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Original Article

Dentistry Section

Comparative Analysis of SLA and SLActive Implant Surfaces on Peri-implant Clinical, Radiographic, and MMP-8 Parameters after One Year of Functional Loading: A Cross-sectional Study

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ABSTRACT

Introduction: The longevity of dental implants depends on stable osseointegration and controlled host response. Surface modifications such as Sandblasted, Large-grit, Acid-etched (SLA), and chemically modified SLActive implants aim to enhance osseointegration; however, their long-term influence on peri-implant health remains unclear. This study compared clinical and biochemical parameters of SLA and SLActive implants after a minimum of one year of functional loading.

Aim: To comparatively evaluate peri-implant clinical parameters, radiographic Crestal Bone Levels (CBL), and Peri-Implant Crevicular Fluid (PICF), Matrix Metalloproteinase-8 (MMP-8) concentrations in SLA and SLActive implant surfaces after a minimum of one year of functional loading.

Materials and Methods: This cross-sectional study was conducted at the Department of Periodontology, Saveetha Dental College and Hospitals, Chennai, Tamil Nadu, India, from December 2024 to December 2025. A total of 70 systemically healthy patients aged 30-60 years with single-tooth implants placed in healed mandibular posterior sites and functionally loaded for at least 12 months were included. Participants were divided into two groups: Group 1-SLA (n=35) and Group 2-SLActive (n=35). Baseline characteristics, including age, gender, Plaque Index (PI), and Gingival Index (GI), were recorded. Peri-Implant Probing Depth (PPD), CBL, and PICF, MMP-8 concentrations were assessed. PICF samples were collected using microcapillary pipettes and analysed via ELISA. Continuous variables were compared using Independent t-tests, and categorical variables (gender) were analysed using the Chi-square test; $p<0.05$ was considered statistically significant.

Results: Baseline characteristics, including age, gender, PI, and GI, were comparable between groups ($p>0.05$). The mean PPD was 4.50±0.45 mm in SLA and 4.48±0.50 mm in SLActive implants ($p=0.86$). CBL values were 0.84±0.18 mm and 0.82±0.20 mm, respectively ($p=0.66$). MMP-8 concentrations showed no significant difference (3.21±0.40 ng/mL for SLA vs. 3.18±0.38 ng/mL for SLActive; $p=0.75$).

Conclusion: SLA and SLActive implants demonstrated comparable peri-implant clinical, radiographic, and biochemical parameters after one year of functional loading, suggesting similar tissue response under clinically stable peri-implant conditions.

Keywords: Dental implants, Inflammation, Microgeometry, Peri-implant health, Surface modification

INTRODUCTION

Dental implants are a well-established and predictable modality for the rehabilitation of edentulous spaces, with their long-term success dependent on maintaining a delicate balance between stable osseointegration and the host immune response [1]. Disruption of this equilibrium can precipitate peri-implant diseases, ranging from reversible peri-implant mucositis to the more destructive peri-implantitis. Peri-implant mucositis is characterised by inflammation confined to the peri-implant soft tissues without bone involvement, whereas peri-implantitis is defined by progressive peri-implant bone loss. These conditions are multifactorial in origin, with microbial biofilms and dysregulated host inflammatory mechanisms playing central roles. Once triggered, the inflammatory cascade promotes the release of cytokines and proteolytic enzymes, leading to extracellular matrix degradation and alveolar bone resorption [2,3].

In parallel with advances in understanding host-pathogen interactions, considerable research has focused on optimising implant surface properties to enhance osseointegration and mitigate peri-implant inflammation [4-6]. Surface topography and chemical composition significantly influence cellular adhesion, proliferation, and differentiation, thereby shaping both the stability of bone–implant integration and the local immune milieu [7,8]. Among the most widely used surface treatments, SLA surfaces and their advanced variant, SLActive surfaces, have demonstrated substantial clinical relevance [9].

The SLA surfaces are created by sandblasting with large-grit particles followed by acid etching, producing a micro-roughened surface that facilitates early bone anchorage and enhances osteoblast activity. This surface design significantly improves the mechanical interlocking between the implant and the surrounding bone, accelerating the early phases of osseointegration compared with machined implants. However, SLA surfaces exhibit hydrophobic properties, which may influence protein adsorption and cellular interactions during the early healing phase[10,11].

To overcome this limitation, the SLActive surface was developed as a chemically modified version of SLA, preserving the same microtopography while introducing a higher surface energy and enhanced hydrophilicity through chemical conditioning and storage in an isotonic saline solution. These characteristics promote rapid blood wetting, improved fibrin adhesion, and more effective protein and cell attachment, resulting in faster and more predictable osseointegration [12]. Clinical and preclinical studies have indicated that SLActive surfaces may provide superior early implant stability and increased bone-implant contact compared with conventional

SLA surfaces [13,14]. However, the long-term biological implications of these modifications, particularly their influence on the peri-implant inflammatory environment after functional loading, remain an important area of investigation.

Biochemical markers such as Matrix Metalloproteinase-8 (MMP-8) provide a sensitive means of assessing peri-implant tissue responses. MMP-8, also known as neutrophil collagenase, is a key enzyme responsible for degrading type I collagen, the principal structural component of periodontal and peri-implant connective tissues. Elevated levels of MMP-8 levels in Peri-implant Crevicular Fluid (PICF) indicate early inflammatory changes and connective tissue breakdown, often preceding clinical signs of peri-implant disease [15]. Monitoring MMP-8 levels thus provides valuable insight into the host–implant interaction and the potential inflammatory risk associated with different surface modifications.

Against this background, the present cross-sectional study aimed to compare peri-implant clinical and radiographic parameters along with PICF MMP-8 levels in implants with SLA and SLActive surfaces after a minimum of one year of functional loading.

The null hypothesis stated that there would be no significant differences in peri-implant clinical, radiographic, or MMP-8 outcomes between SLA and SLActive implants, whereas the alternative hypothesis proposed that significant differences would be present, reflecting a distinct biological response to the surface modification.

MATERIALS AND METHODS

This cross-sectional study was conducted at the Department of Periodontology, Saveetha Dental College and Hospitals, Chennai, Tamil Nadu, India, from December 2024 to December 2025. Ethical approval was obtained from the Scientific Review Board (Approval number: SRB/SDC/PERIO-2403/24/532), and written informed consent was obtained from all participants in accordance with the Declaration of Helsinki (1975, revised 2013).

Sample size: The sample size was calculated using G*Power software (version 3.0) based on mean±Standard Deviation (SD) values of PPD reported in a previous study [16], which were 3.16±0.55 mm for SLA and 2.80±0.41 mm for SLActive implants. With a significance level of 0.05 and 80% power, this calculation yielded a total sample size of 70 implants (35 per group).

Inclusion criteria: The inclusion criteria were systemically healthy individuals aged 30-60 years, with single-tooth implants placed in healed sites (delayed placement) in the mandibular posterior region, adequate bone volume, and functionally loaded for at least 12 months before enrolment. A minimum of 2 mm of keratinised mucosa around the implant and maintenance of plaque and Gingival Index (GI) scores between 0.1-0.9 and 0.1-1.0 [17], respectively, were also required. These criteria were used to identify implants with clinically stable peri-implant conditions at the time of evaluation.

Exclusion criteria: Smokers, pregnant or lactating women, patients with poor oral hygiene or parafunctional habits, those with systemic conditions, metabolic bone disorders, a history of previous implant failure, or undergoing therapy with intravenous amino-bisphosphonates, as well as individuals on long-term medications or those who had undergone bone grafting procedures during implant placement were excluded.

Study Procedure

The study included patients aged 30-60 years who had received single-tooth implants with SLA or SLActive surfaces in the mandibular posterior region, placed in healed sites (delayed placement), with adequate bone volume, and functionally loaded for a minimum of 12 months before enrollment. A total of 70 subjects who fulfilled the criteria were recruited, each with a single implant. Based on the surface modification, participants were divided into two groups:

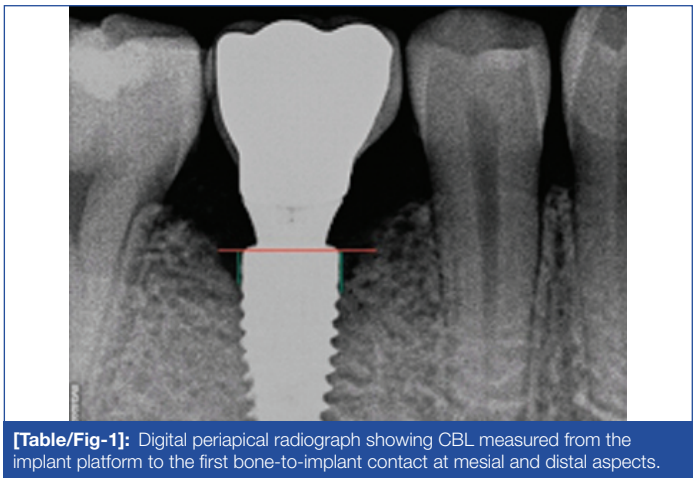
- Group 1 (n=35): SLA implants (SLA®, Straumann, Basel, Switzerland).
- Group 2 (n=35): SLActive implants (SLActive®, Straumann, Basel, Switzerland).

All implants were bone-level, internal-hex, root-form designs with different platform dimensions.

Clinical assessment and sample collection: The implants included in the study had been previously placed and functionally loaded for a minimum of 12 months before evaluation. All measurements and sample collection were performed at a single time point during the study period. At the time of assessment, PPD, CBL, and PICF samples were obtained for MMP-8 analysis.

Clinical examination: The PPD was recorded at six sites per implant (mesiobuccal, midbuccal, distobuccal, mesiolingual, midlingual, and distolingual) using a calibrated periodontal probe. The mean PPD for each implant was calculated and documented.

Radiographic examination: Digital periapical radiographs were obtained using the paralleling angle technique. CBL was calculated by measuring the distance from the implant platform to the first implant-to-bone contact at both the mesial and distal aspects [Table/Fig-1], with the average being recorded.



[Table/Fig-1]: Digital periapical radiograph showing CBL measured from the implant platform to the first bone-to-implant contact at mesial and distal aspects.

All clinical and radiographic measurements were performed by a single trained examiner (NJ). Prior to the study, the examiner underwent calibration sessions to ensure measurement reliability. Intra-examiner reliability was assessed by repeating PPD and CBL measurements on 10 randomly selected implants after 48 hours, yielding a Cohen's kappa value of 0.92, indicating excellent agreement.

Analysis of MMP-8: Supragingival plaque was removed using sterile curettes, and the site was isolated with sterile cotton rolls. PICF samples were collected using calibrated microcapillary pipettes and stored at -20°C until analysis. The concentration of MMP-8 was determined using a human MMP-8 ELISA kit (Elabscience®, USA) in accordance with the manufacturer's protocol. Optical density was measured at 450±2 nm using a spectrophotometer, and results were expressed in ng/mL. The assay detection range was 0.16-10 ng/mL.

STATISTICAL ANALYSIS

Data were analysed using IBM Statistical Package for Social Sciences (SPSS) software version 23.0 (IBM Corp., Armonk, NY, USA). Continuous variables, including age, PI, GI, PPD, CBL, and MMP-8 concentrations, were expressed as mean±SD. Normality of data distribution was assessed using the Shapiro-Wilk test. Since the data were normally distributed, an independent sample t-test was applied to compare continuous variables between the SLA and SLActive groups. Categorical variables such as gender were compared using the Chi-square test. A p-value <0.05 was considered statistically significant.

RESULTS

A total of 70 participants (35 in each group) were analysed. The mean age was 44.2±6.1 years in the SLA group and 45.0±5.8 years in the SLActive group (p=0.52). Gender distribution was similar, with 18 males and 17 females in the SLA group and 17 males and 18 females in the SLActive group (p=0.80). The mean PI was 0.62±0.15 for SLA and 0.60±0.14 for SLActive (p=0.48), while the mean GI was 0.72±0.18 and 0.70±0.16, respectively (p=0.55). These findings indicate no statistically significant differences between the groups at baseline [Table/Fig-2].

Parameters	SLA (n=35) (Mean±SD)	SLActive (n=35) (Mean±SD)	Test value	p-value
Age (in years)	44.2±6.1	45.0±5.8	0.65	0.52a
Gender (M/F)	18/17	17/18	0.06	0.80b
Plaque Index (PI)	0.62±0.15	0.60±0.14	0.70	0.48a
Gingival Index (GI)	0.72±0.18	0.70±0.16	0.60	0.55a

[Table/Fig-2]: Baseline characteristics of participants in the SLA and SLActive groups.
[a]Independent sample t-test; [b]Chi-square test; p-value <0.05 - statistically significant.

The mean PPD was 4.50±0.45 mm in group 1 and 4.48±0.50 mm in group 2 (p=0.86). Similarly, the mean CBL measured 0.84±0.18 mm in group 1 and 0.82±0.20 mm in group 2 (p=0.66). The biochemical marker MMP-8 showed mean values of 3.21±0.40 ng/mL for group 1 and 3.18±0.38 ng/mL for group 2 (p=0.75). These results indicate that both groups were comparable, with no significant differences observed across the evaluated parameters (p>0.05) [Table/Fig-3].

Variables	Group 1	Group 2	Test value	p-value[a]
PPD (mm)	4.50±0.45	4.48±0.50	0.18	0.86
CBL (mm)	0.84±0.18	0.82±0.20	0.44	0.66
MMP-8 (ng/mL)	3.21±0.40	3.18±0.38	0.32	0.75

[Table/Fig-3]: Intergroup comparison of peri-implant parameters between groups.
[a]Independent sample t-test; p-value <0.05 - statistically significant. PPD: peri-implant probing depth; CBL: Crestal bone level; MMP-8: Matrix metalloproteinase-8

DISCUSSION

The long-term success of dental implants is determined by the interplay between implant surface characteristics and peri-implant tissue responses. Among these, SLA and its chemically modified counterpart, SLActive, have been extensively investigated for their potential to enhance osseointegration and maintain peri-implant health. In the present study, PPD, CBL, and PICF MMP-8 concentrations were assessed after a minimum of one year of functional loading. The findings revealed no statistically significant differences between SLA and SLActive implants across all evaluated parameters, suggesting that both surfaces provide comparable peri-implant tissue stability and inflammatory status under clinically stable peri-implant conditions.

These outcomes are in agreement with previous experimental and clinical investigations. Philipp A et al., demonstrated similar bone-to-implant contact in a sheep sinus augmentation model for both surfaces, with only minor differences favouring SLActive at 26 weeks [18]. Long-term clinical observations by Sener-Yamaner ID et al., reported marginal bone loss of 0.71 mm for SLA and 0.53 mm for SLActive over 81 months, with no clinically meaningful differences in soft tissue parameters [19]. Jayaprakash PK et al., observed ISQ values for both SLA and SLActive surfaces tested were not significantly different [20]. Likewise, Ozel GS et al., and Schätzle O et al., documented comparable implant stability between SLA and SLActive surfaces during early healing phases [21,22], while Marković A et al., and Khandelwal N et al., confirmed similar outcomes under medically compromised conditions such as anticoagulant therapy and poorly controlled diabetes [23,24]. Systematic reviews and meta-analyses further corroborate that both surfaces exhibit equivalent survival rates, marginal bone stability, and peri-implant soft tissue health [25,26].

Biochemical evidence supports this clinical equivalence. Gnanajothi J and Rajasekar A reported significantly higher IL-1β levels in anodised TiUnite implants compared to SLA and SLActive at three months and one year, while no difference was observed between SLA and SLActive [27]. Likewise, Janagarathinam P and Rajasekar A found elevated TNF-α and decreased IL-10 in TiUnite implants, indicating a heightened inflammatory response relative to sandblasted and acid-etched surfaces [28]. These findings align with the present study, wherein MMP-8 concentrations, a key collagenolytic enzyme indicative of peri-implant tissue breakdown, remained comparable between SLA and SLActive, reinforcing the concept that both surfaces elicit a similar host response under healthy conditions.

Based on these results, the null hypothesis that there would be no difference in clinical, radiographic, or biochemical parameters between the two surfaces was accepted, while the alternative hypothesis was rejected. These findings suggest that, in systemically healthy patients with well-maintained oral hygiene, either SLA or SLActive implants can be used reliably without expecting significant differences in peri-implant tissue health after one year of functional loading. Implant selection may therefore be guided by practical considerations such as cost, availability, or clinician preference rather than surface modification alone.

Future investigations involving larger patient cohorts, longitudinal designs, multiple inflammatory and bone remodelling biomarkers, and high-risk populations are warranted to explore early-phase host responses and better understand the temporal evolution of peri-implant tissue changes. Such studies may help refine clinical protocols and optimise implant performance across diverse clinical scenarios.

Limitation(s)

The cross-sectional design limits the ability to capture early-phase dynamics of peri-implant biomarkers. Additionally, only a single inflammatory marker (MMP-8) was assessed, which may not fully reflect the complex immunological environment around implants. Further longitudinal studies with multiple biomarkers and stratified patient populations are needed to more comprehensively evaluate the biological performance of SLA and SLActive surfaces.

CONCLUSION(S)

The findings of the present study indicated that SLA and SLActive implant surfaces demonstrate comparable long-term clinical performance in terms of PPD, CBL, and PICF MMP-8 concentrations following a minimum of one year of functional loading. These results suggest that both implant surface modifications are equally effective in maintaining peri-implant tissue stability and controlling inflammatory responses under clinically stable peri-implant conditions.

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