Tufts UNIVERSITY | School of Dental Medicine

Prosthetic factors associated with the prevalence of peri-implant biological complications in fully digital guided implants: a cross-sectional study

A Thesis Presented to the Faculty of Tufts University School of Dental Medicine in Partial Fulfillment of the Requirements for the Degree of Master of Science in Dental Research

By

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May 2024

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ABSTRACT

Aims & Hypothesis:

The aim of this study was:

To determine the association between prosthetic factors and peri-implant diseases in digitally guided implant placement with at least one year in function.

Hypothesis:

The current cross-sectional study posed the hypothesis that prosthetic factors would be associated with the prevalence of peri-implant diseases. This expectation was based on the assumption that the use of digital guidance allows for meticulous prosthetic planning, leading to a more suitable three-dimensional implant positioning in relation to the prosthesis.

Materials & Methods:

In this cross-sectional analysis, the electronic health records of 480 patients with partial or full edentulism who had received implant-supported or implant-retained prostheses at the Implant Center in the Department of Prosthodontics at Tufts University School of Dental Medicine were reviewed. After screening, 164 patients were found eligible, and a detailed assessment was carried out during regular maintenance visits for 115 patients with 417 implants. Implant-related variables (region, loading time, implant connection, loading protocol, implant diameter, implant length, implant surface treatment, type of prosthesis, type of supraconstruction, cement/screw-retained, crown-to-implant ratio (C/I), emergence angle (EA), emergence profile (EP), presence of cantilever, distance to outer contour of prosthesis, type of implant (bone/tissue level), platform switching, surface treatment, mucosal height of abutment, interproximal contact level, horizontal distance from implant to adjacent teeth, inter-implant distance, angulation of implant, angulation of abutment, angulation between long-axis of splinted implants and presence of open contact) were collected by chart review and radiographic assessments. Clinical parameters (plaque index (PI), probing depth (PD), bleeding on probing (BOP), suppuration (SUP), mucosal recession (MR), keratinized mucosa (KM), adhered mucosa (AM) and presence of open contact) were collected at 6 sites of each implant. Periapical radiographs were used to measure marginal bone levels (MBL). Peri-implant diseases were diagnosed according to a defined criterion. Generalized Linear Mixed Model (GLMM) for Bi-variate and multivariable analyses were carried out to evaluate the variables associations with diagnosis, bleeding on probing levels (BOP) and marginal bone level (MBL).

Results:

A total of 115 patients (60 men, 55 women, mean age of 60.87 ± 13.37 years) with 417 implants were included in this study data. Following the 2017 World Workshop definition, the implants were diagnosed as peri-implant health, peri-implant mucositis or peri-implantitis. A total of 156 implants were diagnosed as healthy, 241 with mucositis and 20 with peri-implantitis, corresponding to 37.4%, 57.8% and 4.8% of the total implants, respectively. Multivariable analysis revealed a statistically significant association between peri-implant diseases and type of supraconstruction ($p = 0.049$). An odds ratio (OR) of 2.16 (1.003-4.63) was reported for removable prostheses with prevalence of peri-implantitis. In the multivariable analysis, statistically significant associations were found between mesial interproximal contact level and mesial marginal bone level (MBL) values ($p < 0.0001$). Also, between the emergence angle (EA) ($p < 0.0001$), interproximal contact level ($p = 0.0002$) and MBL values at distal aspects. The mucosal height of abutment ($p = 0.001$) and surface treatment ($p = 0.002$) were also significantly associated with mean MBL values. Regarding the direction of association, an increase in mesial EA or mesial interproximal contact level was associated with lower mesial MBL. An increase in distal EA, distal interproximal contact level or distal cantilever size was associated with lower distal MBL. An increase in mucosal height of implant abutment was associated with higher average MBL. Implant surface treatment with TiUnite anodized showed lower MBL values when compared to SLActive treated surfaces.

Conclusions:

Within the limitations of the present study, it was concluded that there was a significant associations between removable implant supported prothesis and peri-implantitis. The interproximal contact level, the emergence angle of the crown, mucosal height of abutment, distal cantilever length and surface treatment were also significantly associated with marginal bone resorption in fully digital guided implants.

DEDICATION

To my cherished family and Dr. Praewvanit Asavanamuang,

Throughout every triumph and challenge, your steadfast presence has been my source of strength and inspiration. With heartfelt gratitude for your enduring belief in me and the countless sacrifices you've made, I dedicate this endeavor to our bond. May our shared journey be forever marked by love, unity, and boundless love support.

With love,
Piyarat Sirirattanagool

ACKNOWLEDGMENTS

I extend my heartfelt gratitude to the following individuals whose invaluable contributions have played a pivotal role in bringing this project to fruition:

Dr. Maria Elisa Galarraga, as my principal investigator (PI), whose expertise, mentorship, and exemplary leadership have been a guiding force throughout this endeavor. Thank you for generously dedicating your time to walk me through each step of the project. Your guidance in initiating the project, setting up data collection tables to facilitate seamless communication with statisticians, calibrating measurements across various software platforms, and providing continuous support during challenging moments has been invaluable. Additionally, your expertise in manuscript writing has been instrumental in shaping the project's direction.

Dr. Ekaterini Antonellou, for her role as the program director, providing helpful experiences and opportunities to enhance my skills and knowledge in this field.

Dr. Shruti Jain, for her diligent efforts in proposal review and approval, as well as for her invaluable assistance in confirming the feasibility of the research protocol, conducting statistical analysis, and refining interpretations.

Dr. Matthew Finkelman, for his expertise as a statistician, and for his collaborative work with Dr. Shruti Jain in providing precise and accurate final outcomes.

Dr. Yo-Wei Chen, for his invaluable insights into the prosthodontic aspects of this research, which have greatly enriched our perspective on all prosthetic factors.

Dr. Lorenzo Tavelli, for his valuable input and guidance as a committee member, contributing to the overall success of this project.

Dr. Praewvanit Asavanamuang, for serving as a co-pilot on this journey, offering wisdom and dedicated knowledge on conducting this research, guidance on the software of her expertise to facilitate creative presentations, and unwavering support every step of the way.

Dr. Yash Brahmbhatt, as a fellow researcher on this project, whose commitment to working late and diligently adhering to our protocol ensures that we maintain the high standards of our work.

Your dedication, expertise, and support have been indispensable, and I am deeply grateful for your contributions to this endeavor.

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LIST OF ABBREVIATIONS

3-D: 3-Dimensional

AM: Adhered mucosa

BOP: Bleeding on probing

CBCT: Cone-Beam Computed Tomography

C/I: Crown-to-implant ratio

DCD: Discrete Crystalline Deposition

EA: Emergence angle

EP: Emergence profile

KM: Keratinized mucosa

MBL: Marginal bone level

MR: Mucosal recession

OR: odds ratio

PD: Probing depth

PI: Plaque index

SLA: Sandblasted, Large grit, Acid etched

SUP: Suppuration

Prosthetic factors associated with the prevalence of peri-implant biological complications in fully digital guided implants: a cross-sectional study

INTRODUCTION

With the worldwide growth in popularity of dental implant treatment, peri-implant health and diseases have become a prominent topic in contemporary dentistry[1]. Peri-implant diseases are associated with inflammation in the peri-implant soft tissue compartment which arises from the bacterial challenges around functioning implants[2]. The 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions reached a consensus on the definition for peri-implant health, peri-implant mucositis and peri-implantitis[2]. Peri-implant health is defined as the absence of clinical signs of inflammation with no crestal bone loss beyond initial bone remodeling[1]. Peri-implant mucositis and peri-implantitis both involve the inflammation in the peri-implant tissue; however, only the latter presents progressive crestal bone loss, extending beyond physiological bone remodeling[2,3].

The presence of peri-implant mucositis has been linked to various factors such as the accumulation of biofilm, smoking, and exposure to radiation[3]. Individuals with a history of periodontitis, inefficient dental plaque control skills, and a failure to undergo recommended regular maintenance care after receiving dental implants exhibit an elevated risk of developing peri-implantitis[2]. The design of the implant supported prosthesis has been proposed by recent studies as a possible local risk indicator for both peri-implant mucositis and peri-implantitis, as it can impact the ability of individuals to effectively control the plaque[2,4,5]. The importance of fixed dental prostheses' contour regarding the health of the periodontium has been extensively discussed in the literature[4].

Over-contoured dental restorations have been associated with various adverse effects on periodontal health[6]. These include inadequate plaque control, increased difficulty in maintaining proper oral hygiene, heightened susceptibility to gingival inflammation, and deteriorated periodontal health[6]. Despite these observations, there is still limited knowledge on the impact of specific prosthetic design on peri-implant tissue health[7].

Few studies have explored the association of prosthetic factors with peri-implant health. In a prevalence study of 83 patients and 168 implants by Katafuchi et al., an emergence angle exceeding 30 degrees in an implant restoration was identified as a notable risk factor for peri-implantitis[4]. Additionally, a convex profile presented an additional risk specifically for bone-level implants, while it did not exhibit the same impact on tissue-level implants[4]. Another prevalence study by Yi et al. in 169 patients and 349 implants, found that the prosthetic emergence angle demonstrated a noteworthy correlation with marginal bone loss[5]. Statistically higher prevalence of peri-implantitis was found in cases where the prosthetic emergence angle was ≥ 30 degrees, especially in instances of a convex emergence profile and when the middle implants were splinted with both mesial and distal adjacent bone-level implants[5]. However, the correlation was not observed in tissue-level implants[5]. The crown-implant ratio did not exhibit any significant effect on the prevalence of peri-implantitis[5]. Nevertheless, it is crucial to highlight that these studies focused specifically on the prosthetic emergence angle, emergence profile, and crown-to-implant ratio. They did not include any other prosthetic factors or biological complications that may potentially affect the peri-implant health[4,5].

The emergence of technologies such as cone-beam computed tomography (CBCT) and 3-dimensional (3D) printing has established the workflow of guided implant placement using static surgical guide. This workflow has become contemporary standard to ensure simplified, predictable implant dentistry with digitally planned implant placement [8]. The data from both the patient's intraoral scan and CBCT scans enables a meticulous evaluation of virtual implant positioning, with a focus on critical anatomical structures such as bone structure and morphology, nerves, arteries, tooth roots, and the maxillary sinuses[8]. Furthermore, digitally guided surgery facilitates a prosthetically-driven implant placement, potentially mitigating post-operative mechanical complications such as screw or prosthesis loosening and fractures[8]. To the best of our knowledge, no available study has examined or assessed the prevalence of peri-implant diseases in the context of digitally guided implant placement[9].

Given the limited data on the connection between prosthetic factors and the prevalence of peri-implant diseases, this cross-sectional study sought to assess the occurrence of peri-implant mucositis and peri-implantitis in relation to various prosthetic factors.

LITERATURE REVIEW

Peri-Implant Diseases

The consensus reached during the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions established clear definitions for peri-implant health, peri-implant mucositis, peri-implantitis, and identified deficiencies in both soft and hard tissues around implants[10].

Peri-Implant Health

Peri-implant health is characterized by the absence of erythema, bleeding on probing, swelling, and suppuration at peri-implant sites[10]. The probing depths at peri-implant sites are often greater than those observed around natural dentitions[10]. However, there is no defined range for probing depth associated with peri-implant health or diseases; rather, it is contingent upon the presence or absence of clinical signs of inflammation[10]. Consequently, peri-implant health may be evident around implants with reduced bone support, provided there are no clinical signs of inflammation[10]. Based on the 2017 World Workshop consensus, the criteria for clinically diagnosing peri-implant health are as follows[10]:

- Absence of clinical signs of inflammation
- Absence of bleeding and/or suppuration on gentle probing
- Absence of increase in probing depth
- Absence of crestal bone loss beyond initial bone remodeling

Peri-Implant Mucositis

Peri-implant mucositis is characterized by inflammation of the peri-implant mucosa without concurrent and progressive loss of peri-implant bone[3]. Clinical manifestations of inflammation in the peri-implant mucosa include bleeding upon gentle probing, accompanied by or without the presence of erythema, swelling, and suppuration[10]. Plaque is recognized as the primary factor contributing to the development of peri-implant mucositis[3,10]. Factors that indicate an increased risk for this condition include the buildup of biofilm, smoking, and receiving radiation therapy[10]. Additionally, potential risk indicators involve poorly controlled diabetes mellitus (HbA1c levels > 10.1), the absence of keratinized mucosa, and the presence of excessive luting cement[3]. Peri-implant mucositis is a condition that can be reversed, often being resolved within three weeks upon the restoration of plaque or biofilm control [3,10]. Hence, consistent mechanical debridement of peri-implant biofilm is crucial for attaining and sustaining peri-implant health [3]. As per the consensus established during the 2017 World Workshop, the criteria for clinically diagnosing peri-implant mucositis include [10]:

- Presence of bleeding and/or suppuration on gentle probing, with or without increased in probing depth.
- Absence of crestal bone loss beyond initial bone remodeling

Peri-Implantitis

Peri-implantitis is characterized as a pathological condition affecting the tissues surrounding dental implants, marked by inflammation in the peri-implant connective tissue and progressive loss of supporting bone[2]. The advancement of peri-implantitis unfolds in a non-linear and accelerating manner, frequently leading to circumferential marginal bone loss[2]. Risk indicators for peri-implantitis, as determined through longitudinal and cross-sectional studies, include a prior history of periodontitis, insufficient plaque control skills, and a lack of regular maintenance [2]. Potential risk factors for peri-implantitis, backed by inconclusive evidence from existing studies, comprise smoking and diabetes mellitus[2]. The 2017 World Workshop consensus outlined criteria for the clinical diagnosis of peri-implantitis, which include[10]:

- Presence of bleeding and/or suppuration on gentle probing, with increased in probing depth
- Presence of crestal bone loss beyond initial bone remodeling
- In case with no baseline probing depth and/or radiograph:
    - Presence of bleeding and/or suppuration on gentle probing
    - Probing depths greater than or equal to 6 mm
    - Crestal bone loss of greater than or equal to 3 mm

Mechanical Complications and Peri-implant health

Mechanical complications in implant-supported prosthesis have frequently been reported in literature[11]. Mechanical complications include implant fracture, abutment screw fracture, abutment fracture, prosthesis fracture, veneering material fracture, abutment or screw loosening, and loss of retention of cemented prostheses[11]. Yet, mechanical complications effect on peri-implant health rarely exists in literature[11]. Implant failure secondary to mechanical complications, such as implant fracture, is relatively rare but crucial, and requires implant removal[11]. Mechanical complications could also provoke secondary biological complications and affect the peri-implant marginal bone levels[11]. Ferreira et al. conducted a case-control study to investigate the impact of mechanical complications on the success of implant therapy[11]. The group reported no significant effect of mechanical complications on implant survival or marginal bone loss[11]. However, mechanical complications were found to significantly impact the incidence of biological complications[11]. Nevertheless, the author suggested the need for studies with longer follow-up durations[11].

Prosthetic Factors and Peri-implant health

Several studies have delved into the correlation between prosthetic factors and peri-implant health, highlighting their pivotal role in the sustained success of dental implant treatment[4,5].

Emergence Angle and Emergence Profile

Emergence angle (EA) is defined as the angle formed by the transitional contour of an implant restoration, determined by the relationship between the surface of the abutment and the long axis of the implant body[4]. In contrast, emergence profile (EP) is characterized as the contour of a tooth or restoration, such as a crown on a natural tooth or a dental implant abutment, in relation to the adjacent tissues[4]. This can be categorized to straight, concave or convex[4].

Katafuchi et al. reported that the prevalence of peri-implantitis exhibited a notable rise within the bone-level group when the emergence angle exceeded 30 degrees, contrasting with angles of 30 degrees or less (31.3% versus 15.1%)[4]. Conversely, such a correlation was not observed in the tissue-level group[4]. In instances of bone-level implants, the combination of a convex profile with an angle exceeding 30 degrees led to a peri-implantitis prevalence of 37.8%, demonstrating a statistically significant interaction between the emergence angle and emergence profile[4]. Another study by Yi et al. also reported a statistically higher prevalence of peri-implantitis was observed in instances where the emergence angle was greater than or equal to 30 degrees, especially in cases with a convex emergence profile and when middle implants were splinted with both mesial and distal adjacent bone-level implants[5]. However, no similar correlation was observed in tissue-level implants[5]. Additionally, the crown-implant ratio did not exhibit a significant impact on the prevalence of peri-implantitis[5].

Puisys et al. described an intricate interconnection between the vertical dimension of implant supracrestal complex and the contour angle of the transmucosal components[7]. A minimum peri-implant supracrestal tissue height of 3 to 4 mm is essential for establishment of soft tissue seal for crestal bone stability[12]. An excessively wide angle of prosthetic design ascendance from the bone margin can also be perceived as lack of adequate vertical space for the formation of the soft tissue seal[12]. Hence, it is essential to meticulously plan the depth of implant placement to guarantee a suitable emergence angle and sufficient supracrestal tissue height[7]. Overall, it is important to highlight that an over-contoured implant prosthesis has emerged as a crucial local confounder for peri-implantitis in bone-level implants[4,5].

Types of Restoration

Implant dentistry is rich with a multitude of prosthetic designs, each tailored to meet the diverse needs and clinical indications. A fundamental classification within this realm distinguishes between fixed versus removable prosthesis[13].

Removable vs. Fixed Prosthesis

Maintaining hygiene for removable prostheses has been reported to be more straightforward in comparison to fixed prostheses[14]. Currently the types of implant-supported or retained prostheses available in the market include single crowns, bridges, splinted crowns, completed-arch implant-supported prosthesis, implant-retained overdenture, and bar-supported overdenture. This was mentioned in a systematic review, where five clinical studies collectively indicated that maintaining oral hygiene with implant-supported fixed prostheses poses greater challenges for patients[14]. A 2-year retrospective study by Mumcu et al. explored the difference in patient satisfaction, quality of life and marginal bone loss in four-implant-retained overdentures compared to implant-supported fixed prosthesis in the maxilla[15]. The findings of the study unveil a significant difference in patient satisfaction identified in favor of maxillary overdentures concerning hygiene maintenance[15]. However, overdentures also show a significant higher patient-reported pain when compared to the fixed prosthesis[15]. The inferior access for oral hygiene maintenance may attribute to the frequently reported complication of fixed implant-supported prosthesis, which is mucositis[14]. Nevertheless, according to a systematic review, long-term outcomes of marginal bone loss appear to be comparable between fixed and removable implant-supported prostheses[14,16].

Cement-retained vs. Screw-retained

Numerous studies consistently indicate a higher prevalence of peri-implant disease in cement-retained implant-supported prostheses compared to screw-retained implant-supported prostheses[17,18]. Significant disparities were highlighted in the retrospective study conducted by Linkevicius et al.[17]. The findings revealed a prevalence of peri-implant disease in 0.8% of the screw-retained restorations, whereas 75% of the implants with cemented restorations were diagnosed with peri-implant disease[17]. Of those, 64% were identified as positive for excess cement[17]. Additionally, in a systematic review by Staubli et al., the prevalence of peri-implant diseases exhibited a wide range, spanning from 1.9% to 75% among implants with cemented restorations. Notably, proportions between 33% and 100% of the cases were linked to excess cement [18]. This may be explained by the promotion of biofilm formation on the rough surface created by excess cement[2,18]. Furthermore, the occurrence of peri-implant diseases was more commonly observed when the soft tissue healing periods were shorter than 4 weeks[18]. This can be elucidated by the notion that prolonged soft tissue healing periods contribute to the formation of a matured soft tissue cuff, offering increased resistance to the penetration of excess cement into the submucosal region [18].

Cantilever

An issue in implant-supported fixed partial rehabilitations with cantilever extensions is the potential for overloading implants near these extensions, especially in connection with non-axial loads[19]. Yet, conflicting results have been shown in a systematic review by Romeo et al. on the survival rate and the biological, technical, and aesthetic complications of fixed dental prostheses with cantilevers on implants reported in longitudinal studies with a mean of 5 years follow-up[19]. A study has claimed functional overloading as a cause of implant failure, leading to the development of micro-fractures at the bone level rather than at the bone-implant contact point[20]. Consequently, these micro-fractures cannot be repaired through the typical process of bone remodeling[20]. On the other hand, contrasting findings were presented in a systematic review, which suggested that there is no statistically significant difference in terms of bone resorption and mechanical complications between prostheses with cantilever extensions and those without extensions[19]. Another systematic review and meta-analysis by Torrecillas-Martinez et al. also reported insignificant differences of marginal bone loss in implant-supported restorations with and without cantilevers[21]; the review found 0.1 mm difference in marginal bone loss, in favor of the non-cantilever group. Nevertheless, the systematic reviews were based on limited literature availability, non-homogenous study designs and did not concern digital guided implant placement[19,21].

Open contact

Sufficient contact points act as a protective barrier for the periodontium, preventing potential damage from food impaction by redirecting food to the buccal or lingual side[22]. This, in turn, helps prevent peri-implant inflammation[22]. Greenstein et al. reported the incidence of interproximal open contacts ranged from 34% to 66% after the placement of an implant restoration adjacent to a natural tooth[23]. Notably, loss of interproximal contact was observed as early as 3 months after the prosthetic restoration, primarily occurring on the mesial side of the restoration[23]. A retrospective study by Saber et al. investigated the prevalence of interproximal contact loss between implant-supported fixed prostheses and adjacent natural teeth, and its impact on marginal bone loss[22]. The study reported loss of interproximal contact between implant-supported fixed prostheses and adjacent teeth in 32.8% of the cases[22]. Among mesial contact points, 42.1% experienced interproximal contact loss, while 14.5% had such loss on the distal side[22]. Sites with interproximal contact loss showed a mean marginal bone loss of 0.73 mm, which is statistically higher than sites with maintained interproximal contact[22]. Furthermore, Latimer et al. found a significant association between proximal open contacts and increased prevalence of peri-implant diseases[24].

Inter-implant distance

Tarnow et al. conducted a study to evaluate the effect of inter-implant distance on the height of inter-implant bone crest[25]. The group reported an inter-implant distance of greater than 3 mm exhibited a crestal bone loss of 0.45 mm[25]. In contrast, implants situated with a distance of 3 mm or less between them experienced a higher crestal bone loss, measuring 1.04 mm[25]. Therefore, 3 mm inter-implant distance was proposed to preserve the interproximal crestal bone[25]. Another 5-year radiographic study by Chang et al. found a borderline significance for the inter-implant distance and marginal bone loss[26]. Yet, the marginal bone loss was most marked when the inter-implant distance was less than 2 mm[26]. Nevertheless, the results could be influenced by other variables, such as inter-implant angulation and implant connection type.

Surface treatment

Surface treatment of implant surfaces aims to improve osseointegration by attracting osteogenic cells[27]. Techniques for micro-level modifications include modified sandblasting combined with acid etching (SLActive), discrete crystalline deposition (DCD) and anodization[27]. The micro-roughened surface stimulates platelets to release mediators crucial for stabilizing blood clots and forming a fibrin matrix, which serves as an osteoconductive scaffold for osteogenic cell migration and new bone formation[27]. In SLActive, implants are rinsed under a nitrogen-protected environment to prevent carbonate and hydrocarbon absorption, creating a hydrophilic surface maintained by storing in an isotonic saline solution[27]. DCD involves chemical surface modification through the sol-gel process with calcium phosphate particles[27]. Anodization entails electrochemical modification of the titanium implant surface to create a thicker titanium dioxide layer[27]. The various porosities in the titanium dioxide layer facilitate gingival fibroblast deposition, adhesion, and proliferation, as well as osteoblast adhesion[27].

RESEARCH AIMS/HYPOTHESIS

The primary aim of this study was:

To determine the association between prosthetic factors and peri-implant diseases in digitally guided implant placement with at least one year in function.

The hypothesis was that:

Prosthetic factors would be associated with the prevalence of peri-implant diseases. This expectation was based on the assumption that the use of digital guidance allows for meticulous prosthetic planning, leading to a more suitable 3-D implant positioning in relation to the prosthesis.

SIGNIFICANCE

The outcomes of this study are expected to provide dental practitioners with an enhanced understanding of how prosthetic factors are associated with the prevalence of peri-implant diseases. This increased understanding could contribute to raising awareness regarding the significance of appropriate prosthetic considerations after implant placement, addressing a knowledge gap that currently exists in the literature. Moreover, by elucidating the prosthetic biological complications associated with digitally-guided implant placement, this study aimed to underscore the importance of digital implant planning in the field of implant dentistry.

MATERIALS AND METHODS

The study protocol adhered to the principles outlined in the Helsinki Declaration of 1975 (revised in August 2018) and received approval from Tufts Health Sciences Institutional Review Board (MOD-02-STUDY00004004). The current study followed the guidelines set forth by STROBE (The Strengthening the Reporting of Observational Studies in Epidemiology).

In this cross-sectional analysis, the electronic health records of a total of 480 patients who received dental treatment at the Implant Center, Department of Prosthodontics at Tufts University School of Dental Medicine (Boston, MA, USA) were review using clinic management software (Axium, Deltek, Portland, Oregon, USA).

After screening based on the specific inclusion criteria, 164 patients were found eligible. Subsequently, a comprehensive assessment was carried out for 115 of these patients, encompassing 417 implants, during their routine maintenance visits.

Inclusion and Exclusion Criteria

Inclusion Criteria:

1. Tufts University School of Dental Medicine patient age $\geq$ 18 years.
2. Partially/fully edentulous patients rehabilitated with at least one digitally guided endosseous implant under at least one year of loading.
3. Both non-smokers and smokers were included.

Exclusion Criteria:

1. Patients who were pregnant or were breastfeeding.
2. Patients who receive implant treatment with free-hand placements.
3. Patients with digitally guided endosseous implant but with less than one year of loading.

Implant Site Characteristics and Prosthetic Parameters

The implant-related variables collected in this study included:

1. Region (maxilla or mandible; anterior or posterior)
2. Implant connection type (internal connection morse taper, external connection)
3. Presence of platform switching (yes or no)
4. Loading protocol (immediate, delayed)
5. Implant diameter (mm)
6. Implant length (mm)
7. Implant surface treatment
8. Crown-to-implant ratio (C/I)
9. Type of prosthesis (fixed or removable; cement or screw-retained; crown, bridge, splinted crowns, full-arch prosthesis, overdenture, overdenture with bar)
10. Emergence angle (mesial and distal) (degrees)
11. Emergence profile (mesial and distal) (straight, convex or concave)
12. Presence of cantilever (mesial and distal) (yes or no)
13. Distance to outer contour of prosthesis (mesial and distal) (mm)
14. Type of implant (bone or tissue level)
15. Mucosal height of abutment (mm)
16. Interproximal contact level (mesial and distal) (mm)
17. Horizontal distance from implant to adjacent teeth (mesial and distal) (mm)
18. Inter-implant distance (mesial and distal) (mm)
19. Angulation of implant (degrees)
20. Angulation of abutment (degrees)

21. Angulation between long-axis of splinted implants (mesial and distal) (degrees)
22. Presence of open contact (mesial and distal) (yes or no)

Clinical measurements

The following clinical parameters were collected at each implant site using a periodontal probe (PCP-UNC 15, Hu-Friedy, Chicago, USA):

1. Probing depth (PD)
    a. In millimeters
    b. Measured from the gingival margin to the probable pocket
2. Bleeding on probing (BOP)
    a. Presence or absence
3. Mucosal recession (MR)
    a. In millimeters
    b. Measured from the restoration margin to the mucosal margin
4. Keratinized mucosa (KM)
    a. Measured from the gingival margin to the mucogingival junction
5. Suppuration (SUP)
    a. Presence or absence
6. Presence of open contact
    a. Interproximal contacts were examined using dental floss (REACH, Johnson & Johnson, La Palma, CA, USA). A contact was defined open if the dental floss passed through without encountering any resistance.

PD, BOP, MR and SUP were assessed at six positions around each implant: mesiobuccal (MB), mid-buccal (Mid-B), distobuccal (DB), mesio-oral (MO), mid-oral (Mid-O) and disto-oral (DO). KM was measured at three positions around each implant: mesiobuccal (MB), mid-buccal (Mid-B) and distobuccal (DB). The measurements of BOP were categorized into three levels, based on the number of sites with BOP: 0% of sites = none, 1-50% = moderate, and 51-100% = advanced. Presence of open contact was measured at the mesial and distal sites of each implant prosthesis.

Periapical radiographs taken over regular maintenance appointments were evaluated. The radiographs were used to measure MBLs and record prosthetic parameters at each implant site. ImageJ software (Rasband, W.S., ImageJ, U.S. National Institutes of Health, Bethesda, Maryland, USA) was used to measure MBL and also to assess crown-to-implant ratio, emergence angle, emergence profile, distance to outer contour of prosthesis, mucosal height of abutment, interproximal contact level, horizontal distance from implant to adjacent teeth, inter-implant distance, angulation of implant, angulation of abutment, implant depth and angulation between long-axis of splinted implants from the peri-apical radiographs. Before conducting each MBL measurement, the image analysis tool underwent standardization using a reference value derived from the known implant diameter. MBLs were assessed from the implant platform to the crestal bone level at both the mesial and distal aspects. Negative MBL values indicated that the crestal bone level was situated below the implant platform, while positive MBL values indicated that it was above. The lowest MBL recorded, along with other clinical parameters, was utilized to diagnose each implant's condition as healthy, mucositis, or peri-implantitis. Figures 6, 7, 8, 9, 10 demonstrate the measurements of all prosthetic parameters on ImageJ software (Rasband, W.S., ImageJ, U.S. National Institutes of Health, Bethesda, Maryland, USA).

Case definition

As per criteria outlined in the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions, each implant was categorized as either peri-implant health, peri-implant mucositis, or peri-implantitis [10].

The criteria for each diagnosis were as follows:

1. Peri-implant health [10]
    a. Absence of clinical signs of inflammation
    b. Absence of bleeding and/or suppuration on gentle probing
    c. Absence of increase in probing depth
    d. Absence of crestal bone loss beyond initial bone remodeling
2. Peri-implant mucositis [10]
    a. Presence of bleeding and/or suppuration on gentle probing, with or without an increase in probing depth.
    b. Absence of crestal bone loss beyond initial bone remodeling
3. Peri-implantitis [10]
    a. Presence of bleeding and/or suppuration on gentle probing, with an increase in probing depth
    b. Presence of crestal bone loss beyond initial bone remodeling
    c. In cases with no baseline probing depth and/or radiograph:

i. Presence of bleeding and/or suppuration on gentle probing
ii. Probing depths greater than or equal to 6 mm
iii. Crestal bone loss of greater than or equal to 3 mm

Figures 2, 3, 4 illustrate peri-implant health, peri-implant mucositis, and peri-implantitis. Patients diagnosed with peri-implant diseases were given oral hygiene instructions and received appropriate treatment to address the condition.

Statistical Analysis

Descriptive statistics (means, standard deviations, medians, and interquartile ranges for continuous variables; counts and percentages for categorical variables) were calculated for sample demographics, implant site characteristics, clinical parameters, mesial MBL, distal MBL and average MBL. Frequency distribution by diagnosis type and BOP levels were performed. Data for the outcome variables of mesial MBL, distal MBL and average MBL was translated by adding a constant to it to address the presence of negative values. Log transformations were applied when needed. The assumption of normality was assessed. In order to account for the clustering of multiple implants within a patient, bivariate and multivariable analyses were conducted using generalized linear mixed models via the GLIMMIX procedure for each outcome variable. Odds ratios (with 95% confidence intervals) were calculated for categorical outcome variables. The significance level was set at $\alpha=0.05$. All analyses were performed using SAS Version 9.4 (SAS Institute Inc., Cary, NC, USA).

RESULTS

A total of 115 patients (60 men, 55 women, mean age of 60.87 ± 13.37 years) with 417 implants were included in the study data. Table 1 summarizes descriptive statistics for demographic data and implant site characteristics. Implant loading time ranged from 1 to 10 years with a mean of 2.76 years. Three-hundred-and-thirty-seven implants were associated with fixed prosthesis, including single crowns, splinted crowns, bridge and all-on-X prostheses. The remaining 80 implants were associated with removable prosthesis, including overdenture and bar-retained overdenture. This study included 27 cement-retained and 390 screw-retained implant prostheses. Platform switching implants (92.8%) were reported more frequently than non-platform switching implants (7.2%).

The clinical parameters and radiographic assessments of implant prosthetic design are presented in Tables 2 and 3. Mean ± SD MBL on mesial, distal and average were -0.26 ± 1.57mm, -0.37±1.53 and -0.32±1.46, respectively. Mean ± SD EA on mesial and distal sites were 23.73 ± 10.81 and 22.15 ± 10.34 degrees. Mean ± SD distance to outer contour of prosthesis on mesial and distal sites were 2.54 ± 1.04 and 5.05 ± 7.31 mm. Mean ± SD mucosal height of abutment was 2.63 ± 1.42 mm. Mean ± SD interproximal contact level to marginal bone level on mesial and distal were 3.82 ± 1.52 and 3.85 ± 1.54 mm. Mean ± SD crown to implant ratio (C/I) was 1.42 ± 0.51. Mean ± SD horizontal distance from implant to adjacent teeth on mesial and distal were 3.32 ± 1.44 and 3.27 ± 2.25 mm. In prosthesis with multiple implants, the mean ± SD angulation between long axis of implants at mesial and distal sides were 7.46 ± 8.75 and 8.20 ± 9.99 degrees.

The frequency distribution of health and peri-implant diseases is presented in Table 4. A total of 156 implants were diagnosed to be healthy, 241 with mucositis and 20 with peri-implantitis, corresponding to 37.4%, 57.8% and 4.8% of the total implants, respectively. Table 5 presents implant-level associations between diagnosis and implant prosthetic characteristics.

Bivariate and multivariable analyses for the associations between implant prosthetic characteristics and diagnosis using a generalized linear mixed model is presented in Table 6. The multivariable analysis revealed a statistically significant association between peri-implant diseases and type of supraconstruction ($p = 0.049$). An odds ratio (OR) of 2.16 (1.003 – 4.63) was reported for removable prosthesis when using the fixed prosthesis group as a reference category. Mucosal height of abutment, cement/screw-retained restoration and presence of platform switching showed no statistically significant association in both the bivariate and multivariable analyses.

Table 7 presents descriptive statistics for implant-level radiographic assessments by bleeding on probing (BOP) levels. Bivariate and multivariable analyses for the associations between implant prosthetic characteristic parameters and bleeding on probing level using a generalized linear mixed model is displayed in Table 8. EA at distal sites ($p = 0.087$) and platform switching ($p = 0.084$) showed almost statistically significant associations with bleeding on probing level in the multivariable analysis.

Descriptive statistics for radiographic assessments with mesial MBL are shown in Table 9. Table 10 presents the bivariate and multivariable analyses for associations of implant prosthetic characteristic parameters with mesial MBL using a generalized linear mixed model. Statistically significant associations were found between mesial EA ($p = 0.002$) and mesial interproximal contact level ($p = 0.0005$) with mesial MBL at corresponding mesial sites in the bivariate analysis. However, in the multivariable analysis, only mesial interproximal contact level showed a statistically significant association with mesial MBL ($p < 0.0001$). Regarding the direction of the association, an increase in mesial EA was associated with decrease in corresponding mesial MBL. Likewise, an increase in mesial interproximal contact level was associated with a decrease in peri-implant mesial MBLs.

Table 11 shows descriptive statistics for radiographic assessments with distal MBL. Table 12 displays the bivariate and multivariable analyses for associations of implant prosthetic characteristic parameters with distal MBL using a generalized linear mixed model. In the bivariate analysis, statistically significant associations were found between distal EA ($p = 0.0001$), distal interproximal contact level ($p = 0.002$) and distal cantilever ($p = 0.047$) with distal MBL. Nevertheless, in the multivariable analysis, only distal EA ($p < 0.0001$) and distal interproximal contact level ($p = 0.0002$) showed statistically significant associations with distal MBL. An increase in distal EA, distal interproximal contact level or distal cantilever size was associated with lower distal MBL.

Descriptive statistics for radiographic assessments with average MBL are presented in Table 13. Bivariate and multivariable analyses for associations of implant prosthetic characteristic parameters with average MBL using a generalized linear mixed model is shown in Table 14. In the bivariate analysis, statistically significant associations were found between mucosal height of abutment ($p = 0.002$) and surface treatment ($p = 0.011$) with average MBL. In the multivariable analysis, only mucosal height of abutment ($p = 0.001$) and surface treatment ($p = 0.002$) showed a statistically significant association with average MBL. An increase in mucosal height of abutment was associated with higher mean MBLs. Implant surface treatment with TiUnite anodized showed lower MBLs when compared to SLActive.

DISCUSSION

In this cross-sectional analysis, it was observed that following a mean loading period of 2.76 years, the prevalence of peri-implant diseases among digital guided implant placement was 37.4% for health, 57.8% for mucositis, and 4.8% for peri-implantitis. To the author's knowledge, this study marks the initial investigation into the prosthetic factors associated with prevalence of peri-implant diseases following a fully digital guided surgical protocol. A fully digital guided implant planning and placement brings forth several advantages, particularly in enabling prosthetically-driven implant placement[8]. A prosthetically-driven implant placement allowed for prostheses with a more hygienic emergence profile, potentially reduced post-operative mechanical complications, such as screw or prosthesis loosening and fractures, and facilitated the shift towards screw-retained prostheses[8]. Therefore, fully digital guided implant placement could possibly enhance overall peri-implant health[8].

Utilizing the 2017 World Workshop case definitions, the occurrence rates of peri-implant diseases were found to be similar for mucositis and lower for peri-implantitis compared to results from prior studies involving non-digital guided implant placement. In a cross-sectional study by Obreja et al., the prevalence of peri-implant mucositis was observed to be 62.6% at the implant level, while peri-implantitis was 7.5% [28]. These results suggest a comparable occurrence of mucositis but a reduced occurrence of peri-implantitis if implants are placed fully guided. Therefore, implant placement aided by digital guided planning appears to have a beneficial impact on the maintenance of peri-implant health.

However, it is crucial to underscore the significance of establishing precise case definitions for peri-implant diseases. Salvi et al. have suggested that the wide range observed in the prevalence rates is attributable to the variance in case definitions employed across various studies[29]. For instance, Derks and Tomasi et al. reported a peri-implantitis prevalence of only 1% when considering the case definition with a threshold of crestal bone loss of 5 mm[30]. Conversely, Zetterqvist et al. reported a peri-implantitis prevalence of 47% when applying a crestal bone loss threshold of 0.4 mm[31]. This highlights the importance of clear case definitions for accurately comparing the prevalence rates of peri-implant diseases. In this study, the 2017 World Workshop case definitions were used to diagnosed peri-implant health, mucositis and peri-implantitis.

Another significant aspect to emphasize is the variation in mean implant loading times observed across different studies, which can significantly influence study outcomes. Maximo et al. identified a significant positive correlation between loading time and occurrence of peri-implant diseases in the cross-sectional study [32]. The longer loading times, the higher risk dental implants may encounter increased bacterial challenges and external forces, potentially triggering prolonged immunological and tissue responses[32]. Therefore, Salvi et al. suggested that since peri-implantitis requires time to manifest, a short follow-up period may lead to an underestimation of disease prevalence[29]. In this study, the mean implant loading time was 2.76 years (range 1 – 10 years). While more investigation of the direct correlation of implant loading time and the peri-implant health is required, it is possible to speculate that the comparatively shorter mean implant loading time in this study might be a factor contributing to the lower observed prevalence rate of peri-implantitis.

In the present study, the multivariable analysis revealed a statistically significant association with an OR of 2.16 for removable prosthesis with peri-implantitis. This outcome resonates with the findings of Grishke et al., who reported removable dentures as a risk factor for peri-implantitis, showing a significant positive association on patient and implant-level in multivariable analyses[33]. They proposed that the microbiome shift towards heightened activity of *F. nucleatum ss animalis* and *Prevotella intermedia* could account for the increased occurrence of peri-implantitis in removable dentures compared to fixed prostheses [33]. However, Mumcu et al. reported similar levels of marginal bone loss in both four-implant-retained overdentures and implant-supported fixed prostheses after 2 years of function[34]. Hamilton et al. observed that patients find removable prostheses easier to clean[35]. Hence, other prosthetic factors might also influence the development of peri-implant diseases.

To the author's knowledge, this cross-sectional study is the first to explore interproximal contact level association with peri-implant diseases. In both the bivariate and multivariable analyses, this study found a statistically significant association between an increase in interproximal contact level and lower MBL. This finding could possibly align with the results from Yacob et al.'s study on the effect of interproximal contact area and width on periodontal parameters in natural dentition[36]. A strong negative correlation was found between the length of the interproximal contact area and plaque and gingival scores[36], suggesting that a well-established interproximal contact prevents contact separation during function, effectively acting as a barrier against food impaction[36]. Conversely, a smaller interproximal contact area is associated with a higher interproximal space height and decreased fill of the interdental papilla[36]. From an observational study by Tarnow et al. indicates that, when the interproximal contact level exceeds 5 mm from the bone crest, a decrease in interdental papilla volume becomes evident[37]. The so called "black triangle," as the consequence of loss of the papilla volume, creates an unprotected interproximal area prone to food impaction and dental biofilm retention[37]. Given that peri-implant diseases are linked to plaque retention and bacterial challenges, it is possible to conclude that a higher interproximal contact level could increase biofilm retention and decrease MBLs.

Research in natural dentition has established a connection between overcontoured restorations and gingival erythema, as well as plaque retention[6]. In this cross-sectional study, statistically significant associations were observed between EA and MBL at both the mesial and distal aspects of the implant prostheses. These findings suggest that an increase in EA is associated with a reduction in MBL. This result is supported by Katafuchi et al. and Yi et al.'s studies that reported a significant correlation between EA and MBL, where an emergence angle of >30 degrees was a significant risk indicator for periimplantitis[4,5]. This event could potentially be explained by concept of esthetic biological contour in implant restoration reported by Gomez-meda et al.'s [38]. It was highlighted that a restoration with proper contours plays a crucial role in stabilizing peri-implant tissues by ensuring adequate soft tissue thickness. The soft tissue then achieves a long-term stable esthetic outcome and safeguarding the bone crest while facilitating the establishment of the biological width[38]. Therefore, an overcontoured prosthetic design can compromise the thickness of soft tissue barrier, and trigger crestal bone resorption, jeopardizing the stability of the outcome and potentially leading to mucositis or peri-implantitis[38].

Linkevicius et al. have highlighted the importance of supracrestal soft tissue height for maintaining soft tissue stability around implants[12]. Thick supracrestal soft tissue was found to have significantly higher MBL than thin supracrestal soft tissue[12]. However, the mucosa can be compressed through the use of a shorter abutment[39]. Galindo-Moreno et al. explored the effect of prosthetic abutment height as a factor in peri-implant marginal bone loss[39]. The group reported that MBL was found to be lower when prosthetic abutment was shorter than 2 mm in comparison with abutment height greater than 2 mm[39]. Moreover, in a meta-analysis conducted by Munoz et al., it was found that long abutments demonstrated significantly lower changes in MBL compared to short abutments[40]. This aligned with the results of our study which found an increase in mucosal height of abutment was associated with higher average MBL in both the bivariate and multivariable analyses. It has been proposed that sufficient supracrestal soft tissue thickness is necessary for the formation of a pseudo-biological width around implants, ensuring crestal bone stability[41]. Consequently, inadequate supracrestal soft tissue thickness may lead to bone loss as a compensatory mechanism to accommodate the biological width[41].

This study revealed a statistically significant relationship between the size of the distal cantilever and distal MBL. These results indicate that an increase in the size of the distal cantilever correlates with a lower distal marginal bone level. Isidor et al. reported similar findings with the hypothesis that the presence of cantilevers can lead to implant failure due to the development of micro-fractures which cannot be repaired through the typical process of bone remodeling[20]. Duyck et al. demonstrated the presence of crater-like defects lateral to osseointegrated implants after exposure to repetitive bending forces[42]. Additionally, Kim et al. found a positive correlation between the length of the cantilever arm and implant failure, technical complications and bone loss[43]. However, sometimes the cantilever prosthetic design is inevitable when the bone is severely resorbed. Clinicians should be cautious when adapting such a design. A review conducted by Sadowsky et al. suggested that cantilever arms equal to or greater than 8 mm may have an impact on marginal bone loss[44].

The results of this study showed an almost significant association between platform switching with average MBL. Absence platform switching was associated with lower average MBL when compared to the presence of platform switching. This is aligned with the result of a systematic review conducted by Tomar et al., where four randomized controlled trials found lower average marginal bone loss in platform-switched implant-to-abutment connections when compared with platform-matched implant-to-abutment connections[45]. The fundamental purpose of platform switching design is to relocate the micro-gap position at the implant-abutment connection away from the bone crest, aiming to reduce saucerization of the marginal bone[35]. Therefore, it is plausible for implants with platform switching design to show lower average MBL than implants without platform switching design. However, Linkevicius et al. noted that the platform switching design alone may not prevent crestal bone loss in the presence of thin supracrestal tissue. As such, adjunctive soft tissue augmentation could still provide a valuable solution to address thin supracrestal tissue thickness, aiming to restrict crestal bone loss[41].

The surface treatments of implant bodies may affect the peri-implant soft tissue. In this cross-sectional study, the implant with TiUnite anodized surface treatment was associated with lower MBL when compared to implants treated with SLActive. This correlation could be due to the peri-implant microbiome dynamic. Sinjab et al. reported significant differences in microbiome clustering, magnitude and diversity for health and peri-implantitis in anodized implant surfaces[46]. Anodized implants diagnosed with peri-implantitis showed a notable increase in Porphyromonas, Treponema, and Prevotella, with Porphyromonas species being a significant causative bacterium in periodontal diseases and a dominant species in peri-implantitis[45]. On the other hand, no significant difference in microbiome between health and peri-implantitis was found in SLA-modified implants[46]. Therefore, the shift in microbiome may cause the lower levels of MBL in TiUnite anodized implants. However, there are still limited studies in the literature.

The present study has several limitations that warrant attention. Firstly, its cross-sectional design limits the ability to establish causality regarding the observed associations. Future prospective cohort studies with baseline radiographs are needed to provide a more thorough understanding of causality and the incidence of the observed associations. Secondly, the sample size within each type of prosthesis hampers the ability to stratify the analysis by this variable. Furthermore, since peri-implant diseases require time to develop, extending the loading period could offer a more precise depiction of the prevalence of peri-implant diseases.

CONCLUSION

Within the limitations of the present study, it was concluded that there are significant associations between removable implant-retained prothesis, interproximal contact level, emergence angle, mucosal height of abutment, distal cantilever size, and surface treatment with prevalence of peri-implant diseases and marginal bone levels in fully digital guided implant placement.

Appendix A

LIST OF TABLES

Table 1: Descriptive statistics for demographic data and implant site characteristics

Demographic Data	n	%
Patient number (n)	115	100
Female/Male (n)	55/60	47.8/52.2
Age (mean ± SD /median) (years)	60.87 ± 13.37/63	-
Implant site characteristics	**n**	**%**
Implant sites (n)	417	100
Implant loading time (year) (min - max /mean)	1-10/2.76	-
Type of supraconstruction (n) (fixed/removable)	337/80	80.8/19.2
Cemented/screw-retained (n)	27/390	6.5/93.5
Type of restoration (n)		
Single crown	136	32.6
Full-arch fixed prosthesis	140	33.6
Bridge/splinted crowns	61	14.6
Overdenture	72	17.3
Overdenture with bar	8	1.9
Platform switching (n) (no/yes)	30/387	7.2/92.8
Surface treatment (n) (SLActive/Anodized/Nanotite surface)	310/100/7	74.3/24/1.7

Table 2: Descriptive statistics for implant-level clinical parameters

Clinical Parameters	Mean ± SD /Median
Plaque index	0.43 ± 0.52/0.17
Mucosal Recession (mm)	0.17 ± 0.45/0
Keratinized mucosa (mm)	3.64 ± 2.00/3.67
Adhered mucosa (mm)	1.03 ± 1.96/1
Bleeding on probing (site)	0.30 ± 0.33/0.17
Bone change (mesial) (mm)	-0.26 ± 1.57/-0.3
Bone change (distal) (mm)	-0.37 ± 1.53/-0.3
Average bone change (mm)	-0.32 ± 1.46/-0.35

Table 3: Descriptive statistics for implant-level radiographic assessments

Radiographic assessments	n	%
Emergence profile (mesial) (n) (convex/straight/concave/not applicable)	94/171/98/54	22.5/41.0/23.5/12.9
Emergence profile (distal) (n) (convex/straight/concave/not applicable)	109/180/73/55	26.1/43.2/17.5/13.2
Open contact (mesial) (n) (no/yes/not applicable)	262/5/150	62.8/1.2/36
Open contact (distal) (n) (no/yes/not applicable)	236/6/175	56.6/1.4/42
Emergence Angle (mesial) (mean ± SD /median)	23.73±10.81/22.36	-
Emergence Angle (distal) (mean ± SD /median)	22.15±10.34/20.07	-
Distance to outer contour of prosthesis (mesial) (mm) (mean ± SD /median)	2.54±1.04/2.50	-
Distance to outer contour of prosthesis (distal) (mm) (mean ± SD /median)	5.05±7.31/2.55	-

Mucosal height of abutment (mm) (mean ± SD /median)	2.63±1.42/2.5	-
Interproximal contact level to bone (mesial) (mm) (mean ± SD /median)	3.82±1.52/3.70	-
Interproximal contact level to bone (distal) (mm) (mean ± SD /median)	3.85±1.54/3.70	-
Crown height (mm) (mean ± SD /median)	14.00±4.32/13.35	-
Implant length (mm) (mean ± SD /median)	10.14±1.49/10.00	-
Crown to Implant ratio (C/I) (mean ± SD /median)	1.42±0.51/1.33	-
Horizontal distance from implant to adjacent teeth (mesial) (mm) (mean ± SD /median)	3.32±1.44/3.10	-
Horizontal distance from implant to adjacent teeth (distal) (mm) (mean ± SD /median)	3.27±2.25/2.70	-
Horizontal distance from implant to adjacent implant (mesial) (mm) (mean ± SD /median)	8.10±4.43/7.05	-
Horizontal distance from implant to adjacent implant (distal) (mm) (mean ± SD /median)	7.29±3.95/6.25	-
Angulation of implant compared to crown long-axis (mean ± SD /median)	2.51±5.68/0.00	-
Angulation between long axis of implants (mesial) (mean ± SD /median)	7.46±8.75/5.33	-
Angulation between long axis of implants (distal) (mean ± SD /median)	8.20±9.99/5.15	-

Table 4: Frequency distribution of health and peri-implant diseases

n=417	n	%
Healthy	156	37.4
Mucositis	241	57.8
Peri-implantitis	20	4.8
Total	417	100.0

Table 5: Implant-level associations between diagnosis and implant prosthesis characteristics

n=417	Healthy (n=156)	Mucositis (n=241)	Peri-implantitis (n=20)
Mucosal height of abutment (mean ± SD (mm) (min-max))	2.73 ± 1.45 (0.5-6.2)	2.54 ± 1.36 (0.0-6.7)	2.84 ± 1.81 (1.0-6.0)
Type of Supraconstruction (n/%)			
Fixed	124/29.74	202/48.44	11/2.64
Removable	32/7.67	39/9.35	9/2.16
Overall	156/37.41	241/57.79	20/4.80
Cemented/Screw retained (n/%)			
Cemented	8/1.92	13/3.12	6/1.44
Screw-retained	148/35.49	228/54.68	14/3.36
Overall	156/37.41	241/57.79	20/4.80
Platform Switching (n/%)			
Yes	148/35.49	223/53.48	16/3.84
No	8/1.92	18/4.32	4/0.96
Overall	156/37.41	241/57.79	20/4.80

Table 6: Bivariate and multivariable analysis for the associations between implant prosthetic characteristicparameters and diagnosis using a generalized linear mixed model (GLMM)

n = 417	Unadjusted odds ratio (95% confidence interval)	p-value (Bivariate unadjusted for confounding)	Adjusted odds ratio (95% confidence interval)	p-value (Multivariable adjusted for confounding)
Mucosal height of abutment	0.93 (0.78-1.12)	0.467	0.87 (0.71-1.07)	0.193
Type of supraconstruction				
Removable	1.57 (0.79-3.13)	0.197	2.16 (1.003 – 4.63)	**0.049***
Fixed	1.00 (reference)	-	1.00 (reference)	-
Cement/Screw retained				
Cement retained	2.44 (0.88-6.73)	0.085	2.10 (0.70 – 6.32)	0.186
Screw retained	1.00 (reference)	-	1.00 (reference)	-
Platform Switching				
No	2.15 (0.77-5.99)	0.144	1.78 (0.58 – 5.43)	0.310
Yes	1.00 (reference)	-	1.00 (reference)	-

Table 7: Descriptive statistics for implant-level radiographic assessments by bleeding on probing level

n=417	Bleeding on probing (BOP)		
	No (0% of sites)	**Moderate (1 – 50% of sites)**	**Advanced (51 – 100% of sites)**
Emergence angle Mesial (mean ± SD)	23.93 ± 11.32	23.16 ± 9.68	24.61 ± 12.22
Emergence angle Distal (mean ± SD)	21.31 ± 10.19	22.39 ± 10.20	23.29 ± 10.97
Mucosal height of abutment (mean ± SD)	2.7 ± 1.42	2.62 ± 1.4	2.46 ± 1.44
Emergence profile Mesial (n/%)			
Concave	34/9.37	48/13.22	16/4.41
Straight	62/17.08	72/19.83	37/10.19
Convex	43/11.85	35/9.64	16/4.41
Total	139/38.29	155/42.70	69/19.01
Emergence profile Distal (n/%)			
Concave	30/8.29	34/9.39	9/2.49
Straight	60/16.57	80/22.10	40/11.05
Convex	48/13.26	41/11.33	20/5.52
Total	138/38.12	155/42.82	69/19.06
Platform Switching (n/%)			
No	9/2.16	13/3.12	8/1.92
Yes	159/38.13	161/38.61	67/16.07
Total	168/40.29	174/41.73	75/17.99
Cantilever (n/%)			
No	129/35.25	147/40.16	61/16.67
Yes	9/2.46	11/3.01	9/2.46
Total	138/37.70	158/43.17	70/19.13

Table 8: Bivariate and multivariable analysis for the associations between implant prosthetic characteristic parameters and bleeding on probing level using a generalized linear mixed model (GLMM)

n=417	Unadjusted odds ratio (95% confidence interval)	p-value (Bivariate unadjusted for confounding)	Adjusted Odds ratio (95% confidence interval)	p-value (Multivariable adjusted for confounding)
Emergence Angle Mesial	1.01 (0.99-1.03)	0.374	1.002 (0.98-1.03)	0.856
Emergence Angle Distal	1.02 (1.0-1.043)	0.104	1.022 (1.10-1.05)	0.087
Mucosal height of abutment	0.93 (0.77-1.12)	0.428	0.911 (0.70-1.19)	0.497
Emergence Profile Mesial				
Concave			1.677 (0.75-3.73)	0.204
Straight			1.447 (0.67-3.13)	0.347
Convex	1.00 (reference)	-	1.00 (reference)	-
Emergence Profile Distal				
Concave	1.00 (0.50-2.01)	0.992	0.764 (0.33-1.78)	0.531
Straight	1.40 (0.77-2.53)	0.266	1.274 (0.61-2.66)	0.517
Convex	1.00 (reference)	-	1.00 (reference)	-
Platform Switching				
No	1.93 (0.69-5.43)	0.210	2.558 (0.88-7.42)	0.084
Yes	1.00 (reference)	-	1.00 (reference)	-
Cantilever Distal				
No	0.53 (0.22-1.27)	0.153	0.579 (0.22-1.52)	0.267
Yes	1.00 (reference)	-	1.00 (reference)	-

Table 9: Descriptive statistics for implant-level by mesial marginal bone level

	Mesial marginal bone level (mean ± SD)
Emergence profile Mesial	
Concave (n=98)	-0.19 ± 1.49
Straight (n=171)	-0.09 ± 1.43
Convex (n=94)	0.42 ± 1.76
Open contact Mesial	
No (n=262)	-0.25 ± 1.56
Yes (n=5)	-1.22 ± 1.65

Table 10: Descriptive statistics for implant-level by distal marginal bone level

	Distal Marginal Bone Level (mean ± SD)
Emergence Profile Distal	
Concave (n=73)	-0.22±1.55
Convex (n=109)	-0.36±1.31
Straight (n=180)	-0.24±1.52
Open contact Distal	
No (n=236)	-0.30 ± 1.55
Yes (n=6)	-0.20 ± 0.75
Cantilever Distal	
No (n=337)	-0.26 ± 1.48
Yes (n=29)	-0.32 ± 1.48

Table 11: Descriptive statistics for implant-level by average marginal bone level

	Average Marginal Bone Level (mean ± SD)
Platform switching	
No (n=30)	-1.08±1.96
Yes (n=387)	-0.26±1.40
Surface treatment	
TiUnite anodized (n=100)	-0.80±1.61
Nanotite surface (n=7)	-1.30±0.73
SLActive (n=310)	-0.14±1.38

Table 12: Bivariate and multivariable analysis for the associations between implant prosthetic characteristic parameters and mesial marginal bone level using a generalized linear mixed model (GLMM)

n=417	Unadjusted Estimates (95% confidence interval)	p-value (Bivariate unadjusted for confounding)	Adjusted Estimates (95% confidence interval)	p-value (Multivariable adjusted for confounding)
Emergence Angle Mesial	-0.001 (-0.00193-(-0.0004))	**0.002***	-0.001 (-0.0039-0.001)	0.266
Emergence Profile Mesial				
Concave	0.011 (-0.012-0.033)	0.356	0.014 (-0.015-0.043)	0.336
Straight	0.004 (-0.017-0.026)	0.6942	0.006 (-0.024-0.036	0.681
Convex	1.00 (reference)	-	1.00 (reference)	-
Overall		0.636		0.625
Distance to outer contour of prosthesis Mesial	0.004 (-0.007-0.015)	0.487	-0.0004 (-0.024-0.023)	0.971
Interproximal contact level Mesial	-0.01 (-0.016-(-0.005)	**0.0005***	-0.020 (-0.0296-(-0.0113))	**<0.0001***
Horizontal distance to adjacent teeth Mesial	-0.002 (-0.011-0.006)	0.612	0.0095 (-0.003-0.022)	0.125
Open contact Mesial				
No	0.02(-0.052-0.091)	0.592	0.0034 (-0.127-0.134)	0.958
Yes	1.00 (reference)	-	1.00 (reference)	-

Table 13: Bivariate and multivariable analysis for the associations between implant prosthetic characteristic parameters and distal marginal bone level using a generalized linear mixed model (GLMM)

n=417	Unadjusted Estimates (95% confidence interval)	p-value (Bivariate unadjusted for confounding)	Adjusted Estimates (95% confidence interval)	p-value (Multivariable adjusted for confounding)
Emergence Angle Distal	-0.002 (-0.002-(-0.001))	**0.0001***	-0.003 (-0.004-(-0.002))	**<0.0001***
Emergence Profile Distal				
Concave	0.008 (-0.013-0.029)	0.470	0.003 (-0.023-0.030)	0.814
Convex	0.006 (-0.015-0.026)	0.595	0.019 (-0.007-0.046)	0.155
Straight	1.00 (reference)	-	1.00 (reference)	-
Interproximal contact level Distal	-0.0097(-0.016-(-0.0035))	**0.002***	-0.015 (-0.022-(-0.007))	**0.0002***
Open contact Distal				
No	0.005(-0.063-0.073)	0.892	-0.034 (-0.0998-0.0318)	0.309
Yes	1.00 (reference)	-	1.00 (reference)	-
Cantilever Distal				
No	-0.029(-0.057-(-0.0004))	**0.047***	-0.016 (-0.062-0.029)	0.479
Yes	1.00 (reference)	-	1.00 (reference)	-

Table 14: Bivariate and multivariable analysis for the associations between implant prosthetic characteristic parameters and average marginal bone level using a generalized linear mixed model (GLMM)

n=417	Unadjusted Estimates (95% confidence interval)	p-value (Bivariate unadjusted for confounding)	Adjusted Estimates (95% confidence interval)	p-value (Multivariable adjusted for confounding)
Mucosal height of abutment	0.010 (0.004-0.017)	**0.002***	0.014 (0.005-0.022)	**0.0014***
Platform switching				
No	-0.038 (-0.075-0.0001)	0.0504	0.013 (-0.030-0.056)	0.552
Yes	1.00 (reference)	-	1.00 (reference)	-
Surface treatment				
TiUnite anodized	-0.034 (-0.061-(-0.008))	**0.011***	-0.048 (-0.079-(-0.018))	**0.003***
Nanotite surface	-0.052 (-0.17-0.06)	0.374	-0.068 (-0.162-0.026)	0.153
SLActive	1.00 (reference)	-	1.00 (reference)	-
Crown to implant ratio (C/I)	-0.002 (-0.021-0.017)	0.8328	-0.003 (-0.022-0.016)	0.762
Angulation of long axis of crown to implant	0.0001 (-0.001-0.002)	0.876	-0.001 (-0.002-0.0005)	0.213

Appendix B

LIST OF FIGURES

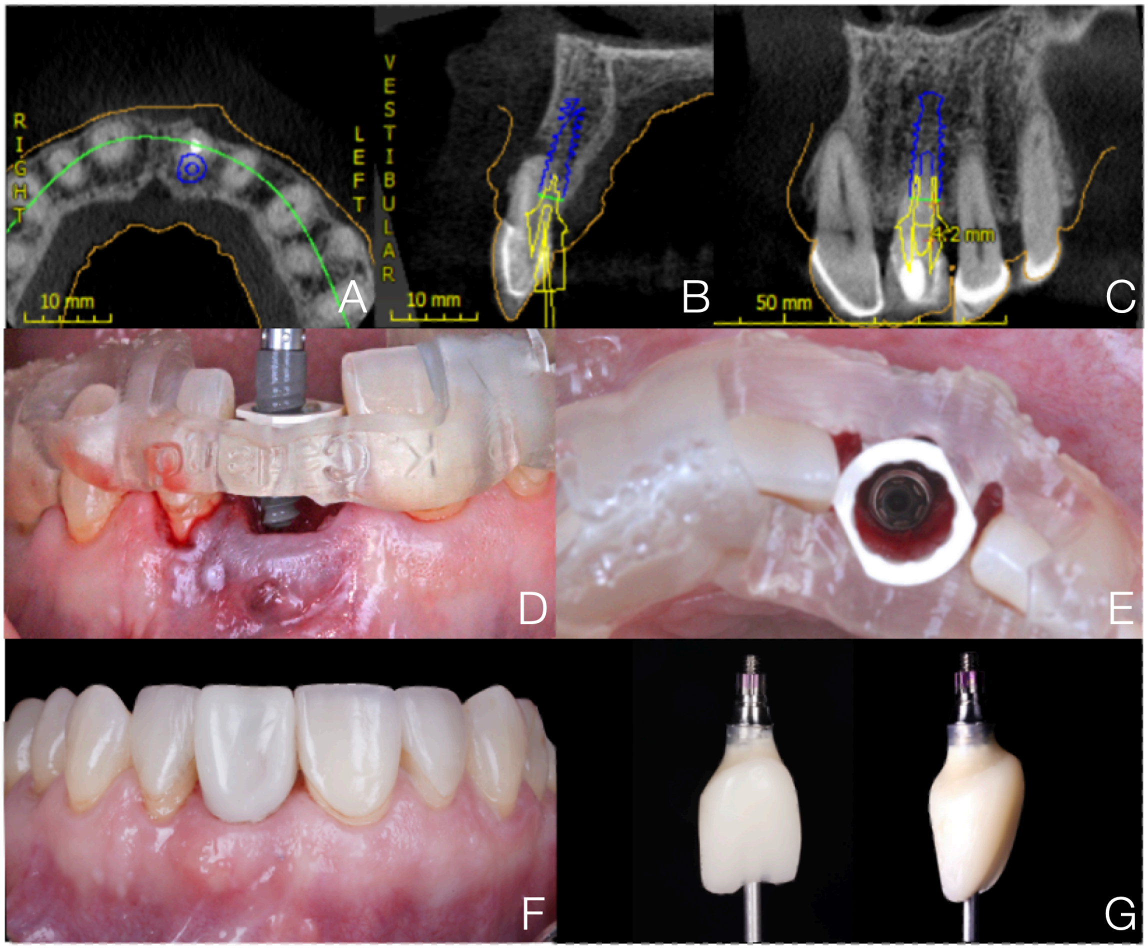

Figure 1: Digital guided implant planning and placement

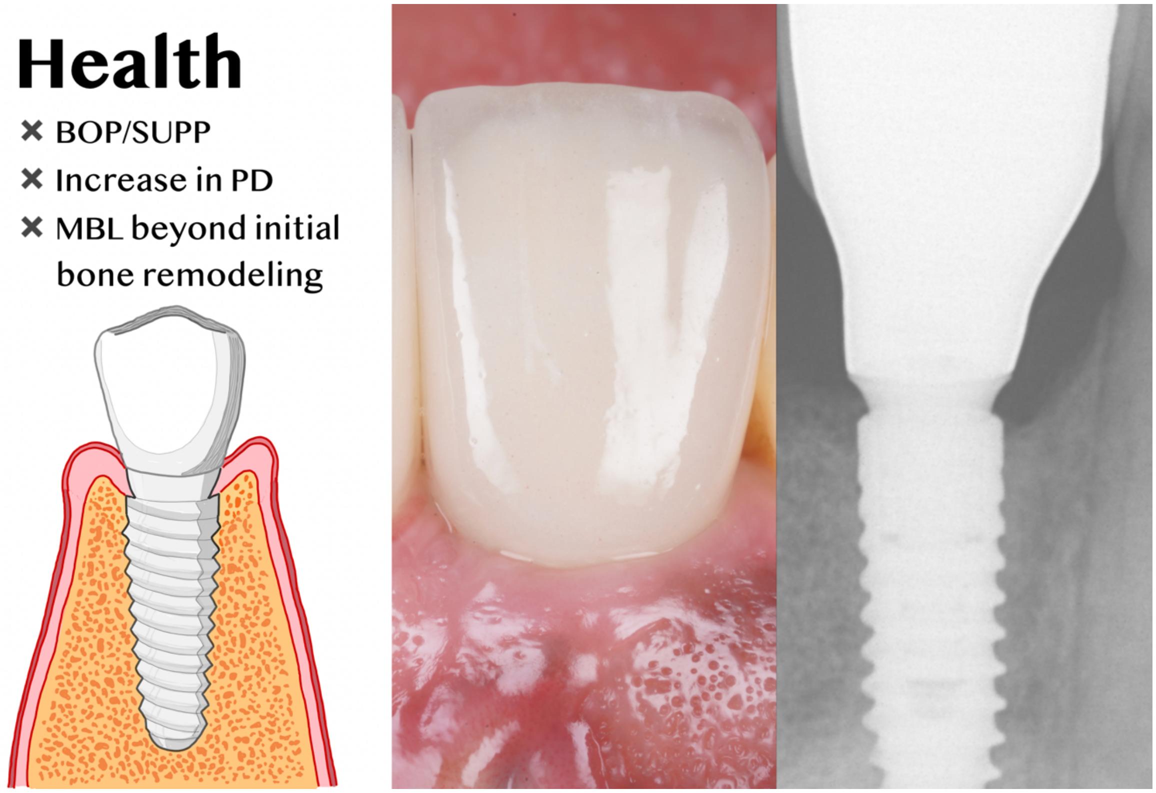

Figure 2: Peri-implant health (Berglundh T et al. 2018)

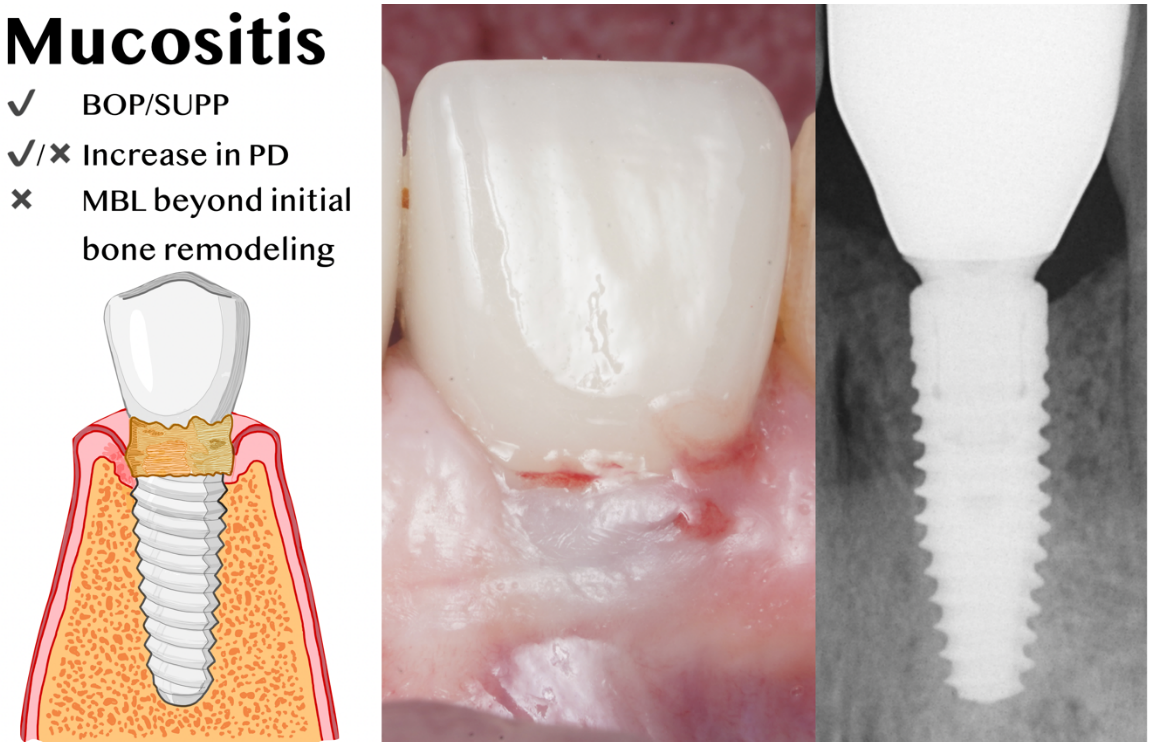

Figure 3: Peri-implant mucositis (Berglundh T et al. 2018)

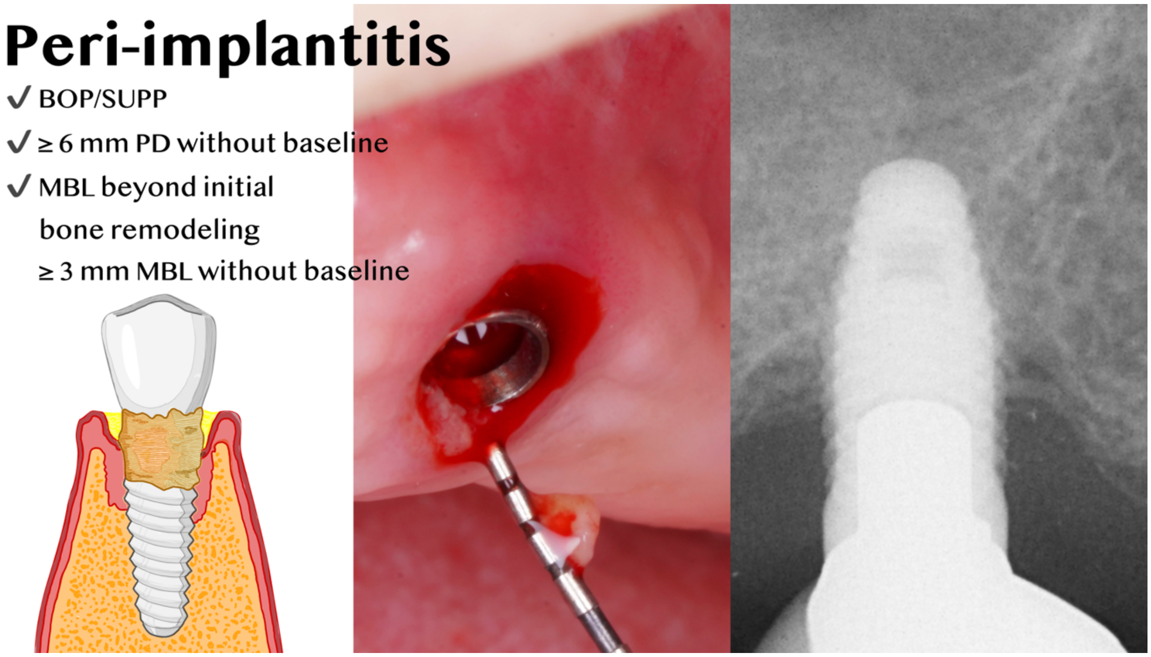

Figure 4: Peri-implantitis (Berglundh T et al. 2018)

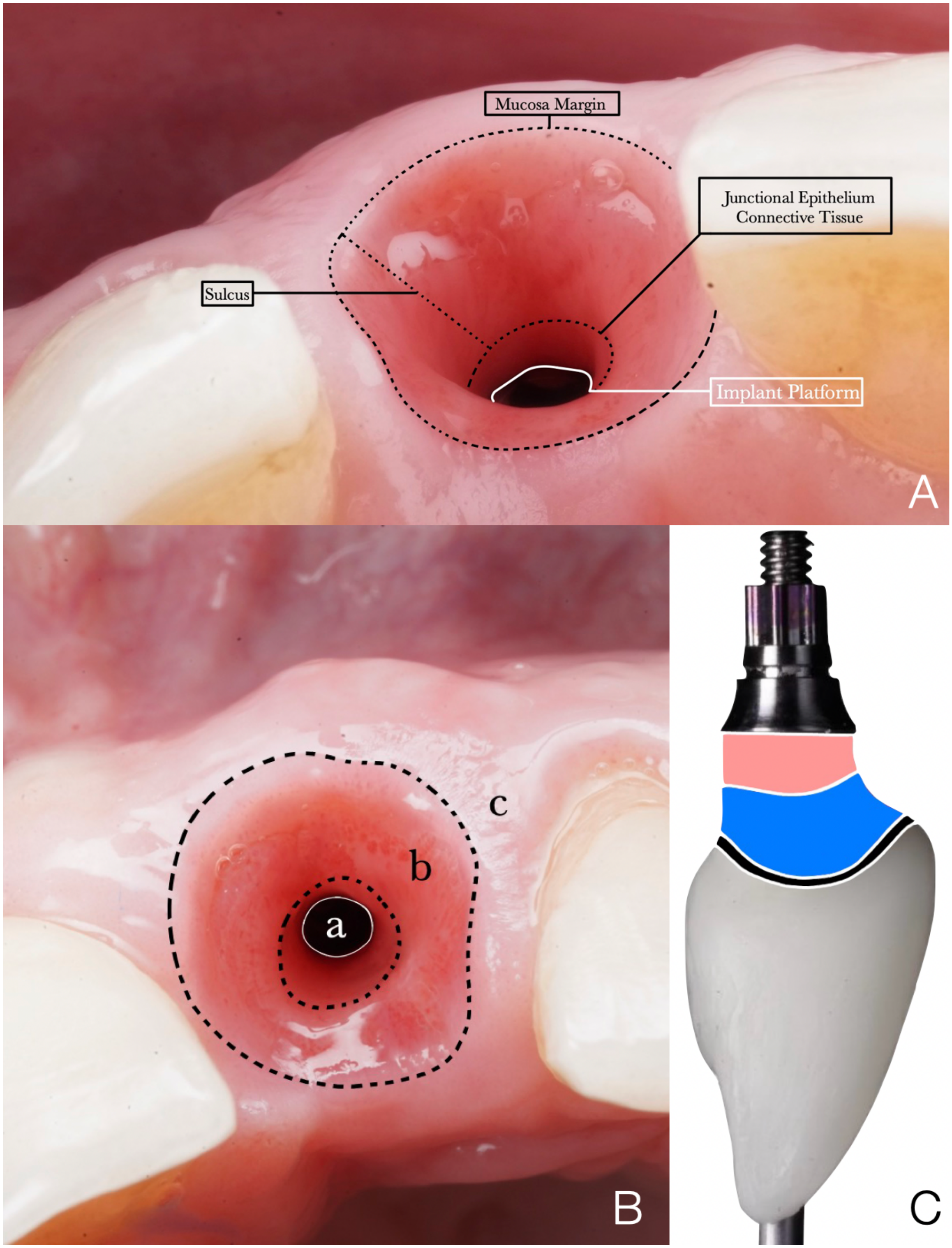

Figure 5: Peri-implant soft tissue compartment and proper prosthesis contour

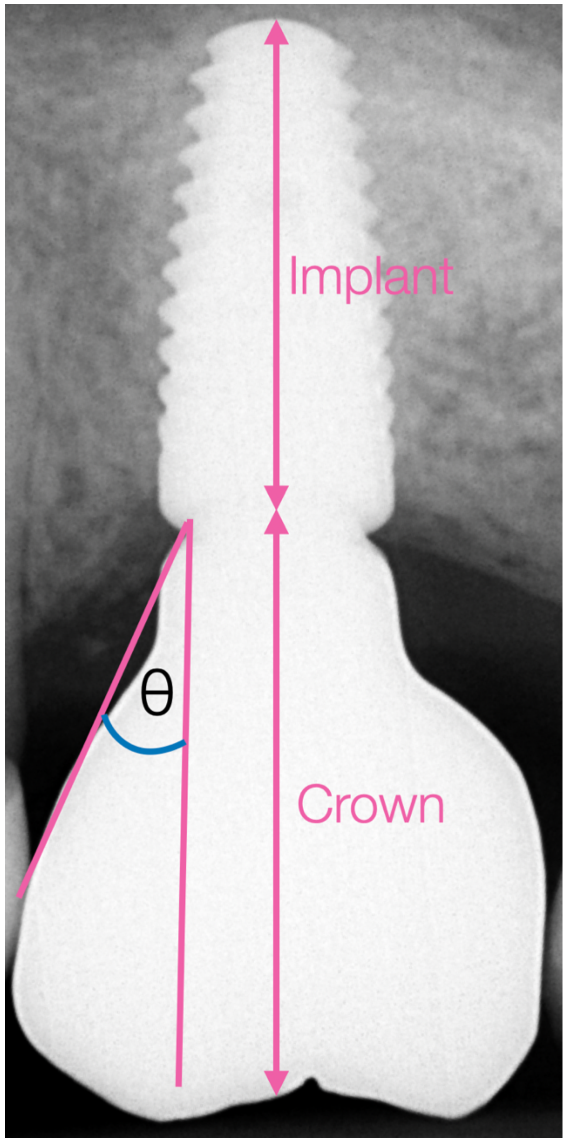

Figure 6: Emergence angle (mesial and distal) and crown-to-implant ratio (C/I)

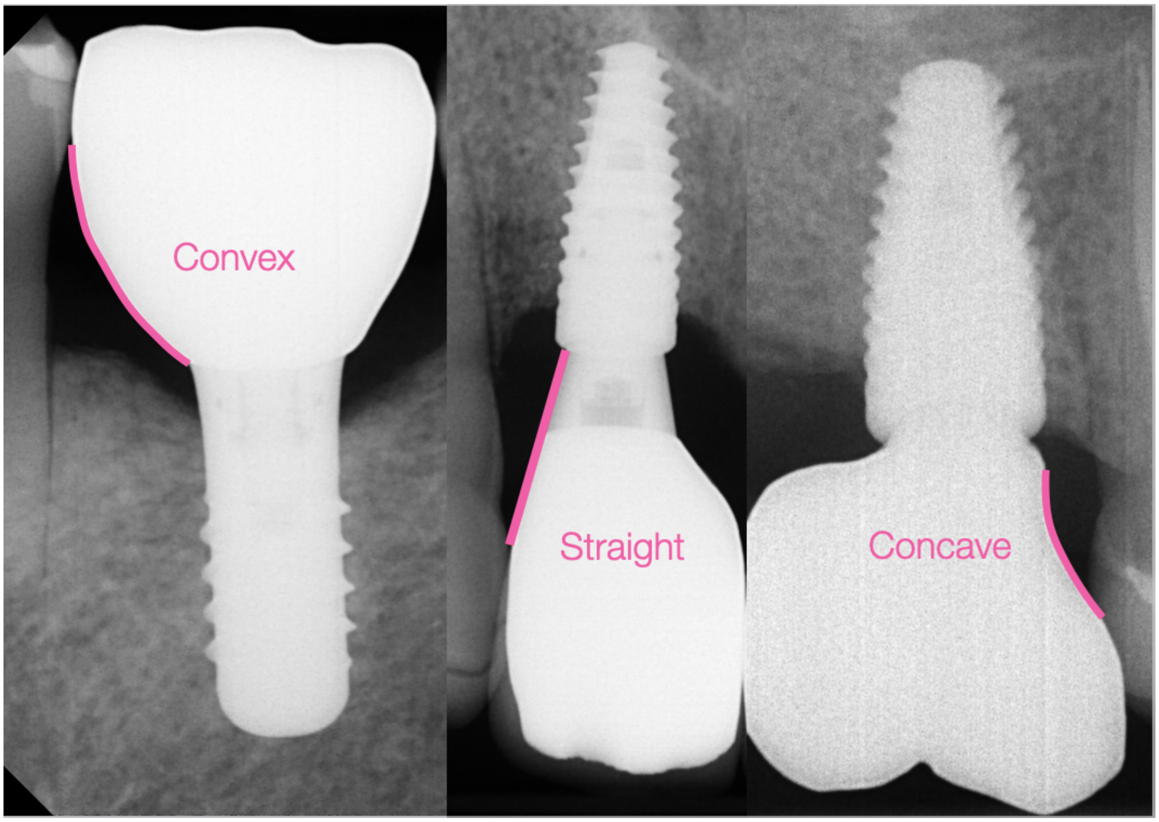

Figure 7: Emergence profile (convex, straight, concave)

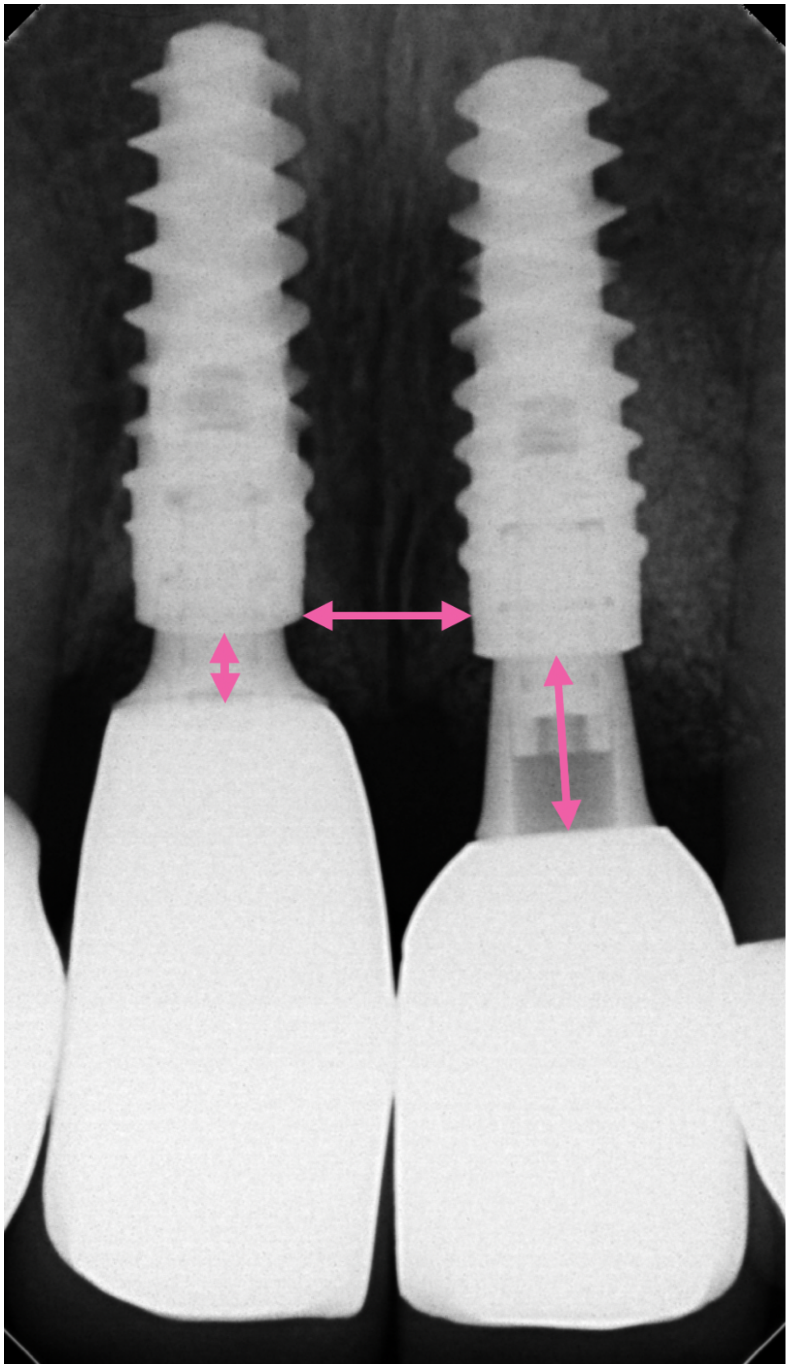

Figure 8: Mucosal height of abutment and inter-implant distance or horizontal distance between implants (mesial and distal)

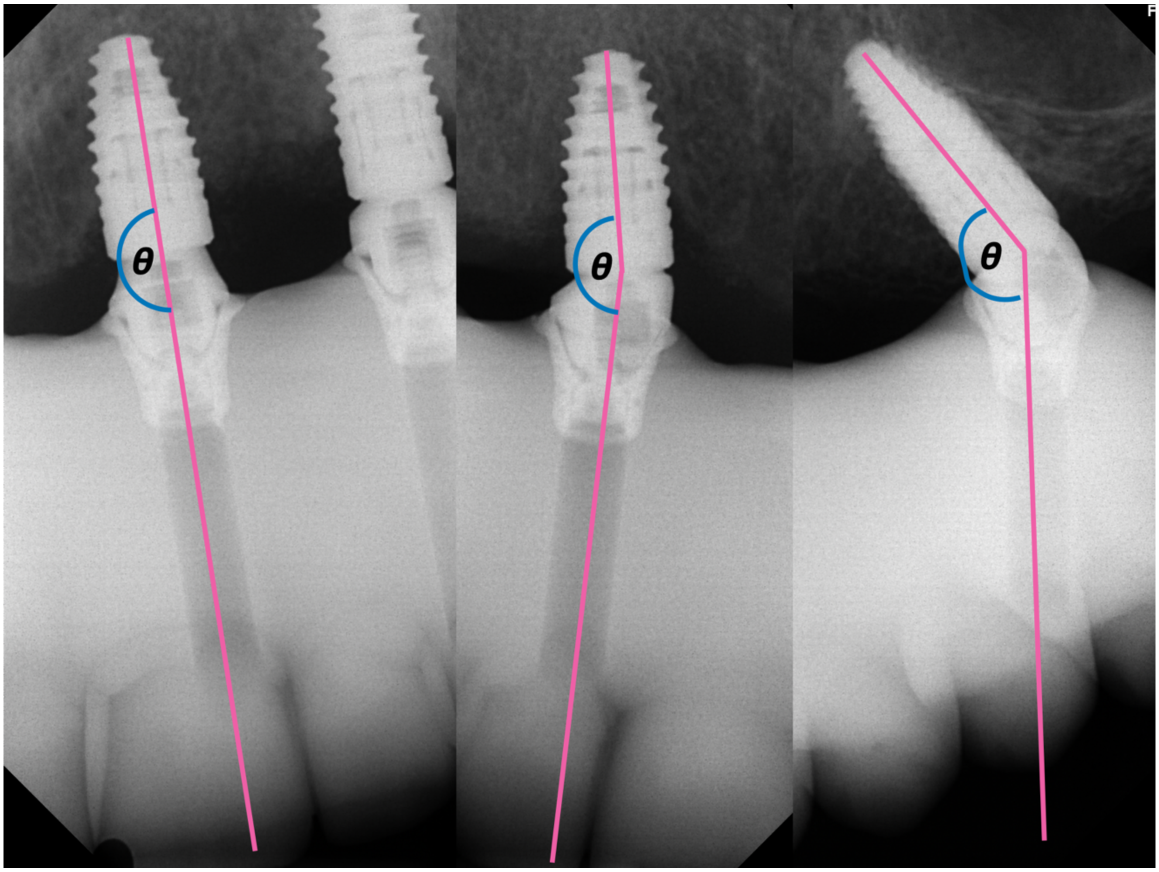

Figure 9: Angulation of abutment, angulation of implant, angulation between long axis of splinted implants (mesial and distal)

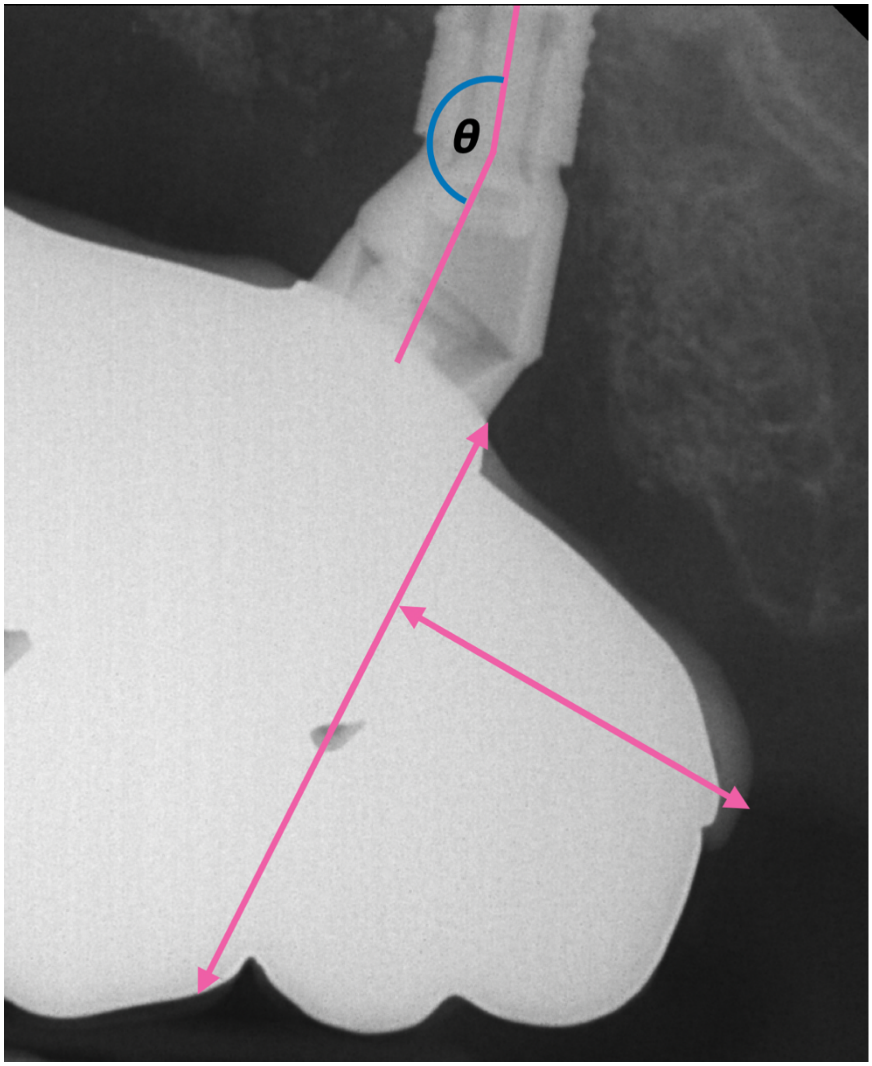

Figure 10: Height of prosthesis, angulation of abutment, angulation of implant, distance to outer contour of prosthesis (mesial and distal), presence of cantilever (mesial and distal)

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