PLA ZnO group was approximately double that of the control group, suggesting improved optical characteristics. While the authors focused

on the negative effects of degradation on light passing through, this study shows how improving material composition can significantly improve light transmission [31]. These results emphasize the importance of preserving material integrity to prevent degradation and the advantages of improving material composition for better light transmission in different uses.

Geriatric dentistry or gerodontics is the delivery of dental care to older adults involving the diagnosis, prevention, and treatment of problems associated with normal ageing and age-related diseases as part of an inter-disciplinary team with other health care professionals. Geriatric health is an ignored and under-explored area worldwide. Oral health reflects overall well-being for the elderly population. Conversely, elderly patients are more predisposed to oral conditions due to age-related systemic diseases and functional changes. Hence, the present study explores the integration of biodegradable PLA and ZnO nanofillers in denture base resins to enhance mechanical properties, biocompatibility, and antimicrobial activity. Findings indicate that PLA-ZnO composites improve light transmission, inhibit microbial growth, and maintain dimensional stability and pH levels, showing promise for dental applications. However, challenges include PLA's natural fragility, potential toxicity of ZnO nanoparticles, and difficulty achieving moisture resistance. Artificial saliva, while useful, may not fully replicate the natural oral environment or long-term effectiveness. Future research should focus on varying ZnO nanofiller levels and assessing the long-term clinical impacts of PLA-ZnO composites to optimize their use in dental prosthetics.

5. Conclusion

The addition of polylactic acid with zinc oxide nanofillers to the denture base acrylic resin observed minimal water adsorption, minimal effect of ph fluctutation and notable enhancement in antimicrobial and anti-fungal properties of the polymer. However In terms of of the optical characterization ad degree of swelling, further material optimization is necessary for future validation of the refdefined polymer composite, in its long term use.

6. Source of Funding

None.

7. Conflict of Interest

None.

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