



Comparative Assessment of Primary Stability and Surface Topography of 3 Different Antimicrobial Implant Surface Coatings by Radio Frequency Analysis (RFA) And Energy Dispersive X-Ray Spectroscopy (EDS)– An in Vivo Original Research Study

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KEYWORDS

Energy Dispersive X-ray Spectroscopy (EDS), radio frequency analysis (RFA), Surface Topography

ABSTRACT:

Aim: This study aims to assess the primary stability and surface topography of 3 different antimicrobial implant surface coatings by radio frequency analysis and Energy Dispersive X-ray Spectroscopy.

Materials and Methods: This study involved 60 patients, seeking replacement for a missing mandibular first molar. Participants were divided into three groups, each receiving a different antimicrobial-coated implant: silver nanoparticles (Group 1), GL13K (Group 2), and copper alloys (Luminore, Group 3). Following informed consent and a chlorhexidine rinse, a single operator performed the procedure, which included implant placement and suturing. Implant stability was measured using radiofrequency analysis (ISQ), and surface topography was analyzed with Energy Dispersive X-ray Spectroscopy, alongside operator feedback to improve treatment understanding.

Statistical Analysis and Results: This study involved 60 patients split into three groups for implant placement. Group 1 (20 patients) received nanoComposix, coated implants Group 2 had GL13K antimicrobial-treated implants, and Group 3 received Luminore-coated implants. Participants, aged 25 to 50, included 32 males and 28 females. Radiofrequency analysis (RFA) showed Group 1 had the highest Implant Stability Quotient (ISQ) of 84 ± 6 , followed by Group 2 at 68 ± 5 , and Group 3 at 50 ± 5 . Energy Dispersive X-ray Spectroscopy (EDS) indicated negligible aluminum and magnesium in Group 1, moderate in Group 2, and a wider variety of elements in Group 3.

Conclusion: Nanocomposite-coated implants showed better antibiotic activity. GL13K antimicrobial peptides effectively addressed microbial threats, while copper alloys provided limited protection. EDS analysis indicated lower levels of aluminum, magnesium, nitrogen, and sulfur in coated implants, associated with peri-implantitis. Long-term studies are planned to confirm these results.



Introduction

Dental implants have significantly transformed the restoration process for individuals who are completely or partially toothless, demonstrating high survival rates for both single and multiple tooth replacements.¹ These implants facilitate the replacement of a missing tooth without affecting the adjacent healthy teeth and allow for fixed restorations in individuals who are missing some or all of their teeth.² Nonetheless, certain implants may encounter complications, such as failure within six months, irreversible bone loss, and deformities.³ A common reason for implant failure is peri-implantitis, a pathological condition associated with plaque accumulation that causes inflammation in the surrounding tissue and leads to gradual bone loss.^{4,5} This condition is frequently linked with increased bacterial populations, especially species like *Porphyromonas gingivalis* and *Tannerella forsythia*.⁶⁻⁸ To effectively combat peri-implantitis, an inflammatory condition that can arise around dental implants, the development of antimicrobial-coated implants has emerged as a promising solution. These innovative implants are engineered to inhibit bacterial adhesion and growth on their surfaces, which plays a crucial role in enhancing their longevity and functionality over time.⁹ Various antimicrobial strategies have been explored, including the incorporation of silver nanoparticles known for their potent antibacterial properties, the use of antimicrobial peptides that disrupt bacterial membranes, and the application of copper coatings that prevent microbial colonization.^{10,11} The stability of dental implants is of paramount importance for their success, as it ensures proper integration with the surrounding bone. A multitude of biological factors, including bone density and quality, influence primary stability. Advanced methodologies, such as radiofrequency analysis (RFA), serve as valuable tools in evaluating the stability quotient of implants, providing insights into their immediate stability and predicting long-term outcomes.¹² Furthermore, the incorporation of Energy Dispersive X-ray (EDX) spectroscopy offers significant advantages in the realm of drug delivery systems, particularly for the assessment of nanoparticles. This analytical technique allows for precise identification and characterization of nanoparticles designed to enhance the effectiveness of therapeutic agents, paving the way for improved treatment modalities in the field of implantology.¹³ This

study concentrates on assessing primary stability and surface characteristics of three unique antimicrobial implant surface coatings through the use of RFA and EDX techniques.

Materials and Methods

This study involved a cohort of 60 patients who want replacement of a missing mandibular first molar. Out of a total of 100 patients who met this criterion, 60 expressed their willingness to proceed with implant placement and receive prostheses supported by implants designed with antimicrobial coatings. The participants were aged between 25 and 50 years and included both males and females, reflecting a diverse demographic. The patients were methodically divided into three distinct groups, each receiving a different type of implant coating. Group 1 included 20 patients who were treated with implants coated in silver nanoparticles (referred to as nanocompox). Group 2 also consisted of 20 patients but received implants coated with the GL13K antimicrobial agent. Meanwhile, Group 3 comprised another 20 patients whose implants were finished with copper-containing alloys known as Luminore. Before any procedures commenced, informed consent was obtained from each patient, ensuring that they understood the risks and benefits associated with the treatment. Inclusion criteria included with a clear absence of a mandibular first molar and could not have any systemic diseases that could contraindicate the procedure. Prior to the placement of the implants, all patients underwent a preoperative rinse with chlorhexidine mouthwash to reduce the risk of infection. The surgical approach began with an incision into the gum tissue, allowing for the reflection of a mucoperiosteal flap. Following this, the antimicrobial-coated implants were precisely inserted into the bony structure of the jaw, accompanied by a cover screw to aid in healing. Once the implants were securely placed, the mucoperiosteal flap was repositioned over the site, and sutures were carefully applied to promote optimal recovery. The entire implant placement procedure was conducted by a single operator using the same implant kit and system for consistency. After the implants were positioned, their stability was evaluated using advanced radiofrequency analysis (Osstell). The primary stability was evaluated in all the three regions coronal, middle, and apical. This involved measuring the implant stability quotient (ISQ),



a value that ranges from 1 to 100. An ISQ value lower than 45 indicates low stability, while a value exceeding 65 signifies high stability. Additionally, the surface topography of all implants across the three groups was analyzed using Energy Dispersive X-ray Spectroscopy, which complemented the stability assessments and provided insights into the effectiveness of the various coatings. The response from the operators regarding the procedure and outcomes was also gathered to enhance the understanding of the treatment's efficacy.

Statistical Analysis and Results

This study utilized SPSS software for thorough data evaluation, uncovering various patient characteristics and treatment variables. The findings included means and standard deviations to summarize data and numerical values to illustrate proportions. To assess statistical significance, the chi-square test was employed, allowing for meaningful comparisons of categorical data across groups

Results

This study consists of 60 patients who were having missing mandibular first molars. The participants were categorized into three distinct groups for the purpose of implant placement. Group 1 consisted of 20 patients who received dental implants coated with silver nanoparticles, sourced from nano Compositex, known for their potential antibacterial properties. Group 2 included another 20 patients whose implants were treated with the GL13K antimicrobial agent, designed to enhance the bioactivity and safety of the implants. Finally, Group 3 was made up of 20 patients with implants coated in Luminore, a material recognized for its innovative surface technology. The age of the participants in the study ranged from 25 to 50 years, encompassing a diverse demographic that included 32 males and 28

females, providing a balanced representation for the research. The assessment of primary stability was conducted through radiofrequency analysis (RFA) at three specific regions: coronal, middle, and apical. Notably, Group 1 demonstrated the highest level of stability in the apical region, achieving an impressive Implant Stability Quotient (ISQ) of 84 ± 6 . In evaluating the groups, it was found that 12 patients in Group 1 reported satisfactory responses, while Group 2, which had an ISQ of 68 ± 5 , showed satisfactory responses from 9 patients. Group 3, on the other hand, had 8 patients reporting satisfactory outcomes, with a significantly lower ISQ of 50 ± 5 . To gain deeper insights into the coatings utilized in the implants, we employed Energy Dispersive X-ray Spectroscopy (EDS) to conduct a thorough elemental analysis. The findings from this analysis were quite revealing. Group 1 displayed only negligible amounts of aluminum (Al) and magnesium (Mg), suggesting a highly refined and targeted composition in their coatings. In contrast, Group 2 showed moderate concentrations of both aluminum and magnesium, indicating a different approach in their material formulation. Interestingly, Group 3 showcased a significantly wider spectrum of elements, including not only the expected constituents but also nitrogen (N) and sulfur (S). This diversity underscores the range of coating materials deployed across the different groups, suggesting various functional properties or enhancements. To systematically analyze the differences among these groups, we employed one-way ANOVA, a statistical method that facilitated a comprehensive comparison of the results. Through this method, we were able to derive meaningful insights into the varying compositions and their potential implications for the performance of the implants

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

Age Group (Yrs)	Male	Female	Total	P value
25-30	12	4	16	0.01*
31-35	6	5	11	0.30
36-40	5	10	15	0.50
41-45	5	5	10	0.80
46-50	4	4	8	0.40
Total	32	28	60	*Significant

*p<0.05 significant



Graph 1: Patients demographic distribution and associated details

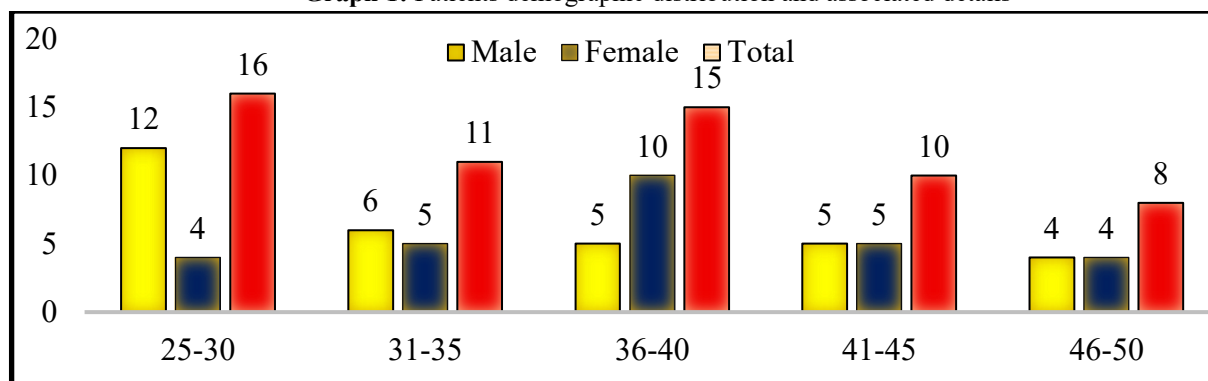


Table 2: Group 1 (n=20) implants were coated with nanoComposix(silver nanoparticles antimicrobial coatings), and primary stability was evaluated in all the 3 region coronal, middle, and apical through radiofrequency analysis, and statistical analysis were assessed using the Pearson Chi-Square test.

Region	ISQ value	Stat. Mean	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Coronal	79±6	1.98	0.113	1.432	1.37	1.065	1.0	0.06
Middle	80±6	2.36	1.098	1.367	2.25	2.078	1.0	0.07
Apical	84±6	2.45	3.008	1.045	2.20	2.765	1.0	0.03*

*p<0.05 significant

Table 3: Operators assessed the clinical response of Group 1 (n=20), where implants were coated with nanoComposix (silver nanoparticles for antimicrobial coatings). Statistical analysis was conducted using the Pearson Chi-Square test.

Clinician response	n	Stat. Mean	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Satisfactory	12	2.24	2.183	3.045	2.24	2.256	1.0	0.02*
Non Satisfactory	4	2.03	1.095	1.330	1.26	1.083	1.0	0.40
Questionable	2	0.08	0.080	0.030	0.45	1.024	1.0	0.06
Hopeless	2	0.08	0.080	0.030	0.45	1.024	1.0	0.06

*p<0.05 significant

Table 4: Group 2 (n=20) implants were coated with GL13k (antimicrobial peptide coating), and primary stability was evaluated in all three regions, coronal, middle, and apical, through radiofrequency analysis, and statistical analysis were assessed using the Pearson Chi-Square test.

Region	ISQ value	Stat. Mean	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
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Coronal	55±4	1.85	0.087	1.345	1.26	1.043	1.0	0.04
Middle	59±4	2.24	1.067	1.287	2.23	2.056	1.0	0.05
Apical	68±5	2.35	2.078	1.040	2.29	2.065	1.0	0.03*
*p<0.05 significant								

Table 5: Operators assessed the clinical response of Group 1 (n=20), where implants were coated with GL13k (antimicrobial peptide coating). Statistical analysis was conducted using the Pearson Chi-Square test.

Clinician response	n	Stat. Mean	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Satisfactory	9	2.18	1.980	2.036	2.46	2.043	1.0	0.02*
Non Satisfactory	5	2.14	1.086	1.240	2.26	2.082	1.0	0.80
Questionable	3	1.07	1.112	0.136	1.34	1.045	1.0	0.46
Hopeless	3	1.07	1.112	0.136	1.34	1.045	1.0	0.46
*p<0.05 significant								

Table 6: Group 3 (n=20) implants were coated with luminore (copper-containing antimicrobial coating), and primary stability was evaluated in all three regions coronal, middle, and apical through radiofrequency analysis, and statistical analysis was assessed using the Pearson Chi-Square test.

Region	ISQ value	Stat. Mean	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Coronal	45±3	1.76	0.034	1.213	1.14	1.034	1.0	0.01
Middle	48±4	2.20	1.056	1.089	2.12	2.045	1.0	0.01
Apical	50±5	2.23	2.012	1.023	2.13	2.056	1.0	0.02*
*p<0.05 significant								

Table 7: Operators assessed the clinical response of Group 1 (n=20), where implants were coated with luminore (copper-containing antimicrobial coating). Statistical analysis was conducted using the Pearson Chi-Square test.

Clinician response	n	Stat. Mean	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Satisfactory	8	2.43	1.089	1.024	1.59	1.034	1.0	0.01*
Non Satisfactory	4	2.03	1.095	1.330	1.26	1.083	1.0	0.40
Questionable	4	2.03	1.095	1.330	1.26	1.083	1.0	0.40
Hopeless	4	2.03	1.095	1.330	1.26	1.083	1.0	0.40
*p<0.05 significant								



Table 8: Group 1(n=20) Energy Dispersive X-ray Spectroscopy (EDS) was used to evaluate the elements on the nanoComposix-coated implant, and statistical analysis was assessed using the Pearson Chi-Square test.

Elements	Mean atomic weight%	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
AL	0.02±0.01	0.011	0.014	0.12	0.034	1.0	0.02*
MG	0.3	0.045	1.034	0.11	1.023	1.0	0.01
N	0	-	-	-	-	-	-
S	0	-	-	-	-	-	-
*p<0.05 significant							

Table 9: Group 2(n=20) Energy Dispersive X-ray Spectroscopy (EDS) was used to evaluate the elements on the GL13k coated implant, and statistical analysis was assessed using the Pearson Chi-Square test.

Elements	Mean atomic weight %	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
AL	0.14±0.24	1.010	1.003	1.12	1.034	1.0	0.02*
MG	0.1±0.2	1.034	1.067	1.10	1.035	1.0	0.02
N	0	-	-	-	-	-	-
S	0	-	-	-	-	-	-
*p<0.05 significant							

Table 10: Group 3(n=20) Energy Dispersive X-ray Spectroscopy (EDS) was used to evaluate the elements on the lumicore-coated implant, and statistical analysis was assessed using the Pearson Chi-Square test.

Elements	Mean atomic weight%	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
AL	1.2±1.287	2.112	1.078	2.09	1.987	1.0	0.02*
MG	0.1±0.3	1.036	1.067	2.11	2.001	1.0	0.01
N	0.45	0.146	1.056	1.10	1.010	1.0	0.01
S	1.22±0.22	2.111	1.023	1.12	0.098	1.0	0.01
*p<0.05 significant							

Table 11: Estimation amongst all studied groups using one-way ANOVA

Variables	Degree of Freedom	Sum of Squares Σ	Mean Sum of Squares $m\Sigma$	F	Level of Sig. (p)
Between Groups	4	2.130	1.453	1.4	0.001*
Within Groups	16	2.023	0.278		-



Cumulative	113.14	6.004	*p<0.05 significant
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Discussion

Tonetti MS et al reviewed in their study that dental implant failure is often due to inadequate osseointegration, where the implant fails to fuse with surrounding bone. Factors such as aging, overall health, poor oral hygiene, and improper patient selection can negatively impact this process. Complications often arise from bacterial plaque accumulation, leading to inflammation and infection. Furthermore, improper restorations or insufficient bone preparation can worsen these problems.¹⁴ Scarano A et al included in their study that a common manifestation of initial complications is peri-implant mucositis, which involves inflammation of the soft tissues surrounding the implant. This condition is characterized by symptoms such as bleeding when probing the tissue and increased pocket depth around the implant, which can ultimately lead to bone loss if not treated promptly.¹⁵ Berglundh T et al reviewed in their study that both peri-implant mucositis and its more severe counterpart, peri-implantitis, are primarily caused by bacterial infections and are responsible for a significant proportion of complications associated with dental implants. To effectively combat these bacterial infections, dental professionals often employ a combination of surgical and nonsurgical treatment strategies, which may include the use of antibiotics to enhance recovery.¹⁶ Z. Sun, L et al showed in their study that to improve biointegration the successful merging of the implant with surrounding bone, researchers are exploring innovative strategies. One promising approach involves the development of antimicrobial coatings made from both organic and inorganic materials, designed to minimize bacterial adhesion while enhancing the biocompatibility of the implant. Various materials, such as antibacterial polymers and metal ions, are being engineered to prevent bacterial colonization on the surfaces of implants. Moreover, advances in nanotechnology and the immunomodulatory properties of antimicrobial peptides are opening exciting new avenues in the fight against biofilm-related challenges. These innovations promise to enhance the longevity and success of dental implants, ultimately improving patient outcomes and satisfaction.¹⁷ Pagliani L reviewed in their study that effective management of peri-implant diseases requires

early diagnosis, risk assessment, and patient involvement in maintenance protocols, alongside regular clinical and radiographic evaluations.¹⁸ Bafjari D et al included in their study that devices that provide Implant Stability Quotient (ISQ) values can accurately measure osseointegration. Resonance Frequency Analysis (RFA) is currently used in research to evaluate implant stability and the impact of different implant designs.^{19,20} Brožek-Mucha Z et al reviewed in their study that Energy Dispersive X-ray Spectroscopy (EDS) is a key analytical technique for determining elemental composition, widely applied in materials science, forensics, and drug studies, known for its speed and versatility in elemental analysis.²¹

Conclusion

This study assessed the primary stability and surface topography of dental implants with three antimicrobial coatings using Resonance Frequency Analysis (RFA) and Energy Dispersive Spectroscopy (EDS). Results concluded that nanocomposite-coated implants, known for broad-spectrum antibiotic activity, outperformed others. GL13K antimicrobial peptides were also highly effective against microbial threats. While copper-containing alloys provided antimicrobial protection and durability, their effectiveness was lower than that of nanocomposites and GL13K. EDS analysis revealed that elements like aluminum (Al), magnesium (Mg), nitrogen (N), and sulfur (S) were less common on implants with antimicrobial coatings, as they are linked to peri-implantitis. Future similar long term studies are expected to be conducted so as to authenticate and confirm our results.

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