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A Detailed Comparative Evaluation to Assess Poly (Lactic-Co-Glycolic) Acid (PLGA) With/Without Incorporation of Silver Nanoparticles (AgNPs) Into Implant, While Analysing Their Effectiveness in Adjacent Periodontal Repair, Utilising Scanning Electron Microscopy (SEM) to Compare Structural Integrity and Periodontal Response: An Original Research Study

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Abstract: ***Aim:*** This study aims to evaluatepoly (lactic-co-glycolic) acid (PLGA) with/without incorporation of silver nanoparticles (AgNPs) into an implant while analysing their effectiveness in adjacent periodontal repair, utilising scanning electron microscopy (SEM) to compare structural integrity and periodontal response. ***Materials and Methods***: This study involved 40 healthy patients aged 25 to 50 with a missing mandibular first molar, who faced chewing difficulties and aesthetic issues. Participants, meeting inclusion criteria of having an edentulous space and intact occlusion, underwent clinical examinations and cone-beam computed tomography (CBCT) to confirm anatomical suitability. After local anaesthesia, dental implants were placed into the cortical bone. Two months later, healing abutments were attached, followed by final crowns three months post-surgery. The implants were coated with either poly(lactic-co-glycolic) acid (PLGA) or PLGA with silver nanoparticles (AgNPs), aiming to assess the coatings' effects on periodontal response and implant integrity. Scanning electron microscopy (SEM) evaluated the antibacterial properties and biocompatibility across three implant sections: coronal, middle, and apex. ***Statistical Analysis and Results:*** This study involved 40 patients aged 25 to 50, including 23 males and 17 females, who were missing their mandibular first molars. Participants were divided into two groups of 20. Group 1 received poly (lactic-co-glycolic acid) (PLGA) coated implants, while Group 2 received PLGA implants with silver nanoparticles (AgNPs). Using advanced scanning electron microscopy (SEM) for evaluation, the results showed that Group 1 had significant antibacterial activity (coronal: 2.05 ± 0.5, middle: 2.11 ± 0.7, apical: 2.25 ± 0.8) and good structural integrity (coronal: 2.09 ± 0.6, middle: 2.12 ± 0.9, apical: 2.33 ± 0.7), as well as healthy biocompatibility (coronal: 2.12 ± 0.5, middle: 2.22 ± 0.7, apical: 2.45 ± 0.9). In contrast, Group 2's implants exhibited superior antibacterial properties (coronal: 3.46 ± 0.4, middle: 3.56 ± 0.2, apical: 3.75 ± 0.1), better structural measurements (coronal: 3.35 ± 0.6, middle: 3.65 ± 0.5, apical: 3.87 ± 0.3), and promising biocompatibility (coronal: 3.45 ± 0.2, middle: 3.54 ± 0.4, apical: 3.98 ± 0.7). Overall, findings presented in results highlighted the performance differences between implant coatings for future clinical applications.

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Conclusion: This study concluded that PLGA combined with AgNPs outperformed PLGA alone, which had rapid degradation and mass loss, risking early titanium exposure. AgNPs enhanced the coating's tensile strength and significantly reduced biofilm formation compared to uncoated or PLGA-only implants.

Keywords: Poly (Lactic-Co-Glycolic) Acid (PLGA), Silver Nanoparticles (AgNP), Scanning Electron Microscopy (SEM), Dental Implant

INTRODUCTION

Dental implants represent a remarkable advancement in dental restoration, consisting of titanium posts that are meticulously surgically inserted into the jawbone. These implants serve as reliable and stable artificial roots designed for both permanent and removable replacement teeth, including crowns, bridges, or dentures. What sets dental implants apart is their ability to provide a durable and aesthetically pleasing solution, effectively mimicking the look and function of natural teeth.[1,2] Furthermore, their integration into the jawbone helps prevent bone loss a common consequence of tooth loss and, with appropriate care and maintenance, they can last a lifetime, representing a long-term investment in oral health. Poly(lactic-co-glycolic acid) (PLGA) is a groundbreaking biodegradable and biocompatible copolymer that has gained significant recognition and acceptance within the field of biomedical applications, primarily due to its proven safety profile and remarkable efficacy.[3,4] This innovative material, sanctioned by the FDA, is employed across a multitude of applications, including sophisticated controlled drug delivery systems, supportive tissue engineering scaffolds, and bio-absorbable medical devices designed for optimal healing and patient safety. What sets PLGA apart is its ability to degrade into harmless by products namely, lactic and glycolic acids over time.[5,6] This degradation process can be finely tuned based on the specific molecular composition of the PLGA, allowing for a versatile material that can be customized for various medical requirements. Such adaptability positions PLGA as a premier option for a wide array of clinical applications, enabling the development of tailored solutions that effectively address specific patient needs.[7,8] On the other hand, silver nanoparticles (AgNPs) are minuscule, nano-sized particles of silver, typically ranging from just 1 nanometer to 100 nanometers. These tiny particles are acclaimed for their exceptional antimicrobial properties, as well as their unique optical and electrical characteristics. Their effectiveness in inhibiting the growth of a broad spectrum of microorganisms makes them invaluable in many sectors, including the development of advanced medical devices, efficient wound dressings, and even various consumer products.[9] AgNPs can be synthesized using a variety of methods, including physical and chemical approaches, along with the increasingly favoured "green" biological techniques, each of which presents distinct advantages that cater to different practical needs. A particularly promising application of silver nanoparticles is the incorporation of AgNPs into the surface coatings of dental implants made with PLGA. This cutting-edge strategy aims primarily to combat peri-implantitis, a significant and often challenging infection that affects the delicate tissues surrounding dental implants. By delivering a potent and sustained antibacterial effect, this approach not only plays a crucial role in preventing infections but also enhances osseointegration, the essential process through which bone effectively bonds with the implant.[10] This bond ensures stability and longevity, ultimately contributing to the overall success and durability of dental implants in patients. Scanning Electron Microscopy (SEM) is a sophisticated imaging technique that uses a focused electron beam to scan sample surfaces, yielding exceptionally detailed three-dimensional images of morphology, topography, and composition, even at high magnifications. Operating in a high vacuum environment, SEM employs electromagnetic lenses to precisely focus the electrons, making it an essential tool in fields such as nanotechnology, materials science, and biology. This high-resolution imaging capability allows researchers to explore and analyse materials at a microscopic level, revealing insights that are crucial for advancing scientific understanding and technological innovation.[11,12] This study aims to evaluate poly (lactic-co-glycolic) acid

(PLGA) with/without incorporation of silver nanoparticles (AgNPs) into an implant while analysing their effectiveness in adjacent periodontal repair, utilising scanning electron microscopy (SEM) to compare structural integrity and periodontal response.

Materials and Methods

This study involved a total of 40 patients who presented with a missing right mandibular first molar, experiencing a range of complications, including difficulties in chewing, poor aesthetics, food impaction, shifting or tipping of adjacent teeth, and a desire for replacement. The clinical examination confirmed that all participants, both male and female, fell within the age range of 25 to 50 years and desired dental implant placement along with an implant-supported prosthesis. The inclusion criteria for the study were stringent, requiring: the presence of an edentulous space in the mandibular first molar region, unilateral missing mandibular first molar, either an intact occlusion or the presence of the opposing maxillary first molar, and systemically healthy patients without debilitating illnesses such as diabetes or leukaemia. Additionally, informed written consent was obtained from all participants. Conversely, patients who met the exclusion criteria were those who were systemically compromised (e.g., those with uncontrolled diabetes, HIV, or periodontal disease), had generalised periodontal disease or severe bone loss, exhibited poor oral hygiene, suffered from bruxism or temporomandibular joint (TMJ) disorders, or provided poor-quality panoramic radiographs. After securing consent, each patient underwent an extensive clinical examination supplemented by cone-beam computed tomography (CBCT) scans. This advanced imaging technique was instrumental in assessing the anatomical suitability of the implant placement site and in meticulously planning the surgical approach. To ensure optimal hygiene standards were upheld throughout the procedure, each patient performed an oral rinse with chlorhexidine, an antiseptic solution effective in reducing microbial load in the oral cavity. Following this, local anaesthesia was administered via an inferior alveolar nerve block, effectively ensuring comfort and minimizing any discomfort during the surgical intervention. A precise incision was made using a 15-blade scalpel, allowing for the gentle elevation of a mucoperiosteal flap. The dental implant was then cautiously positioned into the cortical bone. After the implant was placed, the mucoperiosteal flap was repositioned, and sutures were carefully applied to promote optimal healing conditions. Approximately two months post-surgery, patients returned for a scheduled follow-up appointment during which a healing abutment was attached to the osseointegrated implant. This step was crucial for supporting tissue maturation and preparing for the eventual placement of the prosthetic crown. Three months following the surgical intervention, patients received their final prosthetic crowns, which were securely anchored by the fully integrated implants. During the implant placement, the implants were coated with poly (lactic-co-glycolic) acid (PLGA) combined with silver nanoparticles. Following the coating process, the implants were air-dried to ensure proper adherence of the coating. This study consisted of 40 patients with missing mandibular first molars, divided into two groups. Group 1 included 20 patients who received dental implants coated solely with PLGA, which were subsequently evaluated using scanning electron microscopy (SEM) and analysed statistically. Group 2 comprised 20 patients whose implants were coated with a mixture of PLGA and silver nanoparticles (AgNPs), also evaluated by SEM and statistically analysing, antibacterial property (AgNPs may affect the smoothness of the surface), structural integrity, and biocompatibility properties. All these properties were determined from the neck of the implants to the apex in three portions: coronal, middle, and apex. The overarching of this study was to assess the effectiveness of poly (lactic-co-glycolic) acid (PLGA) with and without the incorporation of silver nanoparticles (AgNPs) into dental implants, focusing on their impact on adjacent periodontal repair while employing scanning electron microscopy (SEM) to compare structural integrity and periodontal response.

Statistical Analysis

In this research, we performed all statistical analyses utilising the SPSS version 31.0 software. This powerful tool allowed us to effectively manage and interpret our data, ensuring robust outcomes for our study. To evaluate the importance of our results, we utilised the chi-square test, which efficiently analyses discrepancies in proportions among different groups. This approach allowed us to systematically compare categorical data and accurately represent patterns within the dataset.

RESULTS

This study focused on a carefully selected cohort of 40 patients, all aged between 25 and 50 years, who were specifically missing their mandibular first molars. The demographic details indicate a balanced distribution of gender among the participants: 23 males and 17 females, which is thoroughly illustrated in Table 1. In this table, a comprehensive statistical breakdown by age and gender is presented to provide insights into the cohort's characteristics. To investigate the effects of different implant coatings, the participants were systematically divided into two distinct groups, each comprising 20 patients. Group 1 was administered dental implants coated exclusively with poly(lactic-co-glycolic acid) (PLGA). The evaluation of these implants involved advanced scanning electron microscopy (SEM), followed by rigorous statistical analyses to quantify the findings. In contrast, Group 2 comprised patients whose implants were coated with both PLGA and silver nanoparticles (AgNPs). This group also underwent thorough SEM evaluations and statistical investigations to compare their outcomes with those of Group 1. The distribution of patients and specifics of the procedures are detailed in Table 2, focusing on the 20 patients in Group 1 who received PLGA-coated implants, specifically targeting those patients missing their right mandibular first molar. The study placed significant emphasis on the antibacterial properties of the implants in Group 1, assessed through SEM. The statistical significance of these findings was established using the Pearson Chi-Square test. Results indicated notable antibacterial activity across varying sections of the implants: coronal (2.05 ± 0.5), middle (2.11 ± 0.7), and apical (2.25 ± 0.8). Moving on to Table 3, a detailed structural integrity analysis of the implants in Group 1 was conducted, providing further insights into the mechanical properties of the implants post-SEM evaluations. The recorded values reflected consistent structural integrity: coronal (2.09 ± 0.6), middle (2.12 ± 0.9), and apical (2.33 ± 0.7), once again verified through the Pearson Chi-Square test. Furthermore, the study explored the biocompatibility properties of the PLGA-coated implants in Group 1, as illustrated in Table 4. Statistical analysis revealed encouraging results for the coronal (2.12 ± 0.5), middle (2.22 ± 0.7), and apical (2.45 ± 0.9) sections, indicating a favourable interaction with surrounding biological tissues. The examination of Group 2, outlined in Table 5, focused on the 20 patients who received implants coated with a mixture of PLGA and silver nanoparticles. Using SEM, the antibacterial properties were rigorously evaluated, and the results showed significantly improved antibacterial activity: coronal (3.46 ± 0.4), middle (3.56 ± 0.2), and apical (3.75 ± 0.1). In continuation, Table 6 presents the structural integrity findings for Group 2, showcasing measurements obtained via SEM analysis. The structural results included coronal measurements of 3.35 ± 0.6, a middle measurement of 3.65 ± 0.5, and apical readings averaging 3.87 ± 0.3, further demonstrating the potentially enhanced mechanical properties of the implants in this group. Finally, the biocompatibility of the implants in Group 2 was assessed, with results presented in Table 7. SEM evaluations yielded promising figures: coronal (3.45 ± 0.2), middle (3.54 ± 0.4), and apical (3.98 ± 0.7), indicating a highly favorable interaction with host tissues. To encapsulate the findings succinctly, Table 8 provides a comprehensive statistical analysis across all studied groups, utilizing one-way ANOVA to portray a broader overview of the findings related to the varied implant coatings and their respective outcomes. This thorough analysis aims to enhance understanding of the performance differences between the two implant coatings, informing future clinical applications.

Table 1: Age & gender based statistical description of contributing patients

Age Group (Yrs)	Male	Female	Total	P value
25-30	5	3	8	0.04
31-35	4	4	8	0.50
36-40	3	4	8	0.02*
41-45	4	2	6	0.80
46-50	7	3	11	0.50
Total	23	17	40	*Significant
*p<0.05 significant				

Graph 1: Patients demographic distribution and associated details

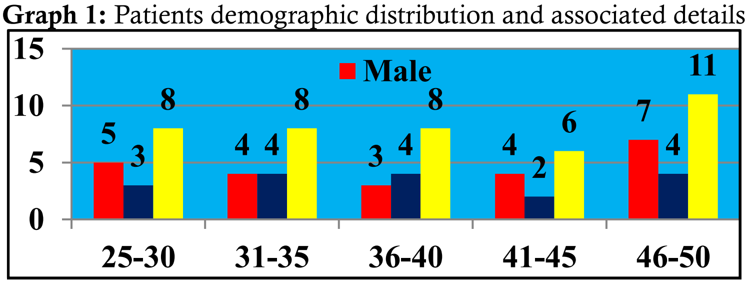

Table 2: Group 1 (N=20) Patients with a missing right mandibular first molar underwent implantation with devices coated solely in PLGA. These implants were subsequently evaluated using scanning electron microscopy (SEM), and the antibacterial properties were statistically analysed. The Pearson Chi-Square test was employed to assess the significance of the results

Division	Stat. Mean	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Coronal	2.05±0.5	0.78	0.13	0.98	1.095	1.0	0.02*
Middle	2.11±0.7	1.57	0.72	0.030	1.045	1.0	0.06
Apical	2.25±0.8	1.89	0.020	0.024	1.80	1.0	0.07
*p<0.05 significant							

Table 3: Group 1 (N=20) Patients with a missing right mandibular first molar underwent implantation with devices coated solely in PLGA. These implants were subsequently evaluated using scanning electron microscopy (SEM), and the structural integrity was statistically analysed. The Pearson Chi-Square test was employed to assess the significance of the results

Division	Stat. Mean	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Coronal	2.09±0.6	0.783	0.123	0.45	1.08	1.0	0.05
Middle	2.12±0.9	1.089	0.017	0.050	1.46	1.0	0.05
Apical	2.33±0.7	1.042	0.067	0.032	1.47	1.0	0.03*
*p<0.05 significant							

Table 4: Group 1 (N=20) Patients with a missing right mandibular first molar underwent implantation with devices coated solely in PLGA. These implants were subsequently evaluated using scanning electron microscopy (SEM), and the biocompatible properties were statistically analysed. The Pearson Chi-Square test was employed to assess the significance of the results

Division	Stat. Mean	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Coronal	2.12±0.5	1.672	1.452	1.97	1.28	1.0	0.80
Middle	2.22±0.7	1.821	1.532	1.65	1.45	1.0	0.02*
Apical	2.45±0.9	1.783	1.721	1.21	1.46	1.0	0.56
*p<0.05 significant							

Table 5: Group 2 (N=20) Patients with a missing right mandibular first molar underwent implantation with devices coated solely mixture of PLGA and silver nanoparticles (AgNPs), also evaluated by SEM and statistically. These implants were subsequently evaluated using scanning electron microscopy (SEM), and the antibacterial properties were statistically analyzed. The Pearson Chi-Square test was employed to assess the significance of the results

Division	Stat. Mean	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Coronal	3.46±0.4	1.696	1.029	1.034	1.078	1.0	0.06
Middle	3.56±0.2	1.826	1.027	1.037	1.098	1.0	0.14
Apical	3.75±0.1	1.915	1.030	1.047	1.12	2.0	0.43
*p<0.05 significant							

Table 6: Group 2 (N=20) Patients with a missing right mandibular first molar underwent implantation with devices coated solely with a mixture of PLGA and silver nanoparticles (AgNPs), also evaluated by SEM and statistically. These implants were subsequently evaluated using scanning electron microscopy (SEM), and the structural integrity was statistically analysed. The Pearson Chi-Square test was employed to assess the significance of the results

Division	Stat. Mean	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Coronal	3.35±0.6	1.754	1.026	1.063	1.046	1.0	0.07
Middle	3.65±0.5	1.822	1.067	1.087	1.076	1.0	0.15
Apical	3.87±0.3	1.817	1.020	1.089	1.042	2.0	0.41
*p<0.05 significant							

Table 7: Group 2 (N=20) Patients with a missing right mandibular first molar underwent implantation with devices coated solely with a mixture of PLGA and silver nanoparticles (AgNPs), also evaluated by SEM and statistically. These implants were subsequently evaluated using scanning electron microscopy (SEM), and the biocompatible properties were statistically analyses. The Pearson Chi-Square test was employed to assess the significance of the results

Division	Stat. Mean	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Coronal	3.45±0.2	1.732	1.025	1.076	1.023	1.0	0.06
Middle	3.54±0.4	1.919	1.026	1.038	1.017	1.0	0.14
Apical	3.98±0.7	1.715	1.019	1.025	1.016	2.0	0.70
*p<0.05 significant							

Table 8: Estimation amongst all studied groups using one-way ANOVA

Variables	Degree of Freedom	Sum of Squares ∑	Mean Sum of Squares m∑	F	Level of Sig. (p)
Between Groups	7	2.672	2.782	1.6	0.01*
Within Groups	56	3.562	2.673	_	
Cumulative	361.24	24.673	*p<0.05 significant		

DISCUSSION

Kwok V et al reviewed in their study that a dental implant is a sophisticated, permanent solution surgically inserted into the jawbone to serve as an artificial tooth root. This implant acts as a foundation for various types of replacement teeth, including crowns, bridges, and dentures. One of the key advantages of dental implants is the process of osseointegration, where the implant fuses with the surrounding bone, providing a stability that closely mimics the feel and function of natural teeth. This integration not only enhances comfort for the patient but also contributes to long-term success rates of the implant.13,14 Kumar L et al showed in their study that PLGA, or poly(lactic-co-glycolic acid), is a notable biodegradable copolymer synthesized from lactic and glycolic acids. One of PLGA's distinctive features is its customizable degradation rate, which can be fine-tuned by varying the ratio of polylactic acid (PLA) to polyglycolic acid (PGA). This property makes PLGA ideal for a myriad of applications in the medical field, particularly in drug delivery systems and tissue engineering, owing to its excellent biocompatibility.15,16 Hadrup N et al showed in their study that the Food and Drug Administration (FDA) has approved PLGA for inclusion in various medical devices, and it can be manufactured into several forms such as microspheres, films, and scaffolds, enhancing its versatility in biomedical applications. Silver nanoparticles (AgNPs) are particularly noteworthy due to their remarkable antimicrobial properties, which have proven advantageous in diverse applications, including wound dressings and targeted drug delivery. AgNPs possess unique optical characteristics and an impressive high surface-to-volume ratio, which contribute to their efficacy in combating bacteria. They can be synthesized through various methods, including chemical reduction and more environmentally friendly approaches using plant extracts. Despite their benefits, concerns linger regarding the potential toxicity of silver nanoparticles and their environmental implications. Integrating silver nanoparticles into a PLGA polymer matrix presents a promising advancement for dental implants.17,18 Fernandez CC et al included in their study that the antibacterial properties of AgNPs are especially effective against oral pathogens such as Streptococcus mutans and Porphyromonas gingivalis, which are known to contribute to biofilm formation and subsequent implant failure. However, managing the rapid release of silver ions remains a challenge. Embedding AgNPs within the PLGA matrix allows for a controlled release mechanism, enhancing their antimicrobial effectiveness while minimising the risk of toxicity.19,20 Joseph et al included in their study that this method supports osteoblast proliferation, crucial for osseointegration between implants and jawbone. Encapsulating silver nanoparticles in biodegradable PLGA addresses cytotoxicity concerns while maintaining antimicrobial action. Modifying PLGA's hydrophobic properties can enhance tissue cell affinity and integration. Innovative strategies, like PLGA-coated Ag-Fe3O4 nanoparticles, help mitigate silver leakage through magnetic anchoring, and 3D-printed scaffolds allow for controlled silver release.21,22 Takamizawa T et al reviwed in their study that hybrid coatings combining silver with bioactive agents like zinc oxide can enhance antimicrobial activity and biocompatibility. However, finding the optimal silver concentration for efficacy and safety remains challenging. Further studies are needed to ensure the long-term stability and functionality of these coatings. Scanning electron microscopy (SEM) offers detailed imaging for material characterization, while energy-dispersive X-ray spectroscopy (EDS) aids in understanding sample composition. Despite its strengths, SEM has limitations with non-conductive or wet samples, requiring alternative imaging techniques for comprehensive analysis.23

Conclusion

Within the limitations of the study, the authors examined poly (lactic-co-glycolic) acid (PLGA) with and without the incorporation of silver nanoparticles (AgNPs) in an implant. They analyzed the effectiveness of these materials in adjacent periodontal repair by utilizing scanning electron microscopy (SEM) to compare structural integrity and periodontal response. The results indicated and concluded that PLGA with AgNPs performs better than PLGA without AgNPs. PLGA alone tends to show rapid degradation and mass loss, which can lead to the earlier exposure of the titanium surface. In contrast, PLGA combined with AgNPs benefits from the presence of AgNPs as structural reinforcing agents, potentially improving the tensile strength of the coating and maintaining its integrity for a longer period. Furthermore, AgNPs significantly reduce biofilm formation on the surface compared to uncoated or PLGA-only implants.

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