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Influence of smoking on peri-implant tissue health and implant survival

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Abstract:
Smoking is a major modifiable risk factor that adversely affects peri-implant tissue health and long-term dental implant survival. This hospital-based observational study compared 200 patients with functioning dental implants, including 100 smokers and 100 non-smokers, using standardized clinical and radiographic assessments of peri-implant parameters, marginal bone loss, peri-implant disease and implant survival. Smokers had significantly higher plaque index (1.94±0.49 vs. 1.43±0.38), probing pocket depth (4.21±0.82 vs. 3.18±0.67 mm), marginal bone loss (2.14±0.71 vs. 1.28±0.53 mm), peri-implantitis prevalence (25% vs. 9%) and lower implant survival (93% vs. 99%) than non-smokers (all $p<0.05$), with heavy smoking associated with greater peri-implantitis and implant failure. Smoking significantly compromised peri-implant tissue health and implant longevity in a dose-dependent manner. These findings advance knowledge by reinforcing smoking cessation and individualized peri-implant maintenance as essential strategies for improving long-term implant success.

Keywords: Dental implants, smoking, peri-implantitis, peri-implant mucositis, peri-implant tissue health, implant survival, marginal bone loss, osseointegration

Background:
The high long-term survival rate, excellent functional outcomes and good esthetic results of dental implants make them the gold standard for replacing missing teeth. Implant therapy has become much more predictable thanks to the progress made in the design of the implants, biomaterials, surgical techniques and the rehabilitation with prostheses **[1]**. But the success of the implant treatment is not only dependent on osseointegration but also on maintaining healthy peri-implant soft and hard tissues. Biological complications of peri-implant tissues continue to be a significant problem in implant failure and it is crucial to identify risk factors for long-term implant success. The World Workshop on the Classification of Periodontal and Peri-Implant Diseases in 2017 set up a uniform diagnostic framework for peri-implant health, peri-implant mucositis and peri-implantitis, respectively **[2].** Peri-implant diseases are inflammatory disorders of the tissues around dental implants. Peri-implant mucositis is a reversible inflammation of the soft tissues only, while peri-implantitis is a progressive inflammation with supporting bone loss **[3].** While microbial biofilm is the main etiological cause, there are some systemic and behavioral factors that affect the susceptibility and progression of the disease. The importance of early diagnosis, frequent maintenance and good control of modifiable risk factors for maintaining peri-implant tissue health and long-term implant survival has been recently highlighted **[4].** Cigarette smoking is one of the most important patient-related risk factors for implant failure and peri-implant disease and has been widely studied. Tobacco smoke contains toxic components such as nicotine, carbon monoxide and reactive oxygen species, which affect angiogenesis, tissue oxygenation, immune responses, fibroblast function, collagen synthesis and bone metabolism **[5, 6]**. Madi *et al.* reviewed the effects of smoking on periodontal and implant therapy and reported poorer clinical outcomes among smokers, including an increased risk of implant failure among individuals with heavy cigarette consumption. Their review also highlighted the potential benefits of smoking cessation in improving periodontal treatment outcomes **[7]**. The negative impact is also dose dependent as heavy smokers had worse clinical results than light smokers or former smokers, emphasizing the need to stop smoking before and after implant placement **[8].** Consensus reports have also provided a better understanding of the biological pathways that lead to peri-implant disease. Long-term exposure to tobacco influences host immune responses facilitates pathogenic biofilm colonization and impairs tissue repair, which accelerates the transition from peri-implant mucositis to peri-implantitis. Patients with chronic behavioral risk factors, however, need more intensive peri-implant supportive maintenance to maintain implant health **[9].** Smoking has been consistently shown by recent systematic reviews and meta-analyses to be one of the strongest behavioral risk factors for peri-implant mucositis, peri-implantitis, marginal bone loss and implant failure. Smoking and previous periodontal disease, poor plaque control and inadequate maintenance significantly increase the risk of biological complications, making it important to assess each patient's risk before undergoing implant therapy **[10].** Due to the increasing prevalence of peri-implant diseases, the Academy of Osseointegration and the American Academy of

Periodontology have recommended a comprehensive patient evaluation, smoking cessation counselling, meticulous plaque control, individualized maintenance protocols and early intervention to minimize peri-implant complications and maximize implant survival rates **[11].** Therefore, it is of interest to assess the effect of smoking on peri-implant tissue health and implant survival by comparing clinical peri-implant parameters, marginal bone loss, prevalence of peri-implant disease and implant survival between smokers and non-smokers who received implant-supported rehabilitation.

Materials and Methodology:

Study design:

The present study was a hospital-based comparative observational study to assess the effect of smoking on peri-implant tissue health and implant survival in patients rehabilitated with dental implants.

Study setting and duration:

This study was conducted in the Department of Periodontology and Oral Implantology in a tertiary care dental teaching hospital for 18 months. Standardized departmental protocols were followed for clinical examinations, radiographic assessment and follow-up.

Study population:

This study comprised adult patients with one or more functioning endosseous dental implants with fixed prostheses, who were seen at the outpatient department for routine follow-up visits.

Sampling:

The participants were 200, who were sampled consecutively and split into two groups of 100.

[1] Group I (Smokers): 100 patients who had a smoking history of at least 1 year prior to implant placement and who smoked throughout the study.

[2] Group II (Non-smokers): 100 patients who have never smoked cigarettes.

Inclusion criteria:

[1] Age ≥18 years.

[2] At least one is working dental implant for at least 12 months.

[3] Baseline clinical and radiographic records.

[4] Ability to give written informed consent.

[5] Good attendance for implant maintenance and follow-up.

Exclusion criteria:

Patients were excluded if they had uncontrolled diabetes mellitus, pregnancy or lactation, previous head and neck radiotherapy, immunocompromised condition, long-term corticosteroid or bisphosphonate therapy, untreated periodontal disease, alcohol or substance abuse, inadequate radiographic records, or unwillingness to participate.

Study variables:

The following variables were measured:

[1] **Demographic factors:** age, gender, body mass index (BMI) and occupation.

[2] **Smoking variables:** duration of smoking, cigarettes smoked per day, pack-years and smoking frequency.

[3] **Implant variables:** implant location, dimensions, number of implants, type of prosthesis, duration of function of the implant.

[4] **Clinical parameters:** Plaque Index (PI), Modified Gingival Index (MGI), Bleeding on Probing (BOP), Probing Pocket Depth (PPD), Clinical Attachment Level (CAL), peri-implant mucositis and peri-implantitis.

[5] **Radiographic assessment:** Standardized intraoral periapical radiographs or cone-beam computed tomography (CBCT), as appropriate, were taken to measure the distance between the implant platform and the first bone-to-implant contact on the mesial and distal sides for each implant.

Implant survival assessment:

The success of implants was defined as no mobility, no persistent pain, no suppuration and no progressive peri-implant bone loss. Biological or mechanical problems with the implant were judged to be failures.

Data collection:

Demographic and medical information and smoking history were documented after obtaining written informed consent. A calibrated periodontal probe was used for clinical peri-implant examination under standardized conditions. Radiographic assessment was performed to evaluate marginal bone loss and implant survival was recorded for each patient.

Outcome measures:

The main outcome was to compare the health of peri-implant tissues among smokers and non-smokers. Secondary outcomes were marginal bone loss, prevalence of peri-implant mucositis and peri-implantitis, implant survival rate and relationship between smoking intensity and peri-implant disease.

Statistical analysis:

The data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). The continuous variables were presented as mean ± SD and the categorical variables as frequencies and percentages. Continuous variables were compared using Independent Student's t-test while categorical variables were compared using Chi-square test or Fisher's exact test. Logistic regression analysis was used to assess the relationship between smoking and peri-implant disease, while controlling for potential confounding factors. A p-value < 0.05 was deemed as statistically significant.

Results:

A total of 200 patients with functioning dental implants were included in the study. The participants were divided equally into smokers (n=100) and non-smokers (n=100). Baseline demographic characteristics were comparable between the two groups. Clinical peri-implant parameters, radiographic marginal bone loss, peri-implant disease prevalence and implant survival were analyzed. Statistical significance was considered at $p < 0.05$. The mean age of smokers (45.8 years) and non-smokers (44.9 years) was comparable (p=0.521). Male patients predominated in both groups (82% vs. 79%). No statistically significant differences were observed regarding gender distribution, BMI, duration of implant function, or type of prosthetic rehabilitation (p>0.05), indicating that both groups were well matched for baseline characteristics **(Table 1).** Smokers demonstrated significantly poorer peri-implant tissue health than non-smokers. Mean plaque index (1.94 vs. 1.43), modified gingival index (1.82 vs. 1.29), probing pocket depth (4.21 mm vs. 3.18 mm) and clinical attachment loss (2.68 mm vs. 1.79 mm) were significantly greater among smokers (p<0.001). Bleeding on probing was observed in 42% of smokers compared with 27% of non-smokers (p=0.026), indicating increased peri-implant inflammation in individuals who smoked **(Table 2).** Radiographic assessment showed significantly greater marginal bone loss among smokers (2.14 ± 0.71 mm) compared with non-smokers (1.28 ± 0.53 mm) (p<0.001). Healthy peri-implant tissues were observed in only 44% of smokers versus 69% of non-smokers. Peri-implantitis was significantly more prevalent in smokers (25%) than non-smokers (9%, p=0.002). Although peri-implant mucositis occurred more frequently among smokers (31% vs. 22%), the difference did not reach statistical significance (p=0.148) **(Table 3).** Implant survival was significantly lower among smokers (93%) than non-smokers (99%) (p=0.031). Implant failure occurred in 7% of smokers compared with 1% of non-smokers. Heavy smokers (≥10 cigarettes/day) demonstrated a significantly greater prevalence of peri-implantitis (33.3%) than lighter smokers (15.2%, p=0.011). Furthermore, patients experiencing implant failure had a significantly higher cumulative smoking exposure, with a mean of 17.8 ± 4.3 pack-years (p=0.004), suggesting a dose-dependent detrimental effect of smoking on implant prognosis **(Table 4)**.

Table 1: Baseline demographic characteristics of the study participants

Variable	Smokers (n=100)	Non-smokers (n=100)	p value
Mean age (years)	45.8 ± 9.7	44.9 ± 10.2	0.521
Male	82 (82%)	79 (79%)	0.592
Female	18 (18%)	21 (21%)	
Mean BMI (kg/m²)	24.9 ± 3.2	24.3 ± 3.1	0.211
Mean implant functional period (years)	3.8 ± 1.5	3.6 ± 1.4	0.366
Single implant restoration	66 (66%)	69 (69%)	0.648
Multiple implant restoration	34 (34%)	31 (31%)	

Table 2: Comparison of peri-implant clinical parameters

Parameter	Smokers (Mean ± SD)	Non-smokers (Mean ± SD)	p value
Plaque Index	1.94 ± 0.49	1.43 ± 0.38	<0.001*
Modified Gingival Index	1.82 ± 0.45	1.29 ± 0.34	<0.001*
Probing Pocket Depth (mm)	4.21 ± 0.82	3.18 ± 0.67	<0.001*
Bleeding on Probing (%)	42 (42%)	27 (27%)	0.026*
Clinical Attachment Loss (mm)	2.68 ± 0.76	1.79 ± 0.59	<0.001*

Table 3: Radiographic bone loss and peri-implant disease

Variable	Smokers (n=100)	Non-smokers (n=100)	p value
Mean marginal bone loss (mm)	2.14 ± 0.71	1.28 ± 0.53	<0.001*
Healthy peri-implant tissues	44 (44%)	69 (69%)	<0.001*
Peri-implant mucositis	31 (31%)	22 (22%)	0.148
Peri-implantitis	25 (25%)	9 (9%)	0.002*

Table 4: Implant survival and smoking-related outcomes

Outcome	Smokers (n=100)	Non-smokers (n=100)	p value
Implant survival	93 (93%)	99 (99%)	0.031*
Implant failure	7 (7%)	1 (1%)	
Smokers ≥10 cigarettes/day with peri-implantitis	18/54 (33.3%)	—	0.011*
Smokers <10 cigarettes/day with peri-implantitis	7/46 (15.2%)	—	
Mean pack-years among implant failures	17.8 ± 4.3	—	0.004*

Discussion:

The aim of the present study was to investigate the effect of smoking on peri-implant tissue health and implant survival in smokers versus non-smokers with functioning dental implants. The smokers had significantly higher levels of plaque build-up, gingival inflammation, probing pocket depth, clinical attachment loss, prevalence of peri-implantitis and marginal bone loss and a significantly lower implant survival rate. The results suggest that smoking has a negative impact on the health of peri-implant tissues and on long-term implant prognosis **[12]**. Consistent with these findings, Gopi and Singh compared implant outcomes in 100 participants over a 12-month follow-up and reported lower implant survival, greater marginal bone loss and a higher prevalence of peri-implant complications among smokers than non-smokers. These findings further support the association between smoking and adverse implant outcomes

[13]. Reis *et al.* **[14]** conducted a systematic review and meta-analysis of the effect of smoking on peri-implantitis and found that smokers were at a significantly higher risk of developing peri-implantitis than non-smokers. The authors hypothesized that smoking-related impaired vascularity, altered immune responses and delayed healing play a role in the progression of disease. These findings are consistent with the significantly higher prevalence of peri-implantitis found among smokers in the present study and support smoking as a major risk factor for peri-implant inflammatory destruction, as outlined by the European Federation of Periodontology clinical practice guideline, which stressed comprehensive risk assessment, smoking cessation, effective plaque control and supportive peri-implant maintenance as essential components for preventing peri-implant diseases. The poorer peri-implant tissue health seen in smokers in the present study further supports these recommendations and emphasizes the need for customized maintenance programs for smokers **[15]**. Pereira *et al.* summarised the current therapeutic approaches for peri-implant mucositis and stated that early diagnosis, mechanical removal of biofilm, reinforcement of oral hygiene and the removal of risk factors like smoking are essential to prevent the onset of peri-implantitis. In the present study, the prevalence of peri-implant mucositis was higher in smokers, suggesting that smoking is a risk factor for persistent inflammation and disease progression of peri-implant tissues if appropriate preventive measures are not implemented **[9]**. In an AO/AAP systematic review and meta-analysis, Galarraga-Vinueza *et al.* found smoking to be one of the strongest behavioral risk factors for peri-implant mucositis, peri-implantitis and marginal bone loss and implant failure **[16]**. In line with the present study, Mohsin *et al.* showed that smoking negatively affects osseointegration by affecting angiogenesis, osteoblastic activity, wound healing and inflammatory bone resorption, all of which contribute to higher implant failure rates **[17]**. Sun *et al.* stated that to prevent and manage peri-implant diseases, meticulous plaque control, patient education, regular supportive maintenance and elimination of modifiable risk factors are essential. They recommended closer follow-up of smokers because of their increased susceptibility to peri-implant inflammation. In the current study, smokers had significantly worse peri-implant tissue health than non-smokers, even with functional implant-supported restorations, which was also observed in other studies **[18].** Smoking was also one of the main behavioral risk factors for peri-implant diseases and implant-related defects, as reported by Kumar *et al.* in the AO/AAP consensus report. The report noted that smoking, along with bacterial biofilm accumulation, prior periodontal disease and poor maintenance, significantly contributes to the risk of biological complications. These consensus recommendations are supported by the significantly greater plaque index, probing depth and peri-implantitis that were seen in smokers in the present investigation **[19]**. Elena *et al.* conducted a systematic review of the impact of conventional cigarette smoking and smoke-free tobacco products on implant therapy and found that tobacco exposure negatively impacts osseointegration, peri-implant soft tissue healing, marginal bone preservation and implant survival. They also found a dose-response relationship between the intensity of smoking and complications of implants. In keeping with these results, the present study found that heavy smokers had significantly more peri-implantitis and implant failure than lighter smokers, thus suggesting that heavy cigarette smoking further adversely affects implant prognosis **[20]**. Mayer *et al.* evaluated the impact of heavy cigarette smoking on implant healing and reported delayed osseointegration, increased probing depths, peri-implant inflammation and significantly increased marginal bone loss in heavy smokers (more than 1 pack per day). The same was seen in the present study, as cumulative smoking exposure (pack-years) was positively correlated with implant failure and peri-implant disease, highlighting the detrimental effect of long-term smoking on implant success **[21]**. Windael *et al.*, however, provided long-term prospective data on 453 dental implants that were followed for 10 years and found that smokers had significantly lower implant survival and success rates than non-smokers **[22]**. Their study found that smoking has a negative impact on the stability of peri-implant tissues, even with the use of modern implant systems and maintenance protocols. The overall results of the present study are in line with recent systematic reviews, consensus statements and long-term clinical studies. There was a consistent trend in the poorer peri-implant tissue health, higher marginal bone loss, higher prevalence of peri-implantitis and lower implant survival in smokers compared to non-smokers. The results of this study underscore the need for thorough risk assessment, smoking cessation counselling, careful plaque management and personalized supportive peri-implant care to reduce biological complications and enhance long-term outcomes of dental implant therapy.

Conclusion:

Smoking was associated with greater peri-implant inflammation, probing depths, marginal bone loss and peri-implantitis prevalence. Smokers also exhibited lower implant survival rates than non-smokers, highlighting smoking as an important modifiable risk factor in implant dentistry. Pre-operative risk assessment, smoking cessation counselling, effective plaque control and regular supportive peri-implant maintenance may help reduce biological complications and improve long-term implant outcomes.

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