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RESEARCH ARTICLE

Comparative Assessment of the Clinical Effectiveness of Thermal Plasma Spray (TPS) and Nonthermal Atmospheric Pressure Plasma (NTAPP) in Reducing Implant Failures by Assessing Osseointegration Through Radiofrequency Analysis Method in Patients Seeking Implant Prosthesis with Standard Surgical and Mucoperiosteal Flap Approach: An (In-Vivo) Original Research Study

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Abstract: ***Aim:*** This study aims to determine the clinical effectiveness of thermal plasma spray (TPS) and nonthermal atmospheric pressure plasma (NTAPP) in reducing implant failures by assessing osseointegration through the Radiofrequency Analysis method in patients seeking implant prosthesis with standard surgical and mucoperiosteal flap approach. ***Materials and Methods:*** In this study, we examined 40 patients aged 35 to 60 with missing right mandibular first molars, excluding individuals with mental health issues, serious illnesses, pregnant women, or smokers. Informed consent was obtained, and a chlorhexidine rinse was used for hygiene before the procedure. An inferior alveolar nerve block was administered for pain management, followed by a mucoperiosteal flap incision to access the bone for dental implant placement. After three months, a prosthesis supported by the implant was made. The patients were divided into two groups: Group 1 received implants coated with thermal plasma spray (TPS), and Group 2 received implants treated with nonthermal atmospheric pressure plasma (NTAPP). Implant stability was assessed using Radiofrequency Analysis (RFA) at three- and six-month post-implantation, measured in the Implant Stability Quotient (ISQ).
Statistical Analysis and Results: In this study, we examined 40 patients aged 35 to 60 missing their right mandibular first molars. The cohort included 17 males and 23 females. Participants were divided into two groups: Group 1 received thermal plasma spray (TPS) implants, while Group 2 received nonthermal atmospheric pressure plasma (NTAPP) implants. Implant stability was assessed using Radiofrequency Analysis (RFA) and Implant Stability Quotient (ISQ) values at three and six months. Group 1 showed an ISQ of 47.1 ± 3 Ncm at three months, increasing to 54.1 ± 4 Ncm at six months. Group 2 had initial ISQ scores of 75.2 ± 6 Ncm at three months and 80.1 ± 6 Ncm at six months. Overall findings were summarized using one-way ANOVA for insights into osseointegration.
Conclusion: This study concluded that both techniques enhanced osseointegration, with NTAPP demonstrating moderate superiority over Thermal Plasma Spray TPS. Nonthermal atmospheric pressure plasma (NTAPP) is preferred for implant surface alteration due to better initial bone contact and lower temperature growth, making it a more cost-effective and safer option. Further research is needed to refine these techniques for clinical application.

Keywords: Thermal Plasma Spray (TPS), Nonthermal Atmospheric Pressure Plasma (NTAPP), Osseointegration, Radiofrequency Analysis (RFA).

INTRODUCTION

A dental implant is a sophisticated alloplastic structure carefully designed to be inserted into oral tissues, serving as a strong foundation for various dental prostheses. This innovative solution plays a key role in effectively replacing missing teeth, ensuring both functionality and aesthetic appeal. The success of dental implants depends on a complex interaction of factors, including local biological conditions, the skill of the clinician, and specific properties of the implant itself. Among these, the design and surface condition of the implant are especially important for achieving osseointegration—the seamless integration of the implant with the surrounding bone.[1-3] Advanced surface modification techniques, such as plasma spraying, help improve the surface features of titanium implants used in orthopaedic and dental applications. This process involves depositing a powdered material onto the implant surface at high temperatures, creating microscopic irregularities. These rough surfaces

promote mechanical interlocking between the implant and the surrounding bone tissue, which is critical for increasing initial stability and reducing the risk of loosening over time.[4,5] Besides plasma spraying, the application of hydroxyapatite (HA) coatings on titanium implants has gained significant attention. This bioceramic, similar to the mineral component of bone, can be effectively applied by heating HA onto the implant surface. Adding HA not only enhances the osteoconductivity of the implant but also encourages cellular response, leading to a stronger and more biologically compatible bond between the bone and the implant.[6,7] Furthermore, optimizing the surface qualities of titanium implants goes beyond texture and coatings. Modifying the surface charge to make it positive can significantly boost its hydrophilicity. This hydrophilic property is crucial for promoting optimal protein absorption, which is vital for the adsorption of growth factors and the formation of a mineralized bone matrix. Techniques such as oxidation or nonthermal plasma (NTP) treatment are typically used to achieve these surface modifications, resulting in an improved interface that supports effective healing and integration of the implant into the body.[8-10] Overall, these advanced surface engineering strategies not only improve the mechanical and biological performance of titanium implants but also lead to better clinical results and longer-lasting implanted devices.[11,12] To evaluate the stability of the implant, clinicians use Resonance Frequency Analysis (RFA). This method measures subtle vibration signals generated by the implant to produce an Implant Stability Quotient (ISQ), a numerical value from 0 to 100. Higher ISQ values indicate better integration with bone, serving as a key metric for treatment planning and monitoring the osseointegration process during the critical healing phase.[13,14] This study aims to assess the clinical effectiveness of thermal plasma spray (TPS) and nonthermal atmospheric pressure plasma (NTAPP) in reducing implant failures by evaluating osseointegration through the Radiofrequency Analysis method in patients seeking implant prosthesis using standard surgical and mucoperiosteal flap approaches.

MATERIAL AND METHODS

In this comprehensive study, we initiated our investigation with a carefully selected cohort of 50 patients who presented with a specific complaint of having lost their right mandibular first molar. The study was planned, abstracted and executed in the department of Prosthodontics of the institute. All participants expressed a strong desire for a suitable and effective replacement to restore both function and aesthetics. Out of these 50 individuals, 40 chose to proceed with dental implant placement accompanied by implant-supported prostheses. Our inclusion criteria were meticulously defined to focus on patients aged between 35 and 60 years, encompassing both male and female participants who had specifically experienced the loss of their right mandibular first molar. To ensure the well-being of participants and the validity of our findings, we established strict criteria for our study. Individuals were excluded if they had mental health conditions, serious illnesses, were pregnant, or had a history of smoking. This approach was taken to maintain the integrity of the research results. Before the initiation of any treatment, we ensured that informed consent was obtained from all patients, thereby guaranteeing that they fully understood the procedure and its potential implications. For hygiene purposes, each participant was administered a chlorhexidine mouthwash rinse before the implant placement procedure, reinforcing our commitment to maintaining a sterile environment. The subsequent step involved the administration of an inferior alveolar nerve block, which effectively numbed the targeted area to alleviate discomfort during the surgical procedure. A precise incision was then made using a 15-scalpel blade, allowing for the careful reflection of a mucoperiosteal flap, a critical step in gaining access to the underlying bone. Once the flap was elevated, the dental implant was strategically placed into the meticulously prepared site. Following the implant placement, the flap was delicately repositioned, and sutures were applied to ensure proper healing and stability during the recovery phase. Two months post-implant placement, the healing abutment was placed. Then, three months after the implant placement, the prosthesis supported by the implant was provided. After the insertion of the implant-supported prosthesis, a CBCT evaluation was performed on the 40 patients to examine the bony details. Ultimately, our study comprised a total of 40 patients, who were systematically divided into two distinct groups for comparative analysis. Group 1 included 20 patients whose implants were coated with a thermal plasma spray (TPS), known for enhancing osseointegration. In contrast, Group 2 also included 20 patients, but their implants were coated using a nonthermal atmospheric pressure plasma (NTAPP) technique, offering a different approach to enhancing implant success. To evaluate the stability of the dental implants, we employed Radiofrequency Analysis (RFA) using the state-of-the-art Ostell instrument. The RFA values, articulated in the Implant Stability Quotient (ISQ), ranged from 1 to 100, which represented varying degrees of implant stability. These critical measurements were meticulously recorded at both the three-month and six-month intervals following the implantation, allowing us to assess stability across all surfaces of the implants over time. A thorough statistical analysis was conducted to interpret the data collected, ensuring our findings were robust and reliable. The primary objective of this study was to determine the clinical effectiveness of both thermal plasma spray (TPS) and nonthermal atmospheric pressure plasma (NTAPP) in mitigating implant failures. This was achieved by assessing osseointegration through the sophisticated

Radiofrequency Analysis method, specifically targeting patients seeking implant prostheses via a standard surgical approach that employed the mucoperiosteal flap technique.

In this study, we used SPSS software version 29.0 for statistical analysis. To assess the significance of our findings, we employed the chi-square test to examine differences in proportions among groups. This method enabled a thorough comparison of categorical data, ensuring our results accurately represented the underlying trends.

RESULTS AND OBSERVATIONS:

In this comprehensive study, we meticulously investigated a cohort of 40 patients, aged between 35 and 60 years, all of whom were missing their right mandibular first molars. To ensure the integrity of our findings, we excluded individuals with mental health disorders, serious medical conditions, pregnant women, and smokers. All participants provided informed consent, affirming their understanding of the study's procedures and objectives. Before the surgical intervention, we employed a chlorhexidine rinse to uphold the highest standards of oral hygiene. For pain control during the procedure, we utilized an inferior alveolar nerve block, a technique designed to effectively numb the area. Following this, we performed a precise mucoperiosteal flap incision, which allowed us to gain direct access to the bone for the placement of dental implants. After a healing period of three months, we fabricated a prosthesis supported by the newly inserted implant. The demographic composition included both male and female patients, with a distribution of 17 males and 23 females, as detailed in Table 1, which offers a comprehensive statistical overview of patient ages and gender. Graph 1 visually represents the demographic distribution along with related insights. The patients were stratified into two distinct groups for treatment: Group 1, which received dental implants coated with thermal plasma spray (TPS), and Group 2, which was treated with implants coated using nonthermal atmospheric pressure plasma (NTAPP). We meticulously assessed implant stability through Radiofrequency Analysis (RFA) at both the three-month and six-month intervals following implantation, quantifying stability using the Implant Stability Quotient (ISQ) metric. In Table 2, we present the profile of Group 1 (n=20), where subjects received implants featuring a coating of Thermal Plasma Spray (TPS). The osseointegration assessment was rigorously carried out using radiofrequency analysis on all four surfaces of each implant at the three-month mark. Statistical evaluations, performed using the Pearson Chi-Square test, indicated an ISQ value of 47.1 ± 3 Ncm on the buccal surface. Moving to Table 3, we reveal the findings for Group 1 at the six-month assessment, where the ISQ value on the buccal surface was recorded at 54.1 ± 4 Ncm, following the initial three-month radiofrequency analysis. Table 4 details the results for Group 2 (n=20), whose implants were treated with nonthermal atmospheric pressure plasma (NTAPP). The osseointegration evaluation, conducted three months post-implantation, demonstrated a remarkable ISQ value of 75.2 ± 6 Ncm on the buccal surface, as calculated through the Pearson Chi-Square statistical analysis. Furthermore, Table 5 showcases the outcomes for Group 2 at the six-month evaluation, registering an impressive ISQ value of 80.1 ± 6 Ncm on the buccal surface, indicating a strong osseointegration process. Finally, Table 6 offers a synthesized estimation across all studied groups using one-way ANOVA, enabling us to draw meaningful conclusions from our data.

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

Age Group (Yrs)	Male	Female	Total	P value
35-40	3	5	8	0.04*
41-45	4	6	10	0.30
46-50	3	4	7	0.02*
51-55	3	5	8	0.40
56-60	4	3	7	0.20
Total	17	23	40	*Significant
*p<0.05 significant				

Graph 1: Patients demographic distribution and associated details

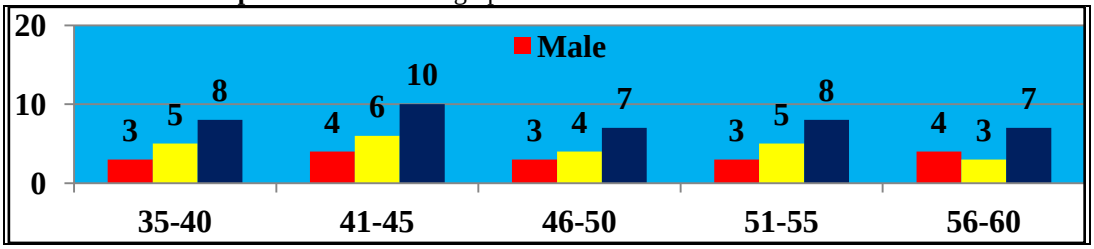

Table 2: Group 1 (n=20) received implants that were coated with Thermal Plasma Spray (TPS). The assessment of osseointegration was conducted using radiofrequency analysis on all four surfaces of each implant three months after implantation. Statistical analysis was performed using the Pearson Chi-Square test

Tooth Surfaces	ISQ value	n	Stat. Mean	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Buccal	47.1±3Ncm	9	2.24	2.044	2.065	2.26	2.300	1.0	0.01*
Lingual	43.1±3Ncm	5	2.13	1.185	1.143	2.45	2.186	1.0	0.40
Mesial	37.3±4Ncm	3	1.06	1.198	1.105	1.19	1.136	1.0	0.65
Distal	35.2±3Ncm	3	1.06	1.198	1.105	1.19	1.136	1.0	0.65
*p<0.05 significant									

Table 3: Group 1 (n=20) received implants that were coated with Thermal Plasma Spray (TPS). The assessment of osseointegration was conducted using radiofrequency analysis on all four surfaces of each implant six months after implantation. Statistical analysis was performed using the Pearson Chi-Square test

Tooth Surfaces	ISQ value	n	Stat. Mean	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Buccal	54.1±4Ncm	6	2.16	1.189	1.167	2.67	2.196	1.0	0.50
Lingual	52.3±4Ncm	7	2.20	1.201	1.178	2.87	2.206	1.0	0.45
Mesial	50.4±5Ncm	4	1.19	1.089	1.240	1.08	1.264	1.0	0.02*
Distal	49.5±3Ncm	3	1.06	1.198	1.105	1.19	1.136	1.0	0.65
*p<0.05 significant									

Table 4: Group 2 (n=20) received implants that were coated with nonthermal atmospheric pressure plasma (NTAPP).The assessment of osseointegration was conducted using radiofrequency analysis on all four surfaces of each implant three months after implantation. Statistical analysis was performed using the Pearson Chi-Square test

Tooth Surfaces	ISQ value	n	Stat. Mean	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Buccal	75.2±6Ncm	6	2.16	1.189	1.167	2.67	2.196	1.0	0.50
Lingual	74.3±5Ncm	4	1.19	1.089	1.240	1.08	1.264	1.0	0.02*
Mesial	72.2±5Ncm	6	2.16	1.189	1.167	2.67	2.196	1.0	0.50
Distal	69.5±4Ncm	4	1.19	1.089	1.240	1.08	1.264	1.0	0.02*
*p<0.05 significant									

Table 5: Group 2 (n=20) received implants that were coated with nonthermal atmospheric pressure plasma (NTAPP). The assessment of osseointegration was conducted using radiofrequency analysis on all four surfaces of each implant six months after implantation. Statistical analysis was performed using the Pearson Chi-Square test

Tooth Surfaces	ISQ value	n	Stat. Mean	Std. Dev.	Std. Error	95% CI	Pearson Chi-Square Value	df	p value
Buccal	80.1±6Ncm	8	2.24	1.234	1.278	2.98	2.212	1.0	0.50
Lingual	81.2±5Ncm	4	1.19	1.089	1.240	1.08	1.264	1.0	0.02*
Mesial	78.1±6Ncm	5	2.13	1.185	1.143	2.45	2.186	1.0	0.40
Distal	79.5±5Ncm	3	1.06	1.198	1.105	1.19	1.136	1.0	0.65
*p<0.05 significant									

Table 6: 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	5	1.230	1.438	1.6	0.001*
Within Groups	16	2.164	1.023	_	
Cumulative	114.13	6.264	*p<0.05 significant		

DISCUSSION

Bassir SH et al reviewed in their study that dental implants represent a groundbreaking advancement in modern dentistry, providing effective solutions for replacing single teeth, multiple teeth, or even entire arches. The success of these implants is heavily reliant on a vital process known as osseointegration, in which the implant subtly bonds with the surrounding alveolar bone. Several key factors can influence this complex integration, including the overall health of the patient, the quality and density of the bone, the materials used for the implant, and specific surface treatments applied to enhance compatibility.15 Chrcanovic BR et al reviewed in their study that complications during the osseointegration process can lead to implant failures. These issues may arise from various sources, such as early bacterial contamination, suboptimal implant design, inadequate surgical techniques, or insufficient post-operative care. One of the critical elements affecting osseointegration is the surface energy of the implant. By modifying the surface, such as through innovative plasma treatment techniques, it is possible to enhance the bonding process with the bone significantly.16 Do T A. et al showed in their study that thermal plasma treatment is an advanced technique that significantly enhances the surface characteristics of dental implants by creating a rough, biocompatible texture. This increase in surface roughness plays a crucial role in promoting osseointegration, as it encourages bone to grow and attach more effectively to the implant compared to smoother surfaces, which can hinder this critical process. By increasing the available surface area for bone apposition, thermal plasma treatment fosters superior healing outcomes and long-term stability of the implant.17,18 Tamimi F et al included in their study that,in addition to thermal plasma, acid etching is another effective method for refining implant surface properties. This technique involves using acidic solutions to selectively remove material from the implant surface, creating microscale texture that enhances cellular attachment and proliferation. The combination of these treatments results in an optimized environment for bone integration, further improving the overall success rates of dental implants.19,20 Canullo L et al showed in their study that on the other hand, nonthermal plasma (NTP) treatment presents unique advantages that complement the benefits of thermal methods. NTP treatment enhances the wettability of the implant surface, promoting better fluid interaction and adhesion of surrounding tissues. This leads to accelerated bone formation around the implant, a vital aspect for ensuring the long-term success of the restoration. The ability to alter surface properties without the high temperatures associated with thermal plasma means that NTP can be applied to a wider variety of materials while preserving their characteristics.21,22 Sennerby L reviewed in their study that to effectively assess the success of dental implants, practitioners often utilize resonant frequency analysis (RFA). This innovative, noninvasive technique measures the displacement and vibrational frequency of the implant when subjected to lateral forces. By analyzing these measurements, clinicians can gain valuable insights into implant stability and monitor the osseointegration process over time. The data gathered from RFA not only helps in gauging the immediate success of the implant but also aids in predicting long-term outcomes, allowing for timely interventions if necessary. Through these advanced technological methods, dental implants are continually evolving and improving, which ultimately translates to enhanced results and better overall outcomes for patients seeking restorative dental solutions. The integration of sophisticated treatments and thorough evaluation techniques highlights the ongoing commitment to advancing dental implantology for optimal patient care.23,24

CONCLUSION

Within the limitations of the study authors focused on the clinical effectiveness of thermal plasma spray (TPS) and nonthermal atmospheric pressure plasma (NTAPP) for reducing implant failures. The authors assessed osseointegration using the Radiofrequency Analysis method. The study involved patients seeking implant prostheses with standard surgical methods, including mucoperiosteal flap approaches. The findings revealed that both TPS and NTAPP enhance osseointegration. However, NTAPP demonstrated a moderate superiority over TPS in improving this process. Both NTAPP and TPS techniques aim to improve osseointegration, but NTAPP is usually preferred for changing implant surfaces. This is because NTAPP helps achieve better initial contact between bone and the implant, and it supports bone growth at lower temperatures. It is also a more affordable and less harmful option compared to TPS. It is important to conduct thorough and extended future research to improve our understanding and to refine how these techniques can be used in clinical settings. There is clear necessity of conducting comprehensive and in-depth future research to enhance our understanding of these techniques and to better refine their application in clinical settings.

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