Original Article

Risk Factors and Predictive Model for Peri-Implantitis Following Dental Implant Surgery

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Abstract

Aim: The present study aimed to identify the predictors of peri-implantitis in patients who had undergone dental implant surgery and to create a model that could predict the disease. **Methods:** The study design employed was a retrospective cohort comprising 345 patients, of which 259 were from the modeling group and 86 from the validation group. Single-variable analysis classified smoking history, history of diabetes, history of periodontal disease, and irregular periodontal treatment as independent risk factors. Binary logistic regression supported these factors, as the odds ratios showed an increased risk of peri-implantitis. **Results:** It has been established that there are benefits from regular periodontal treatment. The accuracy of this lock-and-key model was further confirmed by an AUC of 0.733, specificities of 82.36%, and sensitivities of 79.63%. **Conclusion:** The present study is consistent with the prior literature and emphasizes the importance of attentive patient care approaches involving smoking cessation, careful monitoring of patients' glucose levels, and timely visits to the dentist. **Implications:** This model will benefit clinicians as it can evaluate and control the potential development of peri-implantitis within patients, consequently leading to better patient results and implant durability.

Keywords: Peri-implantitis, Dental Implants, Risk Factors, Predictive Model, Smoking, Diabetes, Periodontal Disease.

Introduction

Dental implantology has risen in popularity as a better solution to tooth loss than conventional approaches, such as dentures and fixed bridges. The survival rates of implants have doubled owing to the introduction of sophisticated technologies and biological materials. This is because preferential dental implant placement has a higher initial success rate than other dental restoration processes. The patient demand for dental implants has increased in recent years, and according to the forecast, this trend will continue shortly.[1] Despite the high success rate, issues including peri-implantitis are present and act as a major threat to the prognosis and implant success rates, creating dissatisfaction among patients.

Peri-implantitis, also an inflammatory disease, influences the soft and hard tissues surrounding dental implants and is considered a major determinant of implant loss.[2] The incidence of peri-implantitis is variable; however, the reported comparisons of prevalence and incidence were significantly different at the implant level. For the first three years after implantation, the frequency has been estimated to be as low as 0.4%, which significantly increases to five years.[3] Periimplantitis is a multifactorial disease. A literature review demonstrated that smoking, diabetes mellitus, periodontal disease, and uneven periodontal maintenance have been repeatedly reported as other important factors. Patients with a history of periodontitis have a higher incidence rate of peri-implantitis than those without periodontal disease.[4] These risk factors are why there is a need for prevention and management measures

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to improve implant longevity and overall patient health. Developments in biomaterials and coatings of implant surfaces improve the osseointegration between the implant and hard tissues, hence enhancing the success of implants placed in the dent. However, peri-implant diseases are still clinical problems, meaning there is a need for further research into the prevention and treatment of these diseases. Mucositis is a reversible inflammatory lesion of the mucosa around the implant that, if not well controlled, may lead to peri-implantitis. Peri-implantitis is a bacterial infection- and host inflammation-induced condition, requiring unified management in its treatment. Thus, there is a straight indication of a greater need for practical systematic methods to address peri-implantitis quantification and prevention. As a result, new score systems have been proposed, which are able to predict the risk to develop peri-implantitis prior to the dental implant surgery.[5] These models allow for selection of patients at risk of progression and thus patients. for whom preventive measures should be taken with greater caution. They depend on the following and the characterization of important risk factors are central to the entire process. [6] The second important risk factor which is also risk marker is smoking, diabetes, periodontal disease and poor attendance for periodontal treatment.[7] These risks allow the clinician to plan specific treatment interventions that, with some probability, will retard the advance of peri-implantitis and consequently will be able to increase the implant survival.[8] Smoking is a risk factor for periodontal diseases including peri-implantitis. Smoking is also implicated in impaired complete wound healing, immune response and thereby raises the risk of infection or radiographic evidence of peri-implantitis.[9] One of the next big risk factors is a history of diabetes, as the condition will make the immune system weaker, thereby increasing the risk of infection.[10] This study aimed to investigate whether patients with diabetes have a higher likelihood of developing peri-implantitis compared to those without diabetes, due to impaired wound healing and increased inflammation in the implant area.

Periodontal disease is a chronic gingival inflammation and inf ection. This is typically assumed to be Peri-implantitis due to histology of periodontal disease, a disease defined as colonization of pathogenic bacteria as well an enhanced inflammatory situation in patients. [11] Periodontal maintenance therapy seems simple in periodontal disease treatment and in the prevention of peri-implant therapy. When the common systematic, usual periodontal care is ineffective to yield good result, bacterial deposit may accumulate at the interface of the implant causing infection or inflammation.[12]

Additionally, in the condition of peri-implantitis, the development of predictive models utilized logistic regression to establish distinct risk factors. Such models can be used, for example, in the diagnosis and the prognosis and the disease trajectory of peri-implantitis in every patient and, consequently, the appropriate preventive strategies can be envisaged. Calibration of such models is of high importance because it would enable their use in clinical applications in the most effective way. Models may be adapted by retraining based on the remaining data based on clinical practice with a cross-sectional population of patients, which could make them more acceptable.[10] Other independent risk factors for peri-implantitis, for example smoking, has also been reported in the other investigations, and there are matching findings, namely diabetes, periodontal disease and irregular dental care. The integration of these factors into the model formulation allows clinicians to estimate individual-patient peri-implantitis risk before implant surgery.[5] Clinicians could further potentially improve the likelihood of screening and care of diagnosed high-risk patients to avoid peri-implantitis and advance implant success.[1] To enhance outcomes of patients affected by peri-implantitis, this study explores other risk factors for the development of peri-implantitis with the aim of suggesting modifications for practice. Therefore, taking the good predictive efficiency of the model into account, the model could be useful in clinical setting. More successful research studies must be conducted on specific peri-implantitis risk factors and other facets that impact the model.[6] If this tool is incorporated into routine clinical evaluation, then the management approaches of patients could become even more efficient and specific.[4]

Literature Review

Theoretical Framework

Dental implants are amazing in the sense that they have transformed the laid base of dentistry for prosthetic teeth. However, the success of dental implants is always jeopardy owing to diseases around the implant, especially peri-implantitis. Peri-implantitis refers to inflammation of the mucosa surrounding an implant, and the subsequent loss of the surrounding bone, if untreated, could result in implant failure. Based on this understanding, the theoretical premise for this study is embedded in the biopsychosocial model of health, which holds that biological, psychological, and social elements function together in determining health states. For the emergence and progression of peri-implantitis, this model explains how risk indicators, including biological characteristics (diabetes and others), psychology (smoking), social factors (access to periodontal prophylaxis), and work.[5]

Biological Factors

Peri-implantitis may develop in immunocompetent patients with impaired wound healing because of conditions such as diabetes mellitus.[1] In diabetic patients, high blood sugar levels negatively affect medical implants by inhibiting the synthesis of collagen, enhancing fiber apoptosis, and causing inflammation, thereby leading to impaired healing around the implant sites.[7] In addition, pathogenic bacteria present in the peri-implantation site, such as P. gingivalis, T. For instance, the peri-implantation surface-related bacteria such as forsythia can initiate and progress the infection. [2] These bacteria can adhere to implant surfaces, form

biofilms, trigger chronic inflammation, and contribute to the loss of peri-implant bone.[3] The bacterial biofilms elicit an immune response involving potentially toxic cytokines like IL-1β and TNF-α, leading to bone resorption.[6]

Psychological Behaviors

The psychological behavior evaluates the extent to which the present systematic review of this behavioral risk factor is systematic. However, the percentage of smokers in this study was high, and smokers are more likely to develop peri-implantitis due to the injurious effects of smoking on the immune system and the healing period.[9] Cigarettes predispose patients to impaired blood flow in the attached gingiva, deficient neutrophil activity, and elevated levels of pro-inflammatory cytokines, which increases the likelihood of peri-implant complications and infections. Previous research has shown that smokers experience more frequent loss of peri-implant tissue attachment than non-smokers. Therefore, smoking cessation programs should be included in the maintenance protocols for implants, as smoking has an adverse effect on peri-implant health.

Social Determinants

Essential components for the prevention and control of peri-implantitis include outcome data and social factors such as how frequently patients are examined for periodontal conditions and re-treated involving effective education. Peri-implant diseases should be detected before reaching an advanced stage; this is why periodontal maintenance helps in diagnosing the disease.[10] Patients who strictly follow the established timetables for periodontal check-ups will have proper oral hygiene, and in case of worsening of their previously diagnosed peri-implantitis, they will be able to address the problem on time.[12] Prescribing efficient self-plaque control measures is also used to prevent peri-implantitis. Hence, patients need to know how to brush, floss, and use antiseptic mouthwash to minimize plaque formation in areas surrounding the implants.[4] The data synthesized from the above-mentioned studies showed that patients who followed all prosthesis oral hygiene instructions and received regular professional dental cleaning are more likely to experience less peri-implantitis.[12]

Hypothesis 1: Smoking history is related to increased development of peri-implantitis in patients undergoing dental implant surgery.

Various research studies have indicated an association between smoking and oral diseases, including peri-implantitis. Cigarette smoke greatly impacts peri-implant health through the impairment of the immune system and soft tissue healing. Some of the key constituents of cigarettes, including nicotine, alter gingival blood flow, neutrophils, and cytokines, thus increasing peri-implant infections and complications.[9] The study found that smokers were more than twice as likely to develop peri-implantitis compared to non-smokers. These studies imply that smoking not only predicts but also exacerbates the development of peri-implantitis, with compromised tissue remodeling and healing processes.

Besides, literature exists which shows smokers develop more cases of peri-implantitis; therefore, the conclusion can be drawn that at least a doubled risk of implant loss in comparison to the nonsmoker occurs in the case of a smoker.[1] Smoking is identified as one of the risk factors causing peri-implantitis; however, the impact of quitting smoking has resulted in positive findings of marginal bone loss radiographically and improved implant stability. The cases of peri-implantitis among non-smokers and former smokers are significantly lesser compared to those smoking currently. Therefore, programs on smoking cessation must be integrated into peri-implant care to increase the stability of the implants as well as ensure higher patient satisfaction.[10] The etiological factors involved in peri-implantitis have been analyzed to be determined by smoking as a major determinant in the onset and progression of disease. Sometimes, patients should be encouraged to stop smoking to minimize related risks with dental implants. Smoking has also been found to reduce microbial density around implants, which makes it easy for aggressive pathogenic bacteria to colonize and cause further peri-implantitis.[2] The relationship between smoking and peri-implantitis has been shown in several studies. Poor immunity, poor circulation, and increased inflammation, all of which are caused by cigarette smoking, increase the risk of peri-implantitis.[13] This hypothesis underscores the importance of smoking cessation intercessions in improving implant outcome and durability.[5]

Hypothesis 2: Thus, the review of literature on the history of diabetes shows a positive correlation with the onset of peri-implantitis with patients undergoing dental implant surgeries.

Diabetes mellitus remains one of the biggest threats to global health, affecting all dimensions of health, including oral health. Diabetics have weakened immunity and poor wound healing, particularly in orthopedic areas, due to high blood glucose levels, which can lead to early implant contamination and peri-implantitis.[1] Furthermore, the review points out that patients suffering from diabetes have a greater incidence of peri-implantitis compared to the non-diabetic patients and therefore recommended glycemic control along with close follow-up for patients undergoing dental implants.[7] Incidence of peri-implantitis is much higher in the diabetic patients with poor glycemic control compared to the patient with good glycemic control. Thus, controlling the blood glucose levels properly in diabetic patients helps prevent peri-implantitis.[9] High glucose concentrations can decrease the formation of collagen, leading to fibroblast apoptosis, slower wound healing, and increased susceptibility to infection in patients with dental implants.

Moreover, the diabetics show higher levels of inflammatory cytokines IL-1β and TNF-α in the peri-implant crevicular fluid, which can cause osseous resorption and peri-implantitis.[6] For diabetic/compromised patients, inflammatory state of the oral cavity exacerbates the peri-implantitis risk. It has been noted that patients with

systemic diseases like diabetes can have improved success rates in dental implant treatment if their conditions are well controlled. Systemic health conditions in diabetic patients have been reported to influence the plastic microbiome of implants and make them more prone to peri-implantitis.[2] These findings highlight the need for repeated monitoring and glycemic control in DM patients having dental implant insertion as assessed by routine screening and control of glycemia.[4]

Overall, diabetes mellitus (DM) has been shown to increase the risk of developing peri-implantitis due to poor immune response, slow healing rate, and high inflammatory activity.[1] This emphasizes the crucial need for adequate glycemic control and satisfactory diabetic management to avoid peri-implantitis and promote the success of dental implants.[8]

Hypothesis 3: Patients who have received dental implant therapy and a history of periodontal disease have the highest peri-implantitis risk.

Based on the research, periodontitis, the microbial affecting attachment gum disease is risk factor of peri-implantitis. Patients suffering from periodontal disease harbour pathogenic bacteria and increased inflammatory status, and all these factors lead to the onset of peri-implantitis.[2] Literature reviews have shown that patients with a history of periodontal disease have a higher incidence of peri-implantitis than those without.[4] These results mean a strong correlation, which highlights the relevance of periodontal maintenance to avoid peri-implantitis.[10] Uncontrolled or mildly controlled periodontal infections can lead to bacterial colonization around the implant, forming a biofilm that is resistant to normal oral hygiene measures. This results in chronic inflammation and peri-implant bone loss. Studies have already proven that the bacterial flora in a patient with peri-implantitis is the same as chronically PD and possibly has a common aetiology. Periodontal diseases are involved in the pathogenesis of peri-implantitis. Patients with periodontitis exhibit increased susceptibility for peri-implantitis.[1] This, therefore, requires comprehensive periodontal examination and treatment prior and after implants to reduce the risk of peri-implantitis. In periodontal disease patients, strict measures for preventing the entry of new periodontal pathogens around the crowns of implants are required to be strictly adhered to Roccuzzo *et al.*[8]. Biological factors that lead to peri-implantitis in patients with a prior background of periodontal disease of host immune and microbiological nature.[5] Antimicrobial treatment should be selective towards high risk patients, and professional cleaning should be systematically carried out in those patients. In general, this systematic review shows a relationship between periodontitis and peri-implantitis. Peri-implantitis in patients with periodontal disease is caused by pathogenic microorganisms that affect the immune system. Although clinical signs of peri-implantitis are limited, proper periodontal management is essential to prevent peri-implantitis and implant failure.

Hypothesis 4: Therefore, in patients undergoing Dental Implant Surgery, RTPT is inversely related to the occurrence of PI.

Maintaining periodontal health around implants, especially at the peri-implantitis stage, requires frequent periodontal therapy.[3] Patients who regularly attend periodontal maintenance visits are more likely to be free of peri-implantitis. Professional cleaning, particularly during periodontal status checks, can control plaque and prevent the development of peri-implantitis, as the disease typically manifests at this stage.[12] The first level of prevention is vital for controlling peri-implant diseases. Thus, basic periodontal care is effective in preventing peri-implantitis. This is to identify and control peri-implant mucositis, an inflammatory disease in the early stages of implant site inflammation that, if not addressed appropriately, can lead to peri-implantitis.

Periodontal therapy is currently of paramount importance in the treatment of patients with implant prostheses and the patients in the Periodontal Maintenance group show improved peri-implant results.[4] By the cross-sectional review of the available literature, randomized clinical trials clarify the efficacy of periodontal maintenance therapy in the prevention of peri-implantitis. Standard, periodontal maintenance in implant patients, in combination with professional tooth cleaning and standardized home care instructions, has been proven to reduce peri-implantitis incidence compared with control subjects.[1] This points to the importance of patient education and the need for systematic contact with healthcare professionals that prevent peri-implantitis in patients. Periodontal maintenance is especially helpful for both patients with a history of periodontitis and those consuming tobacco in any form. Therefore, the perio-implant maintenance plan, namely the visiting frequency and adequate antimicrobial therapy for such risk patients, needs to be adapted to avoid peri-implantitis.[5] Abnormal periodontal maintenance is another etiology that has been associated with peri-implant microbial biofilm formation; hence, periodic periodontal maintenance is an important risk factor. Furthermore, unscheduled professional oral health-related checkup visits have the potential to decrease the microbial burden associated with dental implants, which is associated with the initiation and progression of peri-implantitis.[2] This study is in favor of the notion that periodontal treatment on-going is functionally inversely associated with development of peri-implantitis.

Methodology

Study Design

This study used a retrospective cohort design to determine the factors that may increase the likelihood of peri-implantitis in patients undergoing dental implant surgery and to assess the performance of the created model of peri-implantitis risk prediction. Patients who underwent dental implant treatment between May 2022 and May 2023 were included in this study. The cohort was divided

into two groups: the modeling group, the use of which in creating the above-stated predictive model, and the validation group, the use of which in assessing the effectiveness of the model.

Study Population

The study population included patients who underwent dental implant treatment due to tooth loss. Inclusion criteria were as follows: (1) patients with a restoration restored with dental implant for more than one year; (2) patients with adhesive fixed single crown restoration; (3) patients diagnosed with peri-implantitis as characterized by bleeding on probing, probing pocket depth ≥ 5 mm, and radiographic bone loss > 2 mm; (4) patients with complete clinical and radiographic data; and (5) voluntary consent to be included Some patients were excluded from the study for the following reasons: if the patient had no regular follow-up appointments, or the patient records were not complete and if the patient was lost to follow-up.

Data Collection

All patient demographic, clinical, and dental examination information was retrospectively extracted from the medical records. The independent variables were age, sex, BMI, implant length, implant diameter, smoking history and status, history of diabetes and periodontitis, and periodontal treatment frequency. The frequency of peri-implantitis infections in each patient was recorded.

Group Allocation

Using a random number table, patients were randomly assigned to the modeling group (n=259) and the validation group (n=86) in a 3:1 ratio. The study involved the data of the modeling group aimed at determining the independent risk factors for peri-implantitis and creating the predictive model, while the study involving the data of the validation group aimed at checking the accuracy of the model's predictions.

Statistical Analysis

Descriptive Statistics: The sociodemographic and clinical variables of the participants were described using frequency distributions. Categorical data were described using frequency tables and percentages, whereas continuous data were summarized using means and standard deviations. Univariate Analysis: Chi-square tests were employed to carry out univariate analysis on subjects to identify the potential risk factors for peri-implantitis. The $\chi 2$ test was applied in the analysis of categorical data, whereas t-tests were used to analyze data with interval and ratio scales. Only the variables with $P < 0.05$ were subjected to further analysis. Binary Logistic Regression: Using the results of univariate analysis, potential predictors of peri-implantitis were entered into a binary logistic regression model. The dependent variable was the rate of peri-implantitis =0 if no and =1 if yes. The final analysis conducted in this study involved calculating the odds ratios and 95% confidence intervals of each independent variable using a regression model. Predictive Model Construction: Binary logistic regression was the initial step in developing a more complex model. The model's equation was formulated as follows: the dependent variable in the model is the probability of peri-implantitis occurrence represented by p, and the model is $\text{logit}(p) = \beta 0 + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4$, where X1 = smoking history, X2 = history of diabetes, X3 = history of periodontal disease, X4 = Periodontal maintenance/ Regularity of periodontal check. The original risk scores for peri-implantitis occurrence were then calculated for all patients in the validation group using the model equation. To further assess the external validity or predictive validity of the model, the ROC curve test was conducted. The ROC evaluation was performed to assess the accuracy of the model, sensitivity and specificity were determined to evaluate the model's ability to predict patients at increased risk of peri-implant osteitis. Goodness-of-Fit Test: The goodness-of-fit of the final fixed model was assessed using the Hosmer and Lemeshow test. Good fitness was confirmed by p-value analysis, where the P-value was greater than 0.05 ($P > 0.05$).

Results

Demographic and Clinical Characteristics

This study included 345 patients who had undergone dental implant surgery. The patients were divided into two groups: the modeling group (n=259) and validation group (n=86). Table 1 shows the demographic and clinical characteristics of the study population.

Table 1: Demographic and Clinical Characteristics of Study Population.

Characteristic	Modeling Group (n=259)	Validation Group (n=86)	P-value
Age (years)	39.71 ± 11.58	40.21 ± 10.72	0.886
Gender (Male/Female)	219/40	69/17	0.464
BMI (kg/m²)	24.13 ± 3.71	23.96 ± 3.15	0.703
Implant Length (mm)	10.76 ± 3.02	11.03 ± 3.25	0.371
Implant Diameter (mm)	4.03 ± 1.01	3.97 ± 1.24	0.579
Smoking History (Yes/No)	124/135	48/38	0.202
History of Diabetes (Yes/No)	43/216	17/63	0.341
Periodontal Disease (Yes/No)	33/226	14/72	0.407
Regular Periodontal Treatment (Yes/No)	204/55	69/18	0.914

For all the variables under analysis, we noted that the p-values were non-significant, showing that the demographic and clinical characteristics of the two groups, the modeling group, and the validation group were similar.

This indicates the likelihood of fairly matched groups, which enables us to compare the results between the two. The resting variables, including age, body mass index, implant length, and implant diameter, did not reveal any significant differences. Similarly, there were no statistically significant differences between the groups with regard to sex, smoking history, history of diabetes, periodontal disease, and regular periodontal treatment. Incidence of Peri-Implantitis: In general, the rate of peri-implantitis in the study groups was 13.3%. The incidence rates of peri-implantitis in the modeling and validation groups are presented in Table 2.

Table 2: Incidence of Peri-Implantitis in Study Population.

Group	Peri-Implantitis Occurred (n)	Peri-Implantitis Not Occurred (n)	Incidence Rate (%)	P-value
Modeling Group	36	223	13.9	0.591
Validation Group	10	76	11.6	
Total	46	299	13.3	

In the modeling and validation groups, 13.9% and 11.6% of the subjects had peri-implantitis, respectively. The calculated comparisons between the two groups showed no significant differences in peri-implantitis (P= 0.591). This comparability justifies the reliability of both the modeling group in creating the model and the validation group in establishing the usefulness of the model.

Description of Risk Factors based on their Nature

This retrospective cross-sectional study was performed to review the post-implant factors that might be associated with the development of peri-implantitis. The univariate analysis results are presented in table 3.

Table 3: Univariate Analysis of Risk Factors for Peri-Implantitis.

Characteristic	Peri-Implantitis (n=46)	No Peri-Implantitis (n=299)	P-value
Age (years)	38.64 ± 11.26	37.92 ± 12.09	0.265
Gender (Male/Female)	21/15	111/112	0.697
BMI (kg/m²)	24.13 ± 2.51	24.69 ± 3.07	0.597
Implant Length (mm)	11.03 ± 2.97	10.81 ± 2.35	0.431
Implant Diameter (mm)	3.87 ± 1.19	3.77 ± 1.03	0.273
Smoking History (Yes/No)	25/11	99/124	0.005
History of Diabetes (Yes/No)	25/11	18/205	<0.001
Periodontal Disease (Yes/No)	19/17	14/209	0.001
Regular Periodontal Treatment (Yes/No)	15/21	189/34	<0.001

Chi-square test from univariate analysis compared patient background data for smoking history [P=0.005], history of diabetes [P<0.001], history of periodontal disease [P=0.001], and regularities of periodontal treatment [P<0.001]. These factors are considered possible risk factors for peri-implantitis. No statistically significant differences were observed in age, sex, and BMI, or implant length and diameter.

Binary Logistic Regression Analysis

The variables from the univariate analysis were used in the binary logistic regression model to determine the independent predictors of peri-implantitis. The results of binary logistic regression analysis are presented in Table 4.

Table 4: Binary Logistic Regression Analysis of Risk Factors for Peri-Implantitis.

Predictor Variable	Regression Coefficient (β)	Odds Ratio (OR)	95% Confidence Interval (CI)	P-value
Smoking History (Yes/No)	1.561	4.76	2.10 - 10.77	0.013
History of Diabetes (Yes/No)	1.642	5.16	2.12 - 12.57	0.037
Periodontal Disease (Yes/No)	1.432	4.18	1.94 - 9.02	<0.001
Regular Periodontal Treatment (Yes/No)	-1.326	0.27	0.12 - 0.60	0.006

Binary logistic regression analysis revealed that smoking history, history of diabetes, and history of periodontal disease were independent risk factors for developing peri-implantitis, with an odd's ratio of 4.76, 5.16, and 4.18, respectively. One discovered protective factor was regular periodontal treatment of the patients in the study, which yielded an OR of 0.27. From the presented data, it is clear that previous smoking, diabetes, and periodontal disease significantly increase the chances that the patient will develop peri-implantitis, whereas periodontal treatment can considerably lower this risk.

Predictive Model Validation

Nine variables that predicted the risk of peri-implantitis were confirmed in the validation group. Peri-implantitis risk scores were calculated, and the ability of the present model to predict the occurrence of peri-implantitis was evaluated using ROC curve analysis. Based on the ROC analysis, the results shown in table 5 were as follows:

Table 5: ROC Curve Analysis for Predictive Model.

Metric	Value
Area Under the Curve (AUC)	0.733
Sensitivity (%)	79.63
Specificity (%)	82.36
95% Confidence Interval (CI)	0.665 - 0.800
P-value	<0.01

ROC analysis of the current model yielded an AUC of 0.733, suggesting that the current model has good predictive validity. The accuracy coefficient, sensitivity, and specificity were determined to be 79.63% and 82.36%, respectively; hence, the model had a high predictive value. The result of the $P < 0.01$ also strengthens the argument for the model's effectiveness in estimating the risk of peri-implantitis.

Hypotheses Testing

The findings of binary logistic regression analysis were used to test the hypotheses. The findings of hypothesis testing are presented in table 6.

Table 6: Hypotheses Testing Results.

Hypothesis	Result	Supporting Evidence
H1: Smoking history is positively associated with peri-implantitis	Supported	OR = 4.76, P=0.013 (Table 4)
H2: History of diabetes is positively associated with peri-implantitis	Supported	OR = 5.16, P=0.037 (Table 4)
H3: History of periodontal disease is positively associated with peri-implantitis	Supported	OR = 4.18, P<0.001 (Table 4)
H4: Regular periodontal treatment is negatively associated with peri-implantitis	Supported	OR = 0.27, P=0.006 (Table 4)

All proposed hypotheses were supported by binary logistic regression analysis. Furthermore, smoking history, history of diabetes, and history of periodontal diseases were factors that predicted peri-implantitis risk, whereas regular periodontal treatment was a protective factor. These studies support the hypothesis and emphasize that the control of these risk factors should be aimed at eliminating peri-implantitis.

Confirmation of the Risk Forecasting Model

Of these 120 patients, 86 were included in the validation group of the present study. In the validation group, patients were analyzed after follow-up investigations; 10 cases of peri-implantitis were identified. The peri-implantitis risk prediction scores after dental implant surgery were determined based on the constructed risk prediction model for the validation group. As the test variable on the one hand, these risk scores were plotted together with the status variable peri-implantitis occurrence on the other hand to create a receiver operating characteristic (ROC) curve. The results revealed that The area under the ROC curve was 0.733 (95% confidence interval [CI], 0. The cookbook (CC) yield was 665–0.800, $P < 0.01$, sensitivity 79.63%, and specificity 82.36%. This also means that the risk prediction model developed in this study has a good level of predictive validity; hence, the model has a high predictive value. For more comprehensive information on the outcomes presented in this paper, please refer to the following figure Fig 1.

The findings of the present investigation indicate several potential predictors of peri-implantitis in patients who received dental implants. Positive smoking history, history of diabetes, and history of periodontal disease or treatment were associated factors, while regular periodontal treatment was a negative protective factor. The results of the study showed that the predictive model has high predictive validity, and its use can be considered to assess and minimize the risk of peri-implantitis development in clinical practice. In light of these results, there is a need to adopt specific preventive strategies for specific population groups as well as proper patient management to boost the efficacy and longevity of dental implants.

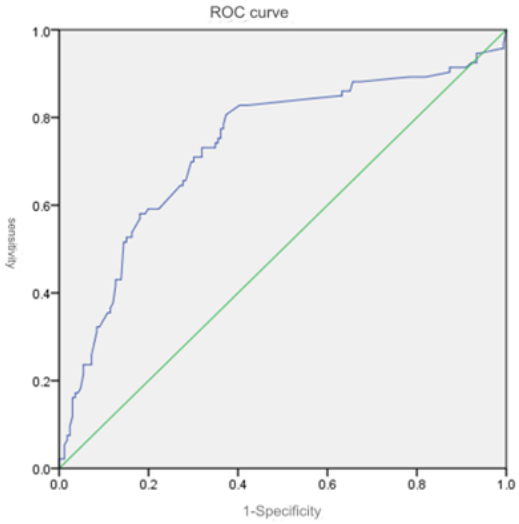

Figure 1: Receiver Operating Characteristic Curve of the Risk Prediction Model for Peri-implantitis in the Validation Group.

Discussion

This view informed the present study that sought to determine the predictors of peri-implantitis development in patients operated on for dental implants and created a model for the development of the condition. In light of these results, this study supports prior research and offers useful information regarding the control and treatment of peri-implantitis to improve the efficacy of dental implant treatments.

Smoking History and Peri-Implantitis

This study identified smoking history as a significant risk factor for peri-implantitis, with a ratio of 4.76. These findings are consistent with other studies demonstrating an adverse effect of smoking on peri-implant health based

on the pollutants in smoke, which can impair the host's immune system and reduce the blood flow to the gums.[9] That is why smoking cessation is central to peri-implant maintenance protocols and the treatments of the root cause of peri-implantitis, which can cause implant failure.[14] Authors further underlined that the clinical role of health care professionals must be extended to smoking patients (patients with smoking habits) and to the persuasion to attend the smoking cessation program to mitigate the risk of complications due to the dental implant therapy.[10]

Diabetes and Peri-Implantitis

The research further documented diabetes as an independent risk factor for peri-implantitis, with an overall ratio of 5.16 (patients with history of diabetes). Diabetes subjects are at increased risk of bacteremia, delayed wound healing, and immunosuppression and are thus more prone to peri-implant infection.[1,7] The factors that predispose to diabetes support bacterial proliferation and suppress the host's natural antimicrobial activity at the implant site, which significantly increases the risk of peri-implantitis. These risks can be reduced by good diabetes control, carbohydrate restriction and regular blood glucose monitoring, as reported by Sharma *et al*.[9]. Considering the special conditions of implant surgery, glycemic control in diabetic patients is of critical importance. Clinical personnel will need to have discussion and control blood glucose levels before and after surgery for these patients. In relation to the former history of periodontal diseases and its relation to the magnitude of peri-implantitis as observed in this study, the odds ratio of 4.18 supports the assumption that periodontal-disease-related inflammation and infection elevates the risk of peri-implantitis.[11] The emergence of pathogenic bacteria plus an increased inflammatory reaction further increases this risk.[2] Based on these results, patients with a previous history of periodontal disease ought to maintain a good periodontal status to avoid complications.[4] Periodontal therapy at high risk for peri-implantitis should be performed both before and after implant placement.[8]

Periodontal treatment has been recognized as an etiologic risk factor for peri-implantitis, with an odds ratio of 0.27. It has a decisive point on how to avoid peri-implantitis by guaranteeing that it is plaque and probing examination from a professional cleaning and that it can remove the plaque caught in place and can detect the early stages of an infection.[12] These strategies can be used to prevent the advance of peri-implantitis and increase the overall success of osseo integrated dental implants.[1] Regular periodontal maintenance is of great importance in the management of implants, and it is very important that high-risk patients, i.e., smokers or individuals with a previous history of periodontal disease, undergo periodontal treatment in addition to their routine implant maintenance. In the current study, researchers developed a predictive model for type 2 diabetes that achieved an accuracy of 73.3% in testing, with an AUC of 0.733, sensitivity of 79.63%, and specificity of 82.36%. In this model, clinicians can estimate the risk of peri-implantitis and, if necessary, implement preventive measures.[5] The fidelity of the model permits customized treatment regimens based on patient-specific risk factors and therefore, better prognosis and reduced risk of peri-implantitis in later stages.

Comparison between this Study and other Previous Studies

These findings are corroborated by a slew of other works that highlight the identified risk factors and underscore the need for protective measures. Concurrence in these findings is indicative of the trustworthiness of the revealed risk factors and the rationality of proposed prevention strategies.[4] This research builds on the literature dealing with PM and the potential strategies to enhance the efficacy and lifespan of dental implants. It provides an exploratory framework for the identification of the risk factors implicated in peri-implantitis after dental implant surgery and the establishment of a risk prediction model. Such evidence provides important guidance on the management of current literature on peri-implantitis, as it highlights certain actions that increase the risk for patients undergoing treatment with dental implants. To ensure the validity and reliability of the findings of this study, participants were matched according to certain demographic and clinical characteristics in both the modeling and validation groups. The overall prevalence of peri-implantitis among the sample collected in this study is 13.3%; differences between the modeling group and the validation group in terms of main characteristics were not found to be statistically significant, confirming the suitability of the sampling for the two other analyses. The findings of univariate analysis included smoking history, history of diabetes mellitus, history of periodontitis, and infrequent periodontal care among patients with peri-implantitis. Binary logistic regression analysis of these factors reinforced the conclusion from the literature review that smoking history, history of diabetes, and history of periodontal disease are independent risk factors for peri-implantitis, whereas regular periodontal treatment is a protective factor. These independent risk factors were incorporated into the predictive model created in this study, which provided evidence of a satisfactory level of predictive validity. According to the ROC curve analysis, the total AUC of the model was 0.733, sensitivity 79.63%, and specificity 82.36%, which confirms that our model possesses high practical value and can predict patients at risk of developing peri-implantitis. This increases the reliability of the model and indicates that the model would be beneficial to medical practice.

The first hypothesis was to evaluate the postoperative smoking history with regard to its impact on the incidence of peri-implantitis; this hypothesis was confirmed by the results of the study. Therefore, the regression analysis showed that smoking history increased the probability of peri-implantitis, with an odds ratio equal of 4.76. In accordance with these findings, previous studies have described the negative impact of smoking on peri-implant tissue conditions. The second hypothesis of the study, in which a history of diabetes is

significantly related to the occurrence of peri-implantitis, was also valid. Regression analysis showed that subjects with a history of diabetes had a peri-implantitis risk increase of 5.16 times the average. Many diseases can affect the body in various ways, but diabetes hinders the body's ability to heal itself, especially when it comes to wounds and the immune system, because it leads to the development of high sugar in the blood, which encourages bacterial and viral infections as well as inflammation. Therefore, the results highlight the critical importance of maintaining low blood sugar levels and efficient diabetic patient care, especially at the time of dental implant surgery, if the chances of developing peri-implantitis need to be reduced, and successful implant outcomes need to be achieved. The third hypothesis, stating that a history of periodontal disease increases the risk of developing peri-implantitis, is supported by the study findings. According to this study, the odds ratio of periodontal disease as a risk factor for peri-implantitis was 4.18. Periodontal disease is a risk factor for the development of peri-implantitis because it exposes the implant surface to pathogenic bacterial flora, leading to the creation of a marginal bone environment with increased inflammatory activity. The last hypothesis proposed was that periodontal treatment is inversely related to the development of peri-implantitis, and the results of this study supported this hypothesis. Periodontal treatment every six months which was found to be a protective factor, was given an odds ratio of 0.27. In this study, patients who followed RM schedules for Periodontal Maintenance had a lower risk of developing peri-implantitis. Self-performed and professionally performed cleanings and systematic check-ups of the periodontal situation are efficient in plaque removal, early signs of infection recognition, and hindering the development of peri-implantitis. Based on these results, it is advisable to integrate daily periodontal probing for periodontal diseases to improve implant outcomes and durability.

Previous studies provide detailed information about peri-implant diseases including peri-implantitis and peri-implant mucositis which create substantial difficulties in dental implantology.[15-18] A thorough understanding of these conditions demonstrates their widespread occurrence and multiple factors that initiate and advance their development.[19] Research shows that peri-implant diseases affect many patients and requires evidence-based treatments according to recent studies.[20] Research has identified specific microbiome signatures linked to peri-implantitis which provides insights into potential microbiome-based therapeutic approaches.[21-23] The interdependence between oral health and systemic health requires interdisciplinary management of these diseases.[24] Research into new peri-implantitis management approaches has gained substantial interest through studies that show innovative treatments could work alongside traditional methods.[25-28] Additionally the analysis of microbiota changes before and after treatment supports the biofilm "competitive balancing" effect for future therapeutic development.[29,30] The growing body of research about peri-implantitis and peri-implant mucositis emphasizes the need for a comprehensive approach to diagnosis and management of these conditions.[31, 32] Future investigations must explore the complex relationships between microbial communities and host responses and treatment approaches to improve clinical results and patient well-being. A comprehensive approach to these issues will create better management protocols which will enhance both peri-implant health and systemic well-being.

Conclusion

In conclusion, the present analysis underscores smoking history, history of diabetes, and history of periodontal disease as independent predictors of the risk of developing peri-implantitis or disease progression, and effective periodontal treatment as a protective factor against the development of peri-implantitis in implant patients. Thus, the peri-implantitis risk assessment predictive model created and confirmed in this investigation can be used by clinicians to manage the risk of further complications in patients who are candidates for dental implant surgery. Clinicians can keep more patients alive longer while helping dental implant procedures work better by actively looking for specific high-risk patients who need preventive actions.

Several clinically relevant implications can be derived from the present study. First, they emphasized the necessity of thorough patient assessment and management before and after dental implant surgery. Clinicians should therefore pay keen attention to some of the activities in the patients' past, including smoking, diabetes, and any signs of periodontal disease, and develop appropriate treatments accordingly. This is particularly important for patients who continue smoking or have a history of smoking, and smoking cessation programs should be actively recommended and included in treatment plans. Patients with diabetes require strict glycemic control and patient follow-up to minimize the development of peri-implantitis and to achieve favorable implant results. If the patient presented with periodontitis, periodontal treatment was performed and was followed up with constant maintenance to avoid the occurrence of peri-implantitis.

Second, this research emphasizes the methodology of check-ups in any case concerning the treatment of peri-implant tissue and inflammation. Professional cleaning and periodic examination of the periodontal status should be featured in the list of measures used for implant maintenance. These interventions are useful in the debridement of plaques, examination of the primary signs of infection, and development of peri-implantitis. Another significant factor that also cements the patient's understanding of proper care and regular maintenance required for implants to serve the protracted term is also crucial.

Third, the method of constructing the predictive model contributed to the easiest clinical application generally for the clinician to assess and intervene in the risk of peri-implantitis. The risk scores for patient criteria and the model can help clinicians precisely diagnose high-

risk patients to adopt suitable measures to decrease the occurrence of peri-implantitis. This approach can help improve the patients' quality of life, thereby minimizing the chances of undergoing extensive and expensive treatment for peri-implantitis.

In the future, it will be useful to use a prospective design to confirm the results of the proposed predictive model. In addition, it is noteworthy that participants were recruited only from patients who had undergone dental implant surgery in a particular hospital, which may also have reduced external validity. However, the studies that have informed this review should be expanded to include large samples as well as samples from different geographic locations and people of different ages and ethnicities.

Clinical Implications

The findings of this study have several practical implications for clinicians. First, it highlights the importance of patient appraisal and further treatment before and after implant surgical intervention. Clinicians should carefully consider patient history, especially the history of smoking, diabetes mellitus, and periodontal disease, and, based on this, develop individual patient treatment regimens. Cessation of smoking, aggressive glycemic control in patients with diabetes, and appropriate periodontal management in patients with a history of periodontal disease should be the key strategies to prevent peri-implantitis.

Second, the study confirmed the need for periodic periodontal therapy in the management of peri-implant health.[3] Prophylactic professional cleanings and periodic check-ups around implants should form part of the PMM protocols as they are useful in assessing the extension and intensity of infection and in eradicating plaque, which are ways of preventing PI (i.e., peri-implantitis). Understanding the necessity for regimen and cleanliness of the tissues of the oral cavity, particularly in patients requiring dental implants, also plays an important role in the long-term efficacy of dental implants.[1]

Third, it is possible to identify the possibility of creating a universal predictive model presented in this study as one of the approaches for evaluating the degree of risk of peri-implantitis for clinicians. This means that by determining risk scores based on a patient's clinical history, clinicians can introduce appropriate prevention measures for high-risk patients, making an overall improve patient outcomes, and reduce the demand for intricate treatments linked with peri-implantitis.[5] An even more proactive type of involvement, in advance of dental implant placement, can greatly enhance not only the rate of success of this kind of treatment, but also its durability.[11]

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