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The Influence of Abutment Macro-Design on Peri-Implant Tissue Dimensions for Guided Placed and Restored Implants: A 1-Year Randomized Controlled Trial and CBCT Analysis

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THE INFLUENCE OF ABUTMENT MACRO-DESIGN ON PERI-IMPLANT TISSUE DIMENSIONS FOR GUIDED PLACED AND RESTORED IMPLANTS: A 1-YEAR RANDOMIZED CONTROLLED TRIAL AND CBCT ANALYSIS.

ABDULAZIZ ALI, BCHD.

A Thesis Presented to the Faculty of the College of Dental Medicine of Nova Southeastern University in Partial Fulfillment of the Requirements for the Degree of

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I certify that I am the sole author of this thesis, and that any assistance I received in its preparation has been fully acknowledged and disclosed in the thesis. I have cited any sources from which I used ideas, data, or words, and labeled as quotations any directly quoted phrases or passages, as well as providing proper documentation and citations. This thesis was prepared by me, specifically for the M.Sc.D. degree and for this assignment.

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DEDICATION

To my mom, for believing in me and supporting my pursuit of a career in dentistry.

To my wife, Nour, for standing by me throughout all the difficulties of studying abroad. I could not have done this without her love and support.

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Abstract

Introduction: For optimal dental implant esthetics the transition of a circumferential implant platform to a proper cervical anatomy has been emphasized. This transition is facilitated by the macro-design of the transmucosal portion of the abutment-restoration complex at the provisional and final stages of implant prosthetic therapy. There is limited information from human studies assessing the impact of abutment macro-design on peri-implant tissue dimensional changes. **Aim:** The aim was to evaluate the peri-implant tissue levels over a 1-year period for implants connected to either convex or concave final abutments at the time of implant placement. **Methods:** Twenty-eight patients with one missing maxillary premolar randomly allocated to receive one single implant with abutments of different emergence shape configuration. Patients of the CX Group had abutments with convex emergence shape and patients of the CV Group had abutments with concave emergence shape. Clinical and radiographic data collected at the time of implant placement (T0), final prosthesis delivery (T1) and 12 months following implant

placement (T2). **Results:** There was 0.42-0.55mm more bone remodeling occurred in the CX group. Soft tissue thickness was 21-37% greater in the CV group. There was a statistically significant moderate correlation between buccal bone thickness and recession T0-T2. No statistically significant difference found in recession between the two groups. **Conclusion:** A concave abutment configuration was associated with less bone remodeling and had greater horizontal soft tissue thickness. However, no difference was seen in the amount of recession between the two groups. Bone thickness was found to be the most significant factor for gingival recess.

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1. Introduction

1.1. Dental Implant Success and Survival

The introduction of dental implants for the treatment of edentulous and partially dentulous patients has greatly influenced the practice of modern dentistry, but like any new treatment modality, it had to evolve to better suit the patients of the 21st century. According to Douglas and Sheets, the modern patient is expected to be more aggressive in the expectation of dental treatment, and the dental professionals will be responsible for the quality of care provided.[1] Patients are looking for not only functional and disease-free oral health but also an aesthetically pleasing look for better self-confidence and social advantages.

As such, assessing the survival of dental implants is not enough, since it may not be successful. Success represents an implant that meets the criteria on which it is being evaluated while survival is when the implant remains in the mouth. The criterion for implant success has progressed. In earlier studies the primary concern was regarding the osseointegration of the implant, and as to date this still holds true for one of the primary successes of dental implants.[2] In addition, this reflected on how the initial criterion for success was seen in the late 70s and early 80s. Tables 1.1 and 1.2 show the numerous criteria and the differences of the same criterion between different authors.

Table 1. 1 Implant success criteria of different authors

Schnitman and Schulman	Cranin et al.
1. Mobility less than 1 mm in any direction	1. In place 60 months or more
2. Radiologically observed radiolucency graded but no success criterion defined	2. Lack of significant evidence of cervical saucerization on radiographs
3. Bone loss no greater than one-third of the vertical height of the bone	3. Freedom from hemorrhage according to Muhleman′s index
4. Gingival inflammation amenable to treatment; absence of symptoms and infection; absence of damage to adjacent teeth; absence of paresthesia and anesthesia; or violation of the mandibular canal, maxillary sinus, or floor of the nasal passage	4. Lack of mobility
	5. Absence of pain or percussive tenderness
5. Functional service for five years in 75% of patients	6. No pericervical granulomatosis or gingival hyperplasia
	7. No evidence of a widening peri-implant space on radiographs

Table 1. 2 Implant success criteria of different authors

McKinney et al.	Albrektsson et al.
Subjective criteria 1. Adequate function 2. Absence of discomfort 3. Patient belief that esthetics and emotional and psychological attitudes are improved	1. Individually unattached implant that is immobile when tested clinically
Objective criteria 1. Good occlusal balance and vertical dimension 2. Bone loss no greater than one-third of the vertical height of the implant, absence of symptoms, and functional stability after five years 3. Gingival inflammation vulnerable to treatment 4. Mobility < 1 mm buccolingually, mesiodistally, and vertically 5. Absence of symptoms and infection associated with the dental implant 6. Absence of damage to adjacent tooth or teeth and supporting structures 7. Absence of parasthesia or violation of mandibular canal, maxillary sinus, or floor of nasal passage 8. Healthy collagenous tissue without polymorphonuclear infiltration	2. Radiography that does not demonstrate evidence of peri-implant radiolucency 3. Bone loss that is < 0.2 mm annually after the implant′s first year of service 4. No persistent pain, discomfort, or infection
Success criterion 1. Provides functional service for five years in 75% of implant patients	5. By these criteria, a success rate of 85% at the end of a 5-year observation period and 80% at the end of a 10-year period are minimum levels for success

A major difference in the studies arises from the maximum amount of bone loss that is considered successful. Schnitman and Schulman (1979) suggested losing up to a third of the total bone height was normal, while McKinney et al. (1984) proposed bone loss no greater than a third of the implant was normal. Nonetheless, a widely known success criterion by Albrektsson et al. (1986) indicated after the first year, less than 0.2 mm of bone loss annually was considered successful. In addition, they indicated dental implants should meet these criteria for up to 5 years 85% of the time and up to 10 years 80% of the

time to be considered successful. Only one article mentioned an esthetic success criterion—which at best was a vague criterion and only indicated there should be an improvement of the esthetic, emotional, and psychological attitudes of the patient.[3-6]

Recently, the success criteria for implants has changed from the previously mentioned. For instance, Misch indicated implant criteria are comparable to that of teeth, which are not evaluated whether they are a success or failure. Instead, ideal conditions are reported, and a quality of health scale is used to describe the intraoral conditions that should be applied to implants. In this health scale, the implants are categorized into either success, satisfactory survival, compromised survival, or failure. A successful implant, which refers to optimal health, requires specific clinical conditions for the prognosis to be very good to excellent. The conditions for optimum health are when the patient has no pain or tenderness, no exudate, no implant mobility, and less than 2 mm of bone loss compared to when the implant was initially placed. In the survival category, there are two groups: satisfactory survival and compromised survival. The satisfactory survival category has the same clinical conditions as the success category, except there is a bone loss of 2–4 mm compared to the initial radiograph. This category has a good to a very good prognosis, which is dependent on the future stability of the bone loss. While the compromised survival category can have symptoms and a more severe radiographic bone loss of 4 mm or less than half of the body of the implant, it has a good to a guarded prognosis, depending on how stable the implant can be after surgery. Lastly, the failure category indicates the implant must be removed due to any of the following: pain on function, exudate, mobility, and radiographic bone loss of more than half of the implant.[7] These categories give good information for clinicians on how to assess the implants and

if further treatment is necessary, but no regards are given to the esthetics of dental implants.

The Pink Esthetic Score (PES) and the White Esthetic Score (WES) are widely used for determining implant esthetic failure. The PES objectively assesses five variables: the mesial papilla, distal papilla, curvature of the facial mucosa, level of the facial mucosa, and root convexity/soft tissue color. The WES objectively assesses the restoration on five variables: general tooth form, outline/volume of the clinical crown, color (hue/value), surface texture, and translucency/characterization. Each variable is scaled from 0–2, with 2 being the ideal and 0 being the poorest. Success for these variables is at least six points for each and an overall 60% combined.[8]

The success of the esthetics and function of dental implants is highly dependent on the bone level around the implant. The concept on how much bone loss can be expected around an implant has changed dramatically over the years due to the implementation and development of better surgical techniques, greater control of systemic local and patient factors, and improved implant design.

1.2. Surgical Factors Affecting Implant Success

The surgeon's experience, skills, and knowledge are important for the success of an implant. A study by Zoghbi et al. found there was a positive influence of experience on the osseointegration of implants. Cases were separated into two groups; the less experienced surgeons had placed less than 50 implants while the more experienced surgeons had placed more than 50 implants. The more experienced surgeons achieved implant osseointegration in 94.4% of the cases while the less experienced surgeons

achieved implant osseointegration in 84% of the cases.[9] However, other studies compared residents in different years of training and clinicians; there was no significant difference between the two groups.[10, 11] This could be attributed to different reasons; one is the number of implants placed does not correlate to the number of years the clinician has been in residency. Also, the extensive training of specialized programs may accommodate the difference in the amount of implant placement.

Another factor that is undoubtedly affected by surgical experience is minimizing the surgical trauma to the area. A temperature of 47°C or higher during drilling can happen within seconds without irrigation. And if this lasts for more than a minute, irreversible damage to the bone can occur, leading to soft tissue interface between the implant and the bone.[12-14]

The knowledge and skills of the surgeon are important for the correct 3D position of an implant, which can help prevent bone loss. The surgeon needs to be aware of the positioning of the implants in terms of the depth, angulation, and inter-implant and tooth-implant distance. The proximity of implants to other implants/teeth can affect the marginal bone levels; therefore, a general recommendation is a minimum distance of 3 mm between implants and 1.5 mm between teeth. According to Buser et al., the distance between an implant shoulder and tooth root surface should be 1 mm, but due to the shape of the implant used in this article, 1.5 mm was recommended.[15] If this recommendation is not followed, the implant has the risk of attachment loss and interproximal recession.[16, 17] The more recently used platform-switched implants with a conical connection displayed different results. Koutouzis et al. examined marginal bone

loss at different implant distances in platform-switched implants and found no significant statistical difference for implants placed 1.97 mm or 3.12 mm apart.

1.3. Morphogenesis of the peri-implant mucosa in animal studies

The peri-implant mucosa provides protection for the underlying bone and is an important factor for the maintenance of the implant's stability and function. Most studies on the morphogenesis of the peri-implant mucosa have been conducted on animals, and the mean values of the peri-implant mucosa are shown in Table 1.3. The peri-implant mucosa is composed of the junctional epithelium, approximately 1.5–2 mm, and the connective tissue portion, approximately 1–1.5 mm, with greater variations in size at the junctional epithelium. The reason why the junctional epithelium does not reach the bone crest is not fully understood, but somehow, there must be a connective tissue integration that prevents the apical migration of the junctional epithelium to the bone crest. Berglundh et al. found no statistically significant difference between the dimension of the epithelium in normal teeth compared with that of implants; however, teeth had a statistically significant less connective tissue length compared with implants.[18]

Table 1. 3 Peri-implant mucosal dimensions

Study	JE (mm)	CT (mm)	GM-BC (mm)	Implant placement technique	Biopsy date after placement of healing abutment
Berglundh et al. [18]	2.14	1.66	3.8	Two-stage implant	6 months
Moon et al. [19]	2	N/A	N/A	Two-stage implant	6 months
Abrahamsson et al. [20]	1.64–2.35	1.28–1.47	3.11–3.5	One- and two-stage implants	6 months
Berglundh and Lindhe [21]	2–2.1	1.3–1.8	2.4–3.65	Two-stage implant	6 months
Berglundh et al. [22]	1.8–2.2	1.5–2	N/A	Two-stage implant	4 months
Berglundh et al. [23]	2	1.5	3.5	One-stage implant	12 weeks
Abrahamsson et al. [24]	1.65–2.04	0.85–1.28	2.5–3.32	Two-stage implant	6 months
Abrahamsson et al. [25]	1.85–1.97	1.16–1.18	3.0–3.15	Two-stage implant	6 months
Abrahamsson et al. [26]	2.04	1.28	3.32	One- and two-stage implants	9 months
Abrahamsson et al. [27]	2.1–2.6	1.6	3.7–4.2	Two-stage implant	6 months
Cochran et al. [28]	0.9–1.4	1–1.1	2.0–2.4	Tissue-level implants	12 months
Hermann et al. [29]	1.33–1.75	1.28–1.62	2.84–3.57	Tissue-level implants, one- and two-stage implants	6 months

JE: Junctional Epithelium; CT: Connective Tissue; GM-BC: Gingival Margin to Bone Crest

Abrahamsson et al. compared the peri-implant dimensions of implants placed in one or two stages, and both approaches showed no statistically significant difference.[20] However, it was found that a certain degree of width of the peri-implant mucosa would be needed for stability; otherwise, bone resorption could occur. In thin tissues, the bone was resorbed so that proper formation of the dimensions of the peri-implant mucosa could occur. This finding was confirmed in Berglundh and Lindhe's study, where the peri-implant connective tissue portion was dissected, leaving a thin soft tissue, which resulted in a statistically significant bone remodeling to accommodate the normal peri-implant mucosal dimensions.[21] Additionally, a 6–8-week time frame was needed for the maturity of the barrier epithelium, whereas the connective tissue maturation required 4–6 weeks.[23]

The two-stage implant placement was the proposed treatment of choice to limit the risks of fibro-encapsulation and microbiological complications.[30] Hermann et al. compared one-piece and two-piece implants with different locations of the smooth and the rough surfaces of the implants. The peri-implant mucosal dimensions were significantly smaller in the one-piece implants and more comparable with those of teeth than the two-piece implants. Additionally, the two-piece implants were associated with a more apical position of the gingival margin due to bone loss.[29] However, a literature review by Rompen et al. indicated that in animal studies, similar soft-tissue integration occurred in both one-piece and two-piece implants.[31]

The peri-implant mucosa differs from that of teeth in orientation, vasculature, and content. The origin of the peri-implant mucosa is the oral epithelium, whereas in teeth, it originates from the reduced enamel epithelium. The peri-implant mucosa has dense collagen fibers that cannot insert into the implant, whereas in teeth, the fibers (Sharpey's fibers) insert into the cementum. These gingival fibers around teeth are perpendicular to the tooth, but in the peri-implant mucosa, they are parallel to the implant and run their course from the periosteum of the bone to the gingival complex.[18, 19]

The peri-implant mucosa also has significantly less fibroblasts and is significantly less vascularized in the connective tissue portion compared with teeth. The reduced vasculature could be attributed to the origin of the blood vessels. Teeth have two sources of vessels (the supraperiosteal and the periodontal ligaments), while in implants, the blood vessels originate from the periosteum of the bone.[22] In theory, the amount of blood supply can affect the tissue turnover rate that can occur around implants, where in teeth, this is known to be high. As such, the peri-implant mucosa is observed as a scar-like

tissue with a low turnover rate. However, a study by Moon et al. showed that despite the low fibroblast amount and vascularity, when the section closest to the implant was examined, more fibroblasts were concentrated in this area. The conclusion was that although the outer layer had significantly less cells and more collagen, the inner area had a significantly rich area of fibroblasts. Thus, the peri-implant mucosal border closest to the implant has a high turnover rate, which is important in the maintenance of the seal and the stability of the implant.[19] This finding was confirmed in a study by Abrahamsson et al., where the inner zone had 30–33% fibroblasts, whereas the outer zone had 10–11% fibroblasts.[27]

1.3.1 Morphogenesis of the peri-implant mucosa in relation to different abutment materials used in animal studies

Numerous types of abutment materials are available, but the main ones used are zirconia and titanium. Most of the studies on different abutment materials were conducted on animals, as shown in Table 1.4. A study by Abrahamsson et al. showed that a proper connective tissue and junctional epithelium were formed around healing abutments made of zirconia or titanium, whereas in gold alloy or porcelain, no proper attachment was observed, resulting in recession and marginal bone loss. In the latter materials, the attachment occurred on the implant surface; thus, the abutment-implant connection was exposed. The hypothesis is that it is either due to the variation in the materials' adhesiveness or corrosion resistance. As such, ceramic and titanium are more corrosion resistant than gold alloy.[25] However, in a more recent study, Abrahamsson and Cardaropoli[32] compared gold alloy and titanium surface abutments and found no difference between the peri-implant mucosal dimensions using the two materials. The

authors concluded that the fibroblasts' adherence to smooth metallic surfaces was adequate regardless of the materials used. The change in the results compared with those of the previous study could be due to the methodological differences and the different brands of implants used, although the bone-to-implant contact in the different materials of the implants used was better in the titanium implants.[32]

Table 1. 4 Effect of different materials on peri-implant mucosal dimensions

Study	Abutment materials	Findings
Abrahamsson et al. [25]	Zirconia, titanium, gold alloy, and porcelain abutments	Bone loss and apical migration of soft tissue in gold and porcelain abutments Proper peri-implant mucosal dimensions in zirconia and titanium abutments
Abrahamsson et al. [32]	Titanium or gold abutments with four different combinations at different levels of the implant	No statistically significant difference between the groups
Welander et al. [33]	Titanium, ZrO_2, and AuPt-alloy abutments	Apical migration of the junctional epithelium and marginal bone loss around the AuPt-alloy abutments compared with the other two

Zr: Zirconia; Au:Gold; Pt:Platinum; O:Oxygen

Welander et al. conducted a study that favored zirconia and titanium healing abutments. They compared healing abutments made of titanium with those made of AuPt-alloy and ZrO_2. After five months, the peri-implant mucosal dimensions remained stable for the ZrO_2 and the titanium healing abutments, whereas in the AuPt-alloy group, an apical shift of the junctional epithelium and marginal bone loss occurred. Additionally, the AuPt-alloy abutments had lower amounts of fibroblasts and collagen fibers and more leucocytes.[33]

A review article by Rompen et al. stated:

> ... titanium is the only material that has proven is biocompatibility towards the soft tissues in long□term clinical studies; some favorable clinical data become available

for zirconium and aluminium oxide; animal studies have shown that dental porcelain or gold isless biocompatible and should be avoided. Materials such as resins and composites should not be recommended up to now; the surface of the core material can be contaminated, altering the composition of the interface.[31]

1.3.2 Morphogenesis of the peri-implant mucosa in relation to different surface topography used in animal studies

There are conflicting results on how the different topographies of abutments affect the peri-implant mucosa, with some studies favoring rougher surfaces for soft-tissue attachment but indicating that more plaque accumulation and inflammation occur as well. Abrahamsson et al. compared smooth surface abutments with a dual thermal acid-etched surface and found no significant difference in attachment between the two in both quantitative and qualitative aspects.[27] However, a study by Cochran et al. found that sandblasting and acid etching (SLActive) implants had significantly more collagen organization than the machine surface and smaller peri-implant mucosal dimensions. These longer peri-implant mucosal dimensions were due to the difference in the junctional epithelium dimension, not the connective tissue dimension. Additionally, a slight bone loss occurred around the machine-surfaced collar, whereas the SLActive implants had a slight bone gain. The authors concluded that the rough surface was osteoconductive for bone formation and had more mature soft-tissue formation. Implants and abutments with a roughened surface have been associated with increased plaque accumulation, but the relevance of this increase may not be significant.[28]

A literature review by Rompen et al. indicated that in in-vitro and in-vivo studies, surface roughness could have early effects on the epithelial and the connective tissue cells' attachment, orientation, proliferation, and metabolism. Additionally, the rough surfaces could theoretically improve the initial stability and prevent the epithelial apical migration. Lastly, the epithelial cell adhesion was lower compared with that of the machine-surfaced abutment.[31]

1.3.3 Morphogenesis of the peri-implant mucosa in human studies

Human studies on the peri-implant mucosal dimensions showed a similar trend to that found in animal studies (Table 1.5) but could vary due to methodological differences, considering the nature of the designs in human studies. Tomasi et al. conducted a study using a special fabricated abutment to be able to conduct a biopsy on the soft tissue around the healing abutment in 21 patients. The peri-implant soft tissue was assessed in the 2-, 4-, 8-, and 12-week healing periods. The peri-implant mucosal dimensions were found to be similar to those in the animal studies (Table 1.5) and took approximately 8–12 weeks for complete healing of the junctional epithelium and the maturation of the connective tissue.[34]

Table 1. 5 Peri-implant mucosal dimensions in human studies

Study	JE (mm)	CT (mm)	GM-BC (mm)	Implant placement technique	Biopsy date (weeks)
Tomasi et al. [34]	2	1.1	3.1	One-stage/bone-level implant	12
Schwarz et al. [35]	1.88–1.96	0.43–0.55	2.35–2.51	One-stage/bone-level implant	8
Glauser et al. [36]	1.8–3.4	0.6–2.6	4–4.5	One-stage/tissue-level mini implant	8
Schupbach and Glauser [37]	1.4–2.9	N/A	N/A	One-stage/tissue-level mini implant	8

JE: Junctional Epithelium; CT: Connective Tissue; GM-BC: Gingival Margin to Bone Crest

Schwarz et al. also showed similar peri-implant mucosal dimensions for hydrophobic machine-surfaced and hydrophilic acid-etched titanium and zirconia abutments. There was more perpendicular collagen fiber orientation on the hydrophilic abutments in contrast to the denser collagen and the parallel hydrophobic healing abutments. This difference may indicate a better peri-implant mucosal seal when using hydrophilic healing abutments, but how this reflects on the clinical relevance needs to be further examined.[35]

Glauser et al. compared the healing of soft tissue in mini implants with 3 different surface topographies in 5 patients receiving a total of 12 mini implants. This process was done as a one-stage approach as it was a tissue-level implant. The different surface topographies were machine-surfaced, oxidized-layer, and acid-etched types. In contrast to the previous studies, these implants were harvested with both soft and hard tissues. The machine-surface implants had a much greater junctional epithelium length compared with the other two surface topographies, as indicated by the large range listed in Table 1.5. The machine surface also had a smaller connective tissue length compared with the other two surface topographies. The surface topographies of the oxidized-layer and the acid-etched types showed peri-implant mucosal dimensions similar to those found in the animal studies, whereas those of the machine-surfaced type varied. In all sections, there was no perpendicular attachment of collagen fibers to the implant surface, differing from the result of the previously mentioned study but consistent with those of the animal studies. Most fibers were in a parallel direction or ran circumferentially. Additionally, connective tissue formed an avascular, thin, and collagen-rich scar tissue, such as around the implant surface. Finally, it was observed that the healing of soft tissue was better around oxidized

or acid-etched surfaces due to the longer connective tissue and the shorter junctional epithelium compared with the machine surface. The possible explanation is that more surface irregularities can have a conductive effect on soft-tissue adhesion, inhibiting the apical migration of the junctional epithelium.[36] This finding differed from those of other studies, which indicated that tissue-level implants, not surface topographies, affected the lengths of the junctional epithelium and the connective tissue. A later study found similar results, where the junctional epithelium was much larger than acid and oxidized healing abutment surfaces. However, oxidized and porous surfaces showed perpendicular fiber attachment compared with the parallel attachment on the smooth machine surface, which was somewhat controversial as most animal and human studies indicated no such findings.[37]

1.3.4 Effect of implant loading timing on the morphogenesis of the peri-implant mucosa and implant success

Brånemark developed the initial load-timing protocol of a three-month healing period for mandibular implants and a six-month healing period for maxillary implants. That protocol was proposed to minimize the chances of micromotion for an implant during the process where it would become osseointegrated with the bone.[38] The concept of not loading implants was challenged in numerous studies. Ledermann et al. immediately loaded three to four implants in overdentures, with a reported 91.2% survival rate over six years.[39, 40]

The peri-implant mucosal dimensions in immediate and conventional loads were found to be similar in several studies. A study by Pontes et al. showed that soft-tissue healing was

not affected by the loading time, and Hermann et al. reported that the peri-implant mucosal dimensions were not significantly different between immediate and conventional loading of the implant.[41, 42] A systematic review by Glauser et al. concluded that soft-tissue healing around immediate implants was comparable to that of conventional loading, with little evidence of the effect of the loading time on the peri-implant mucosal dimensions.[43]

Szmukler-Moncler's literature review concluded that with careful and strict patient selection, successful premature loading could be achieved.[44] A systematic review by Esposito et al. showed a 0.1-mm difference in bone loss when immediate implants were compared with conventional loading, which was too small to be of clinical significance. Overall, there was no clinically important difference in prosthesis failure, implant failure, or bone loss associated with the different loading times. The most important prerequisite for immediate and/or early implant loading was a high value of at least 35 Ncm of the insertion torque. Additionally, the systematic review compared two concepts—immediate occlusal loading and immediate nonocclusal loading—with no significant differences between the two.[45]

1.4. Implant Microgap

In the early time frame of implant dentistry, a 1.5-mm crestal bone loss around an implant during the first year after restoration was considered part of the success criteria because the external hex connection was the implant-abutment connection that was mostly used.[6] This idea was later challenged in a study by Hermann et al., who compared the two-stage implants with the tissue-level implants. The authors found 1.5–2 mm of

bone loss for the two-stage implants, whereas in the tissue-level implants, minimal bone loss occurred. Moving this interface apically in two-stage implants also led to 1.5–2 mm of bone loss.[29,46] Buser et al. reinforced this idea of minimal bone loss around tissue-level implants in a human clinical study spanning over eight years.[47] The bone loss could not be attributed to the occlusion or the placement of an implant because it only occurred when the implant-abutment interface was changed.

One reason for bone loss occurring in the implant-abutment interface is the presence of bacteria, in which the body establishes a safe distance from this inflammatory front.[48] To minimize this presence, reducing the microgap distance in the implant-abutment interface was attempted, but this resulted in no difference in the amount of bone loss.[49, 50]

Another reason for bone loss is the micromotion that occurs in the implant-abutment interface. This phenomenon was demonstrated in a study by King et al., where the healing abutment was welded with the implant in one group, while it was not welded in the other group, but the same microgap distance was maintained. Since the welding eliminated the micromotion, bone loss was significantly reduced. Micromotion is believed to result in bone loss for two reasons: first, the micromotion can have a micro-pumping effect on bacteria and their by-products; second, it can compromise the attachment and the stability of the tissues around the implant neck.[50,51] Furthermore, there is a synergistic effect between the microgap and the micromotion—where the microgap exacerbates the microleakage and the micromotion, which in turn further increases the microgap by fretting, wear, plastic deformation, and screw loosening.[51]

A systematic review by Vouros et al. compared bone loss in tissue-level and bone-level implants. The mean marginal bone loss in the meta-analysis revealed a difference of -0.03–0.13mm, which was not statistically significant. The authors concluded that over a three-year period, there was no statistically significant difference in bone loss between the two types of implants. However, many of the bone-level implants in the study were platform switched, which had less marginal bone loss than the platform-matched ones.[52]

1.4.1 One-abutment, one-time concept

Abutment disconnection/reconnection is associated with marginal bone loss on the implant-abutment seal due to the apical migration of the peri-implant mucosa to protect the bone.[21, 53] Thus, the one-abutment, one-time concept, which means placing the final abutment simultaneously with the implant, is used for impression and implant restoration to minimize the effects on the implant-abutment seal.

Several animal studies investigated the effects of repeated disconnection and reconnection of healing abutments. Abrahamsson et al. evaluated these effects on external hex implants and found a 0.7-mm apical shift of the implant-abutment seal when the abutment was disconnected five times.[53] The same group of researchers conducted another study and found that when the disconnection and the reconnection were done only twice, there were no statistically significant differences between the control group[27] Furthermore, even implants with a platform-switched design showed bone loss when the amounts of disconnections/reconnections were increased although to a lesser extent. The authors emphasized the need for reducing the number of disconnections/reconnections of the abutment to minimize additional bone loss.[54] The clinical study of Romanos et al. was

the first to show that definitive abutments did not affect the long-term prognosis for implants. [55, 56]

Several systematic reviews were conducted on abutment disconnection/reconnection and/or the one-abutment, one-time concept (Table 1.6). A systematic review and meta-analysis by Koutouzis et al. found a statistically significant weighted mean difference of 0.19 mm more bone loss during abutment disconnection/reconnection and concluded that current protocols should be reviewed to try minimizing this effect.[57] Wang et al. also reported that definitive abutments provided less marginal bone loss and soft-tissue recession.[58] Atieh et al. noted a statistically significant difference in marginal bone loss; when the disconnections/reconnections were ≤ 2, there was a 0.18-mm less marginal bone loss in the definitive abutment group, and when the disconnections/reconnections were >2, there was a 0.2-mm less marginal bone loss in the definitive abutment group.[59] Lastly, Tallarico et al. observed a marginal bone loss difference of 0.279 mm between the definitive abutments and disconnection/reconnection groups, favoring the definitive abutments. Furthermore, a greater buccal recession of 0.198 mm occurred in the disconnection/reconnection abutment group.[60] A problem mentioned in these systematic reviews is that several factors may contribute to the bone loss other than the abutment disconnection/reconnection. Therefore, these results should be taken with caution, and more studies are needed to assess the clinical significance of the marginal bone loss since it is small.

Table 1. 6 Systematic reviews on abutment disconnection and reconnection

Study	Number of studies and implants included	Marginal bone loss mean difference	Conclusion
Koutouzis et al. [57]	7 studies 396 implants	Definitive abutment: 0.8–0.34 mm Abutment disconnection/reconnection: 0.09–0.55 mm	"Abutment disconnection and reconnection significantly affected peri-implant marginal bone levels. This information paves the way to revisit current restorative protocols at the restorative treatment planning stage to prevent incipient marginal bone loss."
Wang et al. [58]	6 studies 411 implants	Fixed-effect model in mean values: 0.41 mm, 6 months 1.51 mm, 12 months 2.47 mm, 3 years	"One-time abutment is superior to repeated abutment for platform-switched implant because of less bone resorption and soft tissue shifts in [the] former."
Atieh et al. [59]	7 studies 363 implants	0.20 mm > 2 disconnections/reconnections 0.18 mm ≤ 2 disconnections/reconnections	"Definitive abutments appear to be a viable alternative to healing/provisional abutments at [the] time of implant placement."
Tallarico et al. [60]	14 studies 994 implants (less used for meta-analysis)	0.279 mm	"Repeated abutment disconnections and reconnections considerably increased marginal bone loss and buccal recession."

The problem with using stock abutments as definitive ones is that they do not provide the proper support, the emergence profile, and the contour of a restoration. The margins of stock abutments are not controlled and are dictated by the depth of the implant placement, resulting in deep margins and limiting access to cement removal.[61] Additionally, the deeper the margin of these stock abutments, the greater the amount of the expected excess cement.[62] Unremoved excess cement can be a major concern associated with peri-implant mucositis and peri-implantitis, and Wilson's study found that 81% of cases with peri-implantitis had excess cement.[63]

With custom abutments, the architecture to shape the gingiva can be dictated, providing control of the emergence profile and establishing a more coronal gingival margin. To place the abutment simultaneously with the implant, preoperative digital planning and restorative planning are needed. Typically, this process requires hard- and soft-tissue imaging, using a cone beam computed tomography (CBCT) scan and either an impression or an intraoral scan. Merging these two files provides a full image of a patient's hard and soft tissues, which enables the planning of the three-dimensional position of the implant, the location of the gingival margin, and the architecture of the custom abutment. One problem that arises when planning the custom abutment before surgery is that the mucosal margin cannot be predicted because recession does occur. Numerous studies have shown that 0.6–1.5 mm of recession can occur, and depending on the patient factors—such as the location of the implant, the patient biotype, the smile line, and so on—the clinician needs to plan where the gingival margin should be located. Deep margins can lead to a similar complication in stock abutments where the cement is difficult to remove, whereas the coronal margin will result in an unaesthetic outcome.[64-69]

1.5. Platform switching

The concept of platform switching involves the implant-abutment interface where the healing abutment is smaller in diameter than the implant, thereby creating a platform on the implant coronally. Historically, when wide-diameter implants were used, a situation was created without matching size components, so a smaller diameter abutment was used. Early studies in 2005 found favorable soft- and hard-tissue healing around these mismatched platforms.[70, 71]

Several theories exist on why less bone loss occurs in platform-switched implants. One theory is that due to the horizontal displacement of the interface, there is an increased distance between the bone and the bacteria that can penetrate the interface. A study by Luongo et al. found that an inflammatory infiltrate was localized approximately 0.35 mm above the implant-abutment interphase but did not reach the bone, which could explain the minimal bone loss. They also observed that the stress concentration was more on the implant abutment/screw than the bone; despite the minimal difference, it could have an effect.[72] Another theory is that connective tissue occupies the space in the horizontal displacement of the implant-abutment interface, whereas in the butt joint, the junctional epithelium is usually located apically to the implant-abutment interface. A study on platform-switched implants conducted by Baffone et al. indicated that the most important finding was the presence of connective tissue around the implant-abutment interphase, which was not observed in matching implant abutments.[73] The mismatch between the implant-abutment interface could also reduce the bacterial load and/or increase the stability by means of a Morse taper internal connection.[74]

A study by Trammell et al. showed similar peri-implant mucosal dimensions in platform-switched and platform-matched implants, 1.53 mm and 1.57 mm, respectively.[75] However, less bone loss occurred in the platform-switched implants in this study. This finding was confirmed in the study of Cochran et al., where 12 platform-switched implants were used in dogs and loaded for 6 months. The peri-implant mucosal dimensions used in this study were 1.80–2 mm when the implant-abutment interphase was placed at or above the bone crest compared with 2.3–2.6 mm when placed apical to the bone crest. Submerged and nonsubmerged implants had mean bone losses of 0.34 mm

and 0.38 mm, respectively. This range of bone loss was five to six times less than that of conventional external hex matching connections.[76] In their clinical human study, Fickl et al. showed that after one year of function, platform-switched implants had a mean bone loss of 0.39 mm compared with 1 mm in the nonplatform-switched implants.[77]

Several systematic reviews and meta-analyses have established less bone loss in platform-switched implants. [78-83]The most recent systematic review and meta-analysis by Hsu et al. was the first that observed not only hard-tissue but also soft-tissue differences in platform-switched implants. For hard tissue, crestal bone loss was found to be 0.35 mm in the first year and remained less than 0.5 mm for 5 years. There was a significant reduction in the probing depth around platform-switched implants. Slight losses of the midfacial tissue height and the keratinized mucosa were also observed in the platform-switched implants. However, the authors mentioned that soft-tissue thickness could have played a role, and further studies on this issue would be needed. The location of the implant-abutment interphase also played a role in the amount of the observed vertical bone loss.[84] Several systematic reviews and meta-analyses revealed similar results in terms of improved marginal bone levels in platform-switched implants (see Table 1.7). The degree of the mismatch also affected the mean marginal bone levels, with an increased mismatch leading to less marginal bone loss. A systematic review and meta-analysis by Valles et al. compared subcrestal and equicrestal positions on the peri-implant hard and soft tissues in platform-switched implants. The peri-implant mucosal dimension was larger when the implants were placed in a subcrestal position, which was due to an increase (mean = 0.39 mm) in the junctional epithelium. However, no difference in the length of the connective tissue was found between the two groups. Additionally, the

implants that were placed in a subcrestal position exhibited greater marginal bone losses of 0.18 mm in human studies and 0.45 mm in animal studies. The subcrestal placement of the platform-switched implants also resulted in a more coronal position of the bone. The authors concluded that the implant-abutment interphase location affected the amount of bone loss that occurred.[85]

Table 1. 7 Summary of systematic reviews on platform switching and crestal bone loss

Study	Number of studies and implants included	Mean difference in marginal bone loss (mm)	Degree of implant switching	Conclusion
Santiago et al. [78]	25 studies 2,310 implants	-0.41	N/A	"Platform-switching implants showed greater relevant bone preservation when compared to regular platform implants."
Chrcanovic et al. [79]	28 studies 2,373 implants	-0.29	"There is an increase of the mean difference of marginal bone loss between the approaches with increasing follow-up time and with increase of the mismatch between the implant platform and the abutment."	"Significantly less marginal bone loss at implants with platform switching than on implants with platform matching"
Strietzel et al. [80]	22 studies 2,235 implants	-0.52	N/A	"Results favor the platform switching technique to prevent or minimize peri-implant marginal bone loss, compared to implants with platform matching"
Herekar et al. [81]	15 studies 1,683 implants	-0.34	"A greater mismatch between the diameters of implant and abutment leads to better bone preservation."	"Platform switching holds promise as a simple, functional, and predictable technique for preserving peri-implant crestal bone."
Annibali et al. [82]	10 studies 993 implants	-0.55; 95% CI: -0.86 to -0.24; p = 0.0006	"Limiting marginal bone loss is more evident with increasing the extent of implant-abutment mismatching."	"The present meta-analysis confirmed the effectiveness of platform-switching techniques in limiting marginal bone resorption around dental implants."
Atieh et al. [83]	10 studies 1,239 implants	-0.37; 95% CI: -0.55 to -0.20; p < 0.0001	"Additional improvement in the marginal bone levels around dental implants may also be obtained with a greater degree of shifting."	"Platform switching can be considered a desirable morphologic feature that may prevent horizontal saucerization and preserve the vertical crestal bone."

Notes: CI: confidence interval; p: p-value

1.6. Abutment macro-design effect on peri-implant hard and soft tissue

A change in the macro design of the abutment can impact the bone levels and the soft-tissue levels and lead to excess cement, which is difficult to remove. The two main types of macro designs used are the concave and the convex abutments. Abutment macro designs were evaluated in several animal studies, with varying results. Lopez et al. found that anatomically wider abutments had less marginal bone loss and more connective tissue attachment than concave straight abutments, whereas Finelle et al. reported more bone loss in wider abutments.[86, 87] The differences in these two studies were most likely due to different implant placement timings. In immediate implants, the wider healing abutment prevents the gingival architecture from collapsing and protects the soft and the hard tissues, whereas in healed ridges, the gingival flap reacts more favorably to narrow healing abutments in order to maintain the soft tissue.

One feature of abutment macro designs—the abutment contour—is divided into two portions. One portion, called the critical contour, corresponds 1 mm apically to the level of the peri-implant mucosa. The other portion, called the subcritical contour, extends apically to the critical contour up to the implant junction. An alteration of the subcritical contour to a convex macro design was reported to relocate the peri-implant coronally, thus enhancing the aesthetics.[88] A study by Huh et al. found that the concave machine transmucosal design exhibited less bone loss and better connective tissue attachment compared with the straight machine-profiled implants because of the increased space for connective tissue healing. Since this was an animal study with a 16-week follow-up, any interpretation should be taken with caution.[89]

Kim et al. examined the influence of three transmucosal designs of one-piece implants and found that a concave transmucosal design with a microgrooved surface had a longer connective tissue attachment and less bone loss compared with the rough or the straight abutments. The peri-implant mucosal dimensions for the concave machine grooved design were 1.99 mm for the junctional epithelium and 0.92 mm for the connective tissue, whereas the other two designs (flared and straight) had a significantly greater junctional epithelium length and a significantly less connective tissue length.[90]

In a randomized controlled trial, Patil et al. compared curved and straight abutments. They found that the two groups had no statistically significant difference in marginal bone levels, pink aesthetic scores, and probing depths.[91] Axiotis et al. conducted a retrospective study on one-piece implants with a concave neck and found 0.57 mm of bone loss after five years, which they attributed to the increase in the soft-tissue thickness from the design of the concave neck.[92]

In a case series study conducted by Rompen et al., the abutments with a concave subcritical contour demonstrated stable peri-implant mucosa levels with no recession > 0.5 mm. However, their study had no control group with other types of abutment macro designs.[93]

Sancho-Puchades et al. compared concave and convex abutments in-vitro and how they would affect the removal of cement in the epigingival location and the 1.5-mm and the 3.0-mm subgingival locations. When all these areas were grouped, the concave abutments retained significantly more cement than the convex abutments. However, when the specific areas were compared, there was no statistically significant difference between the

excess cements in the concave and the convex abutments except in two locations—at the distal margin in the epigingival group and at the buccal margin of the 3-mm subgingival placement. The authors also found that the periapical radiographs did not identify all the cements, and the deeper the crown-abutment margin, the more excess cement was left, and the more difficult it was to remove this cement. The authors concluded that although for aesthetic purposes, they could not use a supragingival placement of the margins, they would not recommend having the crown-abutment margin located 1.5 mm apically, and even a 1-mm apical margin resulted in cement remnants.[62]

Due to the different designs used in the cited studies, little evidence is provided for the use of a two-piece implant and how the abutment contour can affect the peri-implant mucosa. As such, the present research aims to assess the difference in two-piece implants with concave and convex definitive abutments.

1.7. Accuracy of CBCT imaging

The accuracy of CBCT implants is important for the presurgical analysis of implant placement. One of the main limitations in CBCT scans is the presence of artifacts, for example, when trying to assess the bone around an implant. For implant treatment planning, a systematic review by Fokas et al. indicated high levels of accuracy and reliability for bony linear measurement, but either overestimation or underestimation can occur. The factors that affect the accuracy are the patient motion, the metallic artifact, device-specific exposure parameters, the software used, and manual/automated procedures. The authors also warned that a 2-mm margin should be used when placing implants near anatomical locations.[94]

Razavi et al. assessed the accuracy of cortical bone thickness at varying distances of 3, 6, and 9 mm from an implant. Two CBCT scanners were used (i-CAT NG and Accuitomo 3D60 FPD) and compared with the gold standard of measurement using a light microscope. The examiners found that the measurement accuracy was significantly underestimated in the i-CAT NG, with mean percentage errors of 68% at 3 mm, 28% at 6 mm, and 18% at 9 mm. The Accuitomo 3D60 FPD measurements were better, except when the bone thickness was < 0.8 mm. The mean percentage errors were 23% at 3 mm, 5% at 6 mm, and 6% at 9 mm. The authors concluded that the Accuitomo 3D60 FPD provided a better resolution in the thin bone areas compared with the i-CAT NG.[95]

Wang et al. used the PaX Duo3D CBCT system and found that the mean difference between the histological section and the CBCT scan was 0.22 mm in the buccal bone. The authors concluded that this system had an approximately 0.5-mm accuracy in assessing the buccal bone thickness.[96] In an in-vitro study, Naitoh et al. examined 5 different thicknesses of the buccal bone in relation to the aluminum steps and found that at a 0.6-mm buccal bone thickness with a 51–102-mm diameter, an exposure volume >50% was observed. . Another study showed that a <0.72-mm buccal bone thickness in the horizontal dimension was not accurately measured using the i-CAT NG, and the thinner the bone, the more its thickness was underestimated.[97]

Liedke et al. assessed the accuracy of detecting the buccal bone thickness adjacent to the implants. They found high sensitivity and low specificity in the buccal bone detection. Additionally, the CBCT measurements overestimated the thickness in all settings compared with the actual measurements. The mean buccal bone measurements using the CBCT had a 1.07–1.21-mm range compared with 0.85 mm true measurement. The

authors concluded that although the buccal bone thickness was overestimated in the CBCT measurements, it lay mostly within 0.5 mm of the actual buccal bone thickness.[98] Different settings and software's can affect the accuracy of CBCT's, but the presence of a metallic object can distort the measurements and as such one needs to be aware that these numbers might not reflect the true value, although as shown in most studies the difference is generally less than 1mm.

1.7.1 CBCT Peri-implant bone evaluation

The importance of an intact buccal bone has been emphasized for both esthetic and functional success of an implant. Re-entry of the area surgically after implant placement to measure the buccal bone can be a risk to the patient as well as unethical. As such, the use of CBCT scan to measure peri-implant bone has been evaluated and done in numerous studies. A pilot study was done by Vera et al. to evaluate the use of CBCT scans to measure the peri-implant bone changes. The authors concluded that buccal bone and alterations in the buccal bone can be seen in CBCT when it is 0.5 to 1.5 mm in buccolingual dimension next to the implant. The authors found a 1.12mm of vertical bone loss and 0.62 of horizontal bone loss 1mm below the apical crest at the 1-year evaluation.[99] Cho et al. evaluated the buccal bone changes in 26 implants with the use of CBCT, with only 4 receiving immediate implants in the anterior maxilla. The authors found a mean vertical resorption of 1.32mm in the 3 years CBCT evaluation.[100] A study by Koutouzis et al. evaluated the marginal bone levels around platform switched implants placed at different positions related to the alveolar crest in a CBCT scan after 10 years. The amount of buccal bone remodeling occurred less when the implants were placed crestal compared to 1mm or 2mm subcrestal positions. In addition, the buccal bone

thickness had a negative correlation to buccal bone remodeling when implants were placed subcrestal. [101]

In immediate implant placement, Kuchler et al. reported a vertical bone loss of 1.7mm with 24% of the implant showing no visible facial bone after 10 years in the CBCT assessment.[102] Another study by Benic et al. showed a vertical bone loss of 3.1mm and 35.7% of absence of buccal bone after 5 years in the CBCT evaluation. [103] Chappuis et al. examined the amount of bone loss associated with early implant placement over 10 years. The authors found that after GBR with early implant placement, a vertical bone gain of 3.16mm and the buccal wall thickness increased by 1.67mm measured by the CBCT scan after 10 years. The authors concluded that early implant placement technique is more predictable for management of the anterior maxillary esthetic area compared to immediate implants, due to the complication risk of loss of buccal bone and risk of mucosal recession. [104] The reason for that is that during immediate implant placement, the alveolar bone resorption that is normally seen during extraction will occur regardless of implant placement. Whereas in early implant placement there are several theories of why this technique works. First, biologically we after 8 weeks we have less activity of inflammatory mediators and increased activity of bone forming proteins and endothelial cells. Second, the morphology of the socket after 8 weeks of healing provides a favorable 2 wall defect which is more stable for bone grafting. Lastly, the autogenous bone used in this technique provides an increased and accelerated new bone formation.

A study by Benic et al. evaluated not only the peri-implant bone, but the peri-implant mucosal dimensions on CBCT. This was done by applying a composite layer around the buccal tissues to be able to have contrast on where the tissues are. Five out of fourteen

implants showed no detectable buccal bone and more apical location of the mucosal margin, however, the apical position of the margin only amounted to 1mm difference compared to the implants with intact facial bone. The mean thickness of the peri-implant mucosa 1mm apical to the gingival margin was 1.5mm irrespective of whether the buccal bone was intact. [103]

2. Materials and Methods

The protocol for the study was approved by the Institutional Review Board (IRB) of Nova Southeastern University and followed the tenets of the Declaration of Helsinki. Informed consent was obtained from the subjects after explanation of the nature and possible consequences of the study.

2.1. Research Plan

This trial was designed as a randomized controlled clinical study in which two groups of fourteen partially edentulous patients had one implant placed in the maxillary premolar region as part of their treatment. Implant placement and abutment design were planned with a computer software for guided implant treatment (SIMPLANT). The surgical implant placement was 3-4 mm below the buccal aspect of the future crown margin. Virtually designed, permanent CAD-CAM fabricated abutments (ATLANTIS, DENTSPLY) with different configuration of the subcritical contour (emergence shape) were connected to the implants and temporary crowns were delivered.

Implants assigned to concave (CV Group) received permanent abutments with a concave configuration of the subcritical contour (emergence shape). Implants assigned to convex (CX Group) group received permanent abutments with a convex configuration of the subcritical contour (emergence shape). Patients had the final implant restoration 3 months following implant installation. A block randomization sequence was utilized to provide equal distribution of subjects between the two groups. Treatment assignments were performed at the planning stage of treatment. Randomization envelops were used and opened following three-dimensional positioning of the implant in the treatment planning

software and immediately prior to ordering the implant abutment. The study was double masked, with both the examiner and subjects not being not aware of the allocated treatment. The null hypothesis is that the abutment macro design has no effect on peri-implant tissue and bone level dimension changes from the time of the implant installation to the 1 year follow up.

2.2. Abutment Design

The abutments of both groups were designed with the aid of an implant treatment planning software (SIMPLANT), in conjunction with planning of the implant placement, and was produced by CAD-CAM technology (ATLANTIS, DENTSPLY) according to patient needs. For both groups the abutments were designed based on the individual topography of the recipient site in terms of soft tissues and relationships with adjacent teeth. Care was taken to position the implant platform 3-4 mm below the buccal aspect of the future crown margin. All abutments were selected in titanium and had the buccal margin planned 1 mm submucosally, the interproximal margins 0.75 mm submucosally and the lingual margin 0.5mm submucosally. For patients in the CV Group, the abutments were designed with a concave configuration between the abutment margin and the Implant-Abutment Interface (IAI). For patients in the CX Group, the abutments were designed with a convex configuration between the abutment margin and the IAI.

2.3. Inclusion and exclusion criteria

General Inclusion criteria:

- Age more than 21 years

- Absence of relevant medical conditions
- Availability for 12-month follow-up

General Exclusion criteria:

- Pregnancy at the screening visit
- Smoking more than 10 cig/day

Specific Inclusion criteria:

- One missing tooth in the maxillary premolar region
- Presence of two adjacent teeth at the implant site
- Absence of periodontal disease
- Healed osseous architecture enough to receive an implant with a diameter of at least 3.5 mm and a sufficient amount of bone for placing implants with a length of at least 9 mm

Specific Exclusion criteria:

- Adjacent implants
- Presence of periapical radiolucency at the adjacent teeth
- Missing adjacent teeth

2.4. Study procedures and visits

Each subject was seen for a total of 6 appointments; Screening, implant placement (T0), suture removal, final crown delivery (T1) and a 1 year follow up from the date of implant placement (T2) (Fig. 2.1 - 2.11). Data collection occurred between November/2015 –

July/2018. All treatment was done in Periodontics clinic at Nova Southeastern University.

First Visit: Screening

Screening of patients was performed to determine if patients were eligible to participate in the study. In the screening visit medical history was reviewed for each patient and if the patient fulfilled the general inclusion criteria a dental clinical exam was performed to ensure that patients had an edentulous space at the maxillary premolar region, with two adjacent teeth. For patients that fulfilled this criterion a full mouth periodontal exam was performed to confirm periodontal status and a periapical radiograph was taken to ensure adequate bone height for implant therapy and the absence of periapical pathology at adjacent teeth. Informed consent was obtained from all eligible patients and the study procedures were explained to them. For eligible patients, a polyvinyl siloxane material, a bite registration and a cone beam computed tomography (CBCT) was taken for planning the placement of the dental implant, designing the abutment, fabricating the surgical guide, abutment and the provisional restoration.

Second Visit, Day 0 (T0): Implant Placement

1. Mucosal thickness measurement
2. Bone measurements
3. Peri-implant bone measurements
4. First peri-implant soft tissue examination
5. First radiographic examination

Implant placement

The surgical treatment was performed under local anaesthesia and according to manufacturer's manual. The implants (Ankylos, Dentsply Sirona Implants, Mölndal, Sweden) used had a diameter of 3.5mm and lengths varying from 9 mm to 14 mm. Sulcular incisions were made at the teeth facing the edentulous area and these incisions were connected by a crestal incision placed on the edentulous area. A buccal full-thickness flap was reflected initially, while the lingual flap was not elevated to ensure direct visibility. Vertical soft tissue thickness was measured with a periodontal probe (PCP 15) to the nearest half mm (see mucosal thickness measurement). After the measurement the lingual flap was raised to completely expose the recipient site. The surgical guide (SIMPLANT SAFE GUIDE) was secured to the adjacent teeth (Fig. 2.2) and the osteotomies were drilled according to the protocol of the manufacturer (ANKYLOS, DENTSPLY) Prior to implant installation, the thickness of buccal and lingual cortical plates was measured 1mm apical to the crest of the ridge (see intrasurgical bone measurements). The implant was installed with the implant platform 3-4mm below the future crown margin (Fig. 2.5). Following implant installation peri-implant bone measurements were performed (see peri-implant bone measurements).

In case that following implant installation, there was a fenestration at the apical part of the implant; a bone replacement graft material covered by a resorbable barrier membrane was utilized to correct the defect.

For patients of the CV Group an abutment with a concave configuration between the abutment margin and the IAI was connected to the implant and a milled polymethyl

methacrylate (PMMA) was delivered. For patients of CX Group an abutment with a convex configuration between the abutment margin and the IAI was connected to the implant and a milled PMMA was delivered (Fig. 2.6, 2.7). Provisional PMMA restorations were adjusted if needed and cemented with temporary cement. Cementation was performed prior to suturing in order to visualize and remove any excess cement. All restorations were kept out of occlusion. Following abutment placement, flaps were adapted and closed with interrupted sutures.

Lab made measurement stent was fabricated using a light cured resin material (Triad, Dentsply). Immediately, after prosthesis placement the measurement stent was used to obtain the peri-implant soft tissue measurements (see peri-implant soft tissue examination) (Fig. 2.13).

Each patient took 500 mg amoxicillin three times daily from the day of the implant surgery for seven days. Each patient rinsed with Chlorhexidine 0.12% mouthwash twice a day for two weeks.

Periapical and bite-wing radiographs were taken from each study site immediately after the implant placement surgery.

Third Visit, day 7-10 days: Suture removal

Patients returned after 7-10 days for examination of implant sites to assess the healing progress, to remove remaining sutures, and to reinforce oral hygiene instructions. This was done according to the standard clinical protocols.

Fourth Visit, day 60 ± 20 days: Final impression

1. Impression
2. Second peri-implant soft tissue examination
3. Clinical photograph

Peri-implant soft tissue examination was performed for each study site. Any exposed abutment margin was recorded. In case that the permanent abutment was functionally and aesthetically acceptable, an abutment level impression was taken in order to produce the final restoration. Clinical photographs were taken (Fig. 2.9).

Fifth Visit, day 90 ± 20 days (T1): Crown delivery

1. Third peri-implant soft tissue examination
2. Second radiographic examination
3. Clinical photograph

Final restoration was delivered. Peri-implant soft tissue examination was performed for each study site. Periapical radiographs were taken from each study site. Clinical photographs were taken (Fig. 2.10).

Visit 6 (Day 360 ±20 days (T2): One year follow up after implant placement

1. Fourth peri-implant soft tissue examination
2. Third radiographic examination
3. Clinical photograph
4. CBCT
5. Impression

Peri-implant soft tissue examination was performed for each study site. Standardized periapical radiographs was taken from each study site. A CBCT imaging was done but prior to this layer of flowable light-curing composite resin was applied onto the soft-tissues around the implant and the adjacent teeth. The radiopaque material was used as a contrast for the visualization of the soft-tissues on the CBCT image. A polyvinyl siloxane impression was taken for a study model that will facilitate evaluation of the peri-implant tissues. Clinical photographs were taken (Fig 2.12).

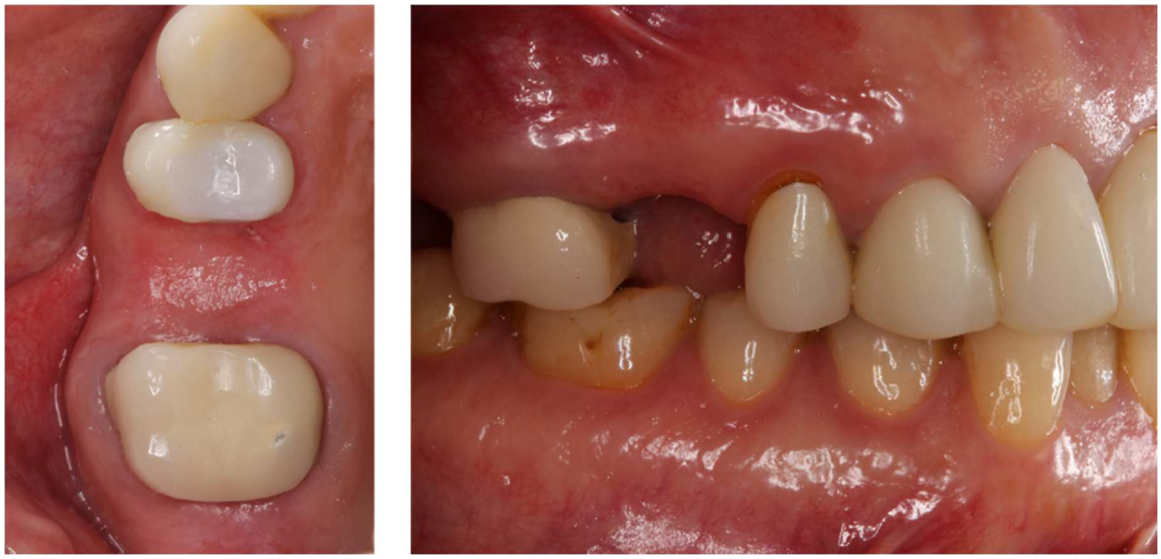


Figure 2. 1. Preoperative photographs.

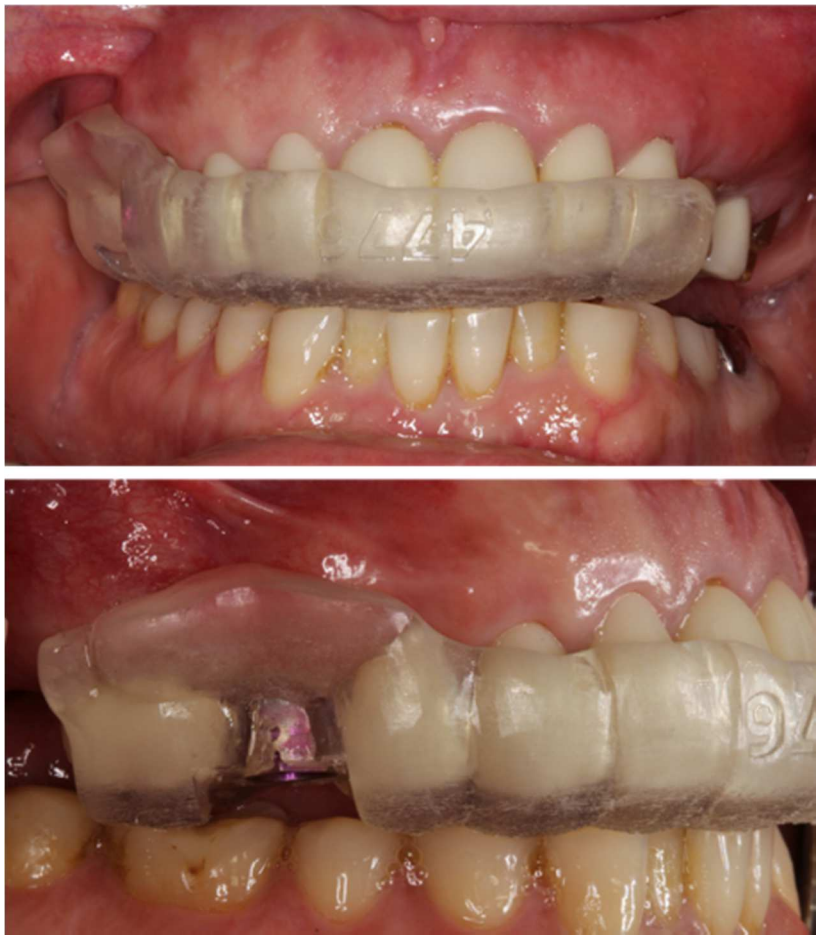


Figure 2. 2. Tooth-supported SIMPLANT guide fitted on teeth.

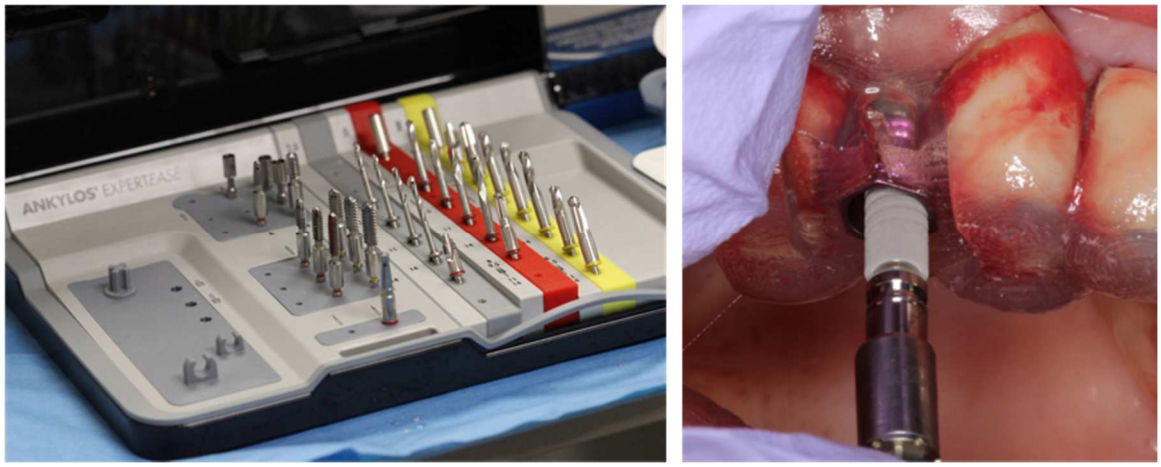


Figure 2. 3. Guided implant placement.

Figure 2. 4. Alignment of the implant holder marker with the Simplant surgical guide groove.

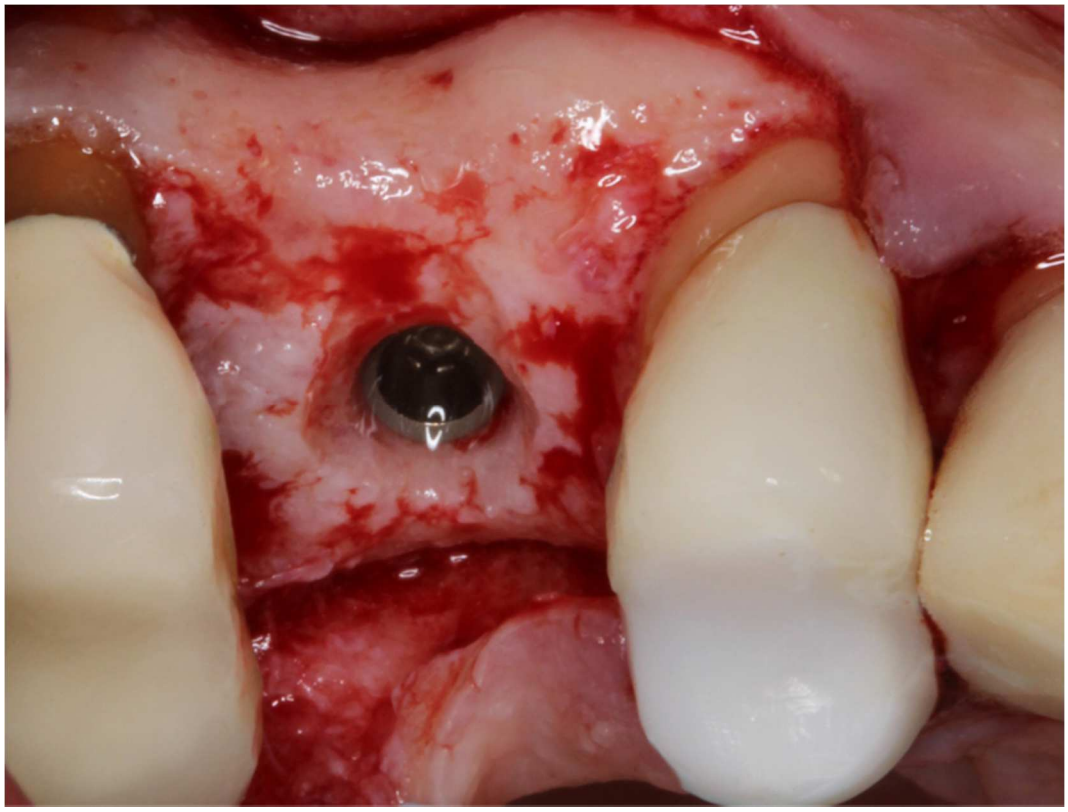
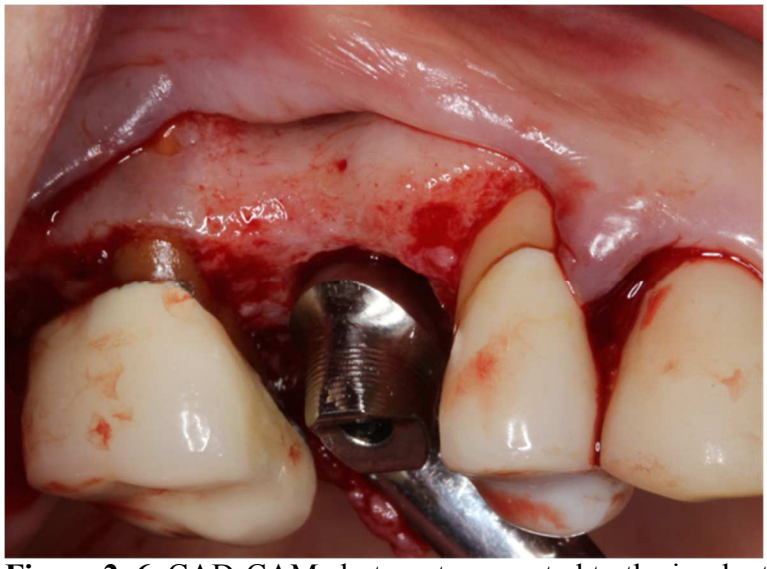


Figure 2. 5. Subcrestal position of the implant.



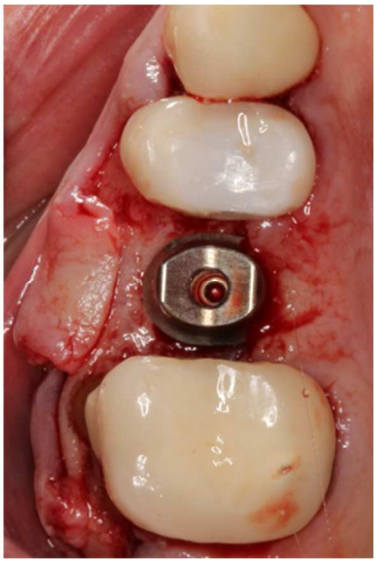


Figure 2. 6. CAD-CAM abutment connected to the implant.

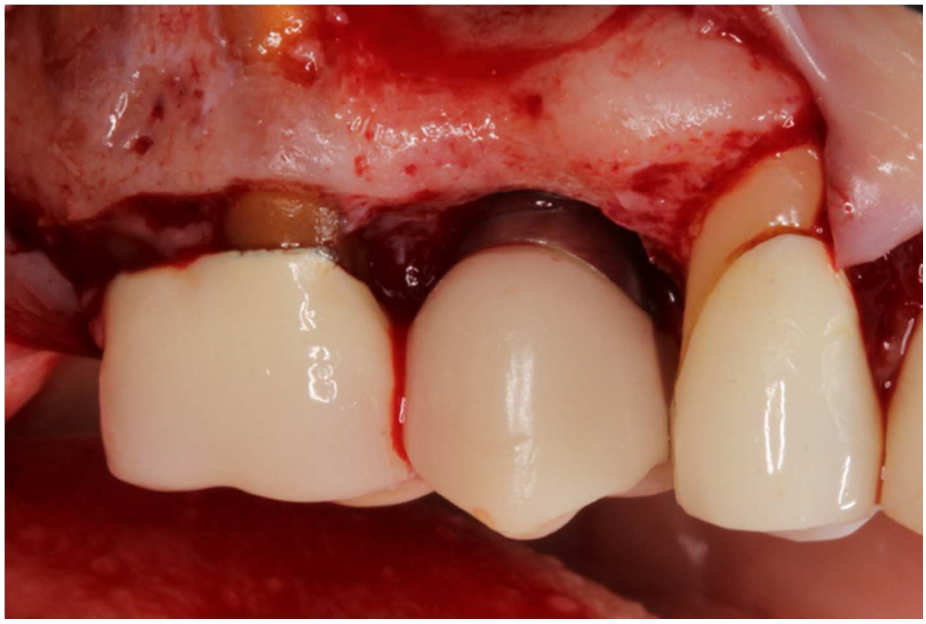


Figure 2. 7. CAD-CAM provisional crown.

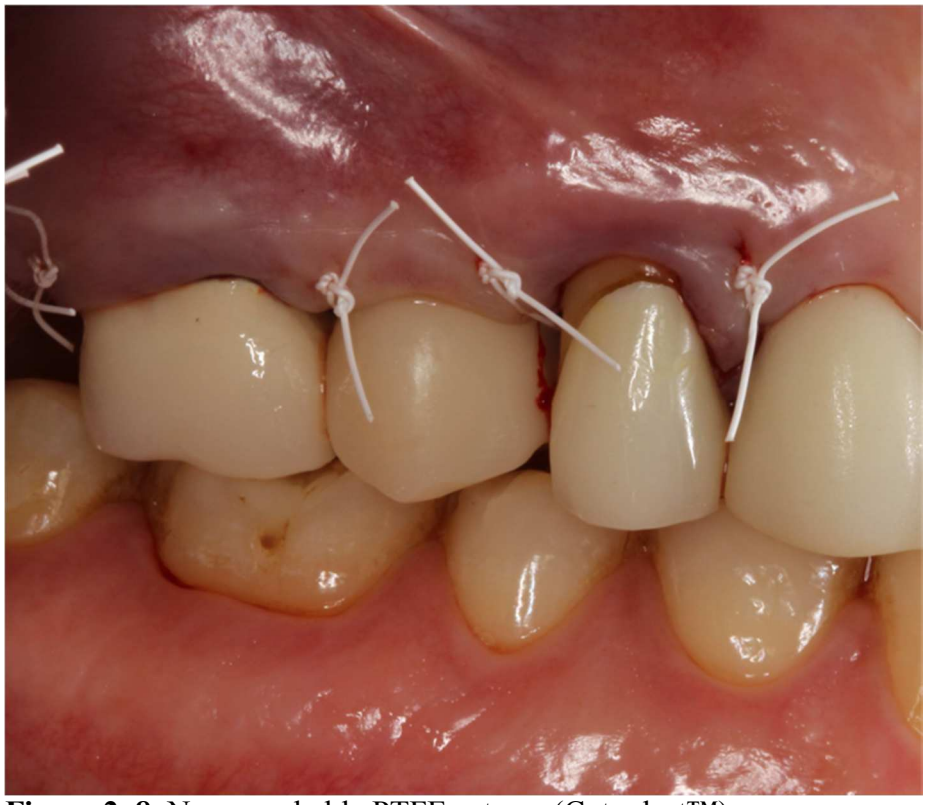


Figure 2. 8. Non resorbable PTFE sutures (Cytoplast™).

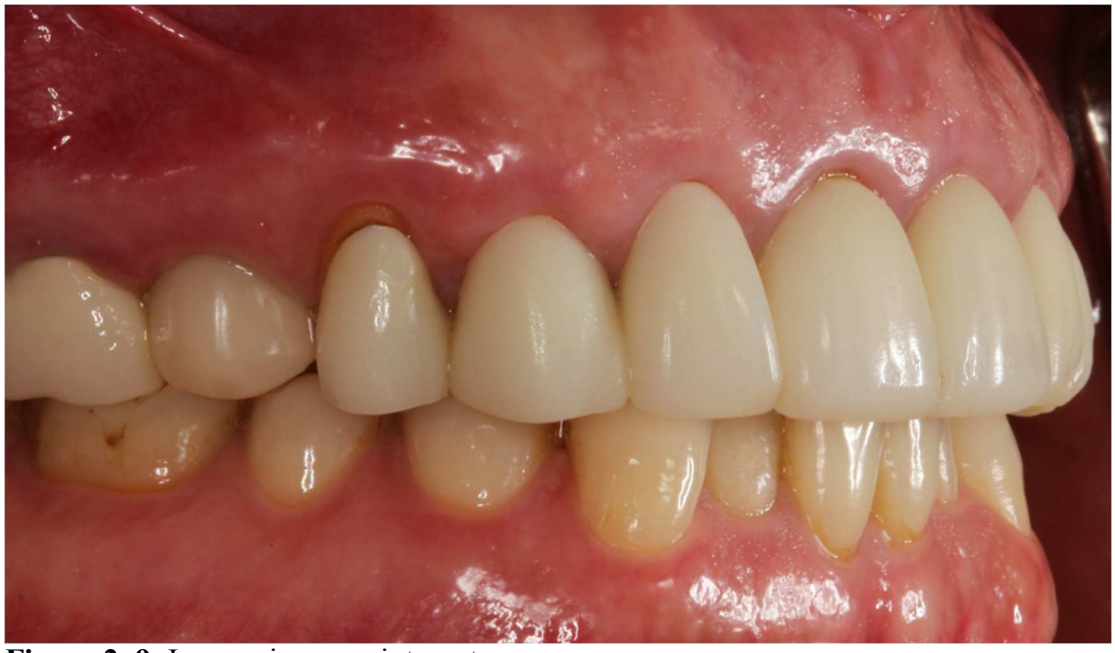


Figure 2. 9. Impression appointment.

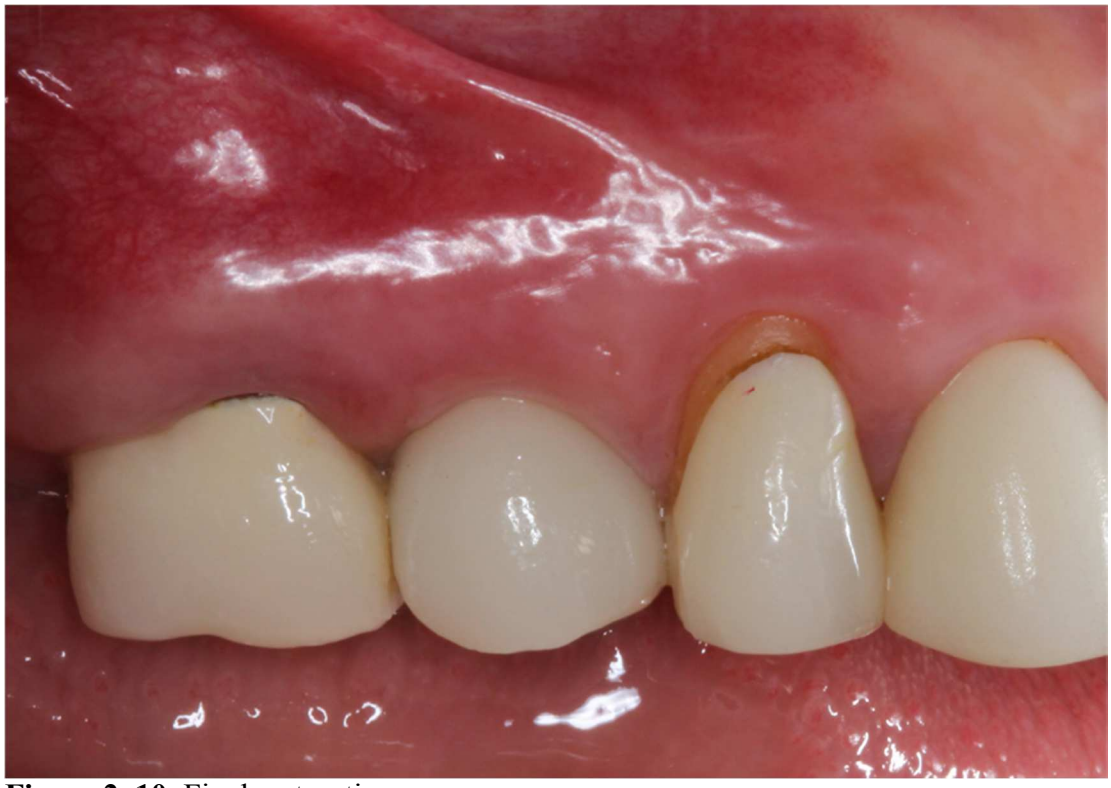


Figure 2. 10. Final restoration.

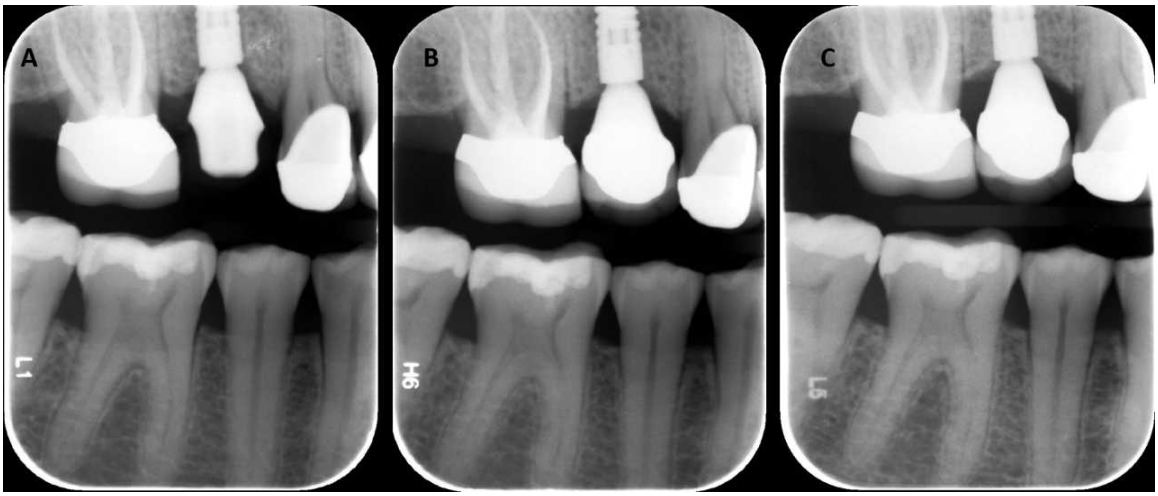


Figure 2. 11. Bitewings radiographs at the time of implant placement (left); at the time of final crown delivery (center); and at 1-year post (right*)*

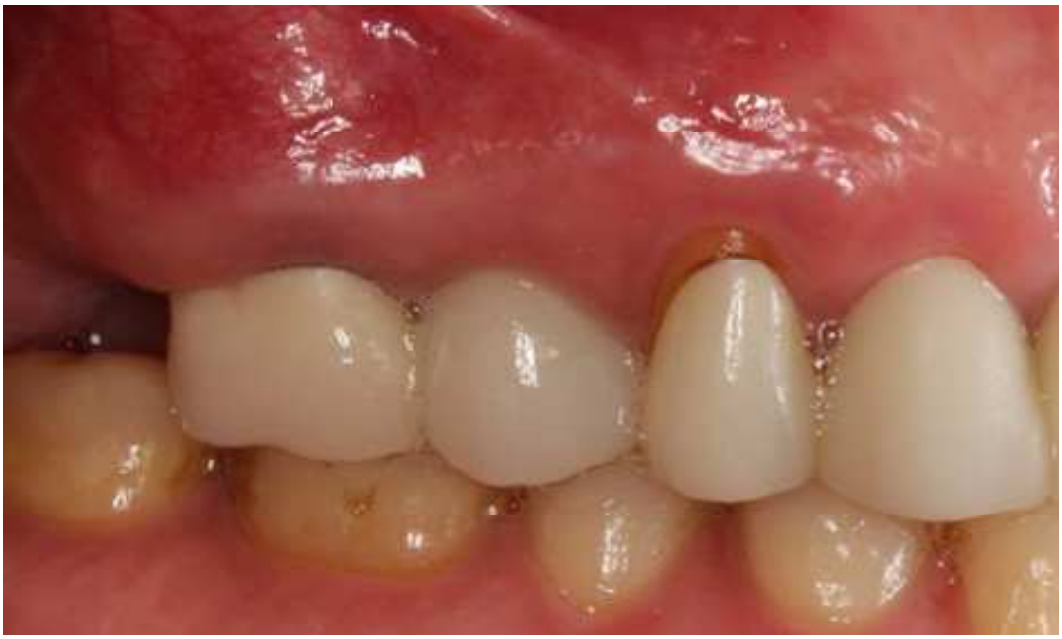


Figure 2. 12. 1-year follow up

2.5. Measurements

Mucosal thickness measurements

Following local anaesthesia, a buccal full-thickness flap was reflected initially, while the lingual flap was not elevated in order to ensure direct visibility. Vertical soft tissue thickness was measured with a PCP 15 periodontal probe to the nearest half mm (Fig. 2.13).

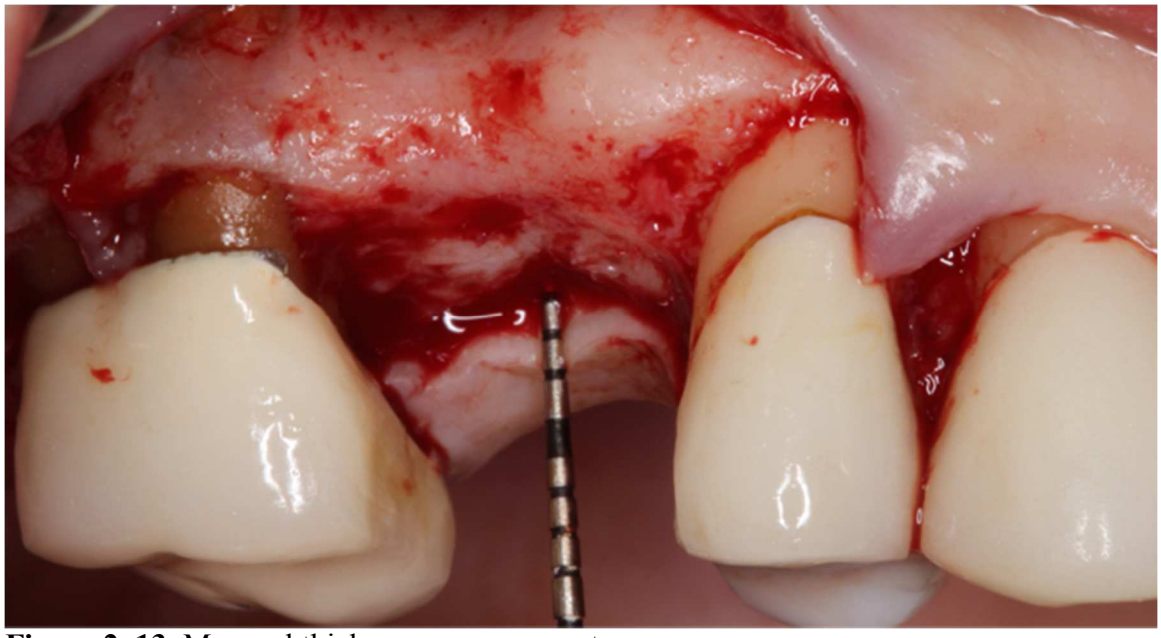


Figure 2. 13. Mucosal thickness measurements.

Bone measurements

Subsequent to osteotomy preparation, thickness of the buccal and lingual cortical plate was measured at a point 1 mm apical to the crest of the ridge. All measurements were performed with a caliper instrument at the lowest half mm.

Peri-implant bone measurements

Subsequent to implant installation the distance from the implant platform to the most coronal part of the osteotomy was measured at four sites per implant (mesial, distal, buccal, lingual), with a PCP15 periodontal probe to the lowest half mm.

Radiographic examination

Radiographic examinations were performed at T0, at T1 and T2 (Figure 4). Vertical bitewing radiographs were taken using a paralleling device (Dentsply Rinn, York, Pennsylvania , USA) and a digital imaging software system (XDR, Dental Imaging, Los Angeles, California, USA).

For each implant, the radiographs were evaluated regarding the degree of subcrestal implant position (SP), as well as marginal bone level (MBL). The method for evaluating peri-implant marginal bone for subcrestally placed implants has been described previously (Donovan, Fetner, Koutouzis, Lundgren 2010). A line following the long axis of the implant was drawn at the mesial and distal aspects of each implant. The distance between the point that this line crossed the alveolar bone crest to the first visible bone to implant contact was considered as the SP. MBL was calculated as the distance between the implant shoulder and the first visible bone to implant contact. In situations where bone was seen above the implant shoulder, marginal bone level still recorded as zero. The radiographs were downloaded as 16-bit, JPEG files and analysed with an image processing system (NIH Image J, National Institutes of Health, Bethesda, Maryland, USA.) The known geometry of each implant was used to assess the distortion of the images.

Clinical photographs

A clinical photograph was taken at 1:1 magnification perpendicular to the buccal surface of the implant using digital camera with macro lens and ring flash. A photograph was taken to include full representation of the adjacent premolar.

Peri-implant soft tissue examination

Clinical assessment of peri-implant tissue was performed including the following variables at four sites per implant (mesial, distal, buccal, lingual):

- Probing depth (PD): the distance between the peri-implant margin and bottom of the probable pocket measured with a PCP15 periodontal probe
- Peri-implant mucosa margin position (MP): The distance between the peri-implant margin and the stent (Fig. 2.14)
- Bleeding on probing (BOP): presence/absence of bleeding within 15 sec following pocket probing
- Presence or absence of visible plaque

Width of keratinized mucosa (KM) was measured at the buccal aspect of each implant.

MP was recorded immediately after implant placement and provisional restoration placement (T0) , at the time of prosthesis placement (T1) and at 1 year following implant installation (T2). KM was evaluated at the same time intervals. PD, BoP and presence of visible plaque were recorded at T1 and T2.

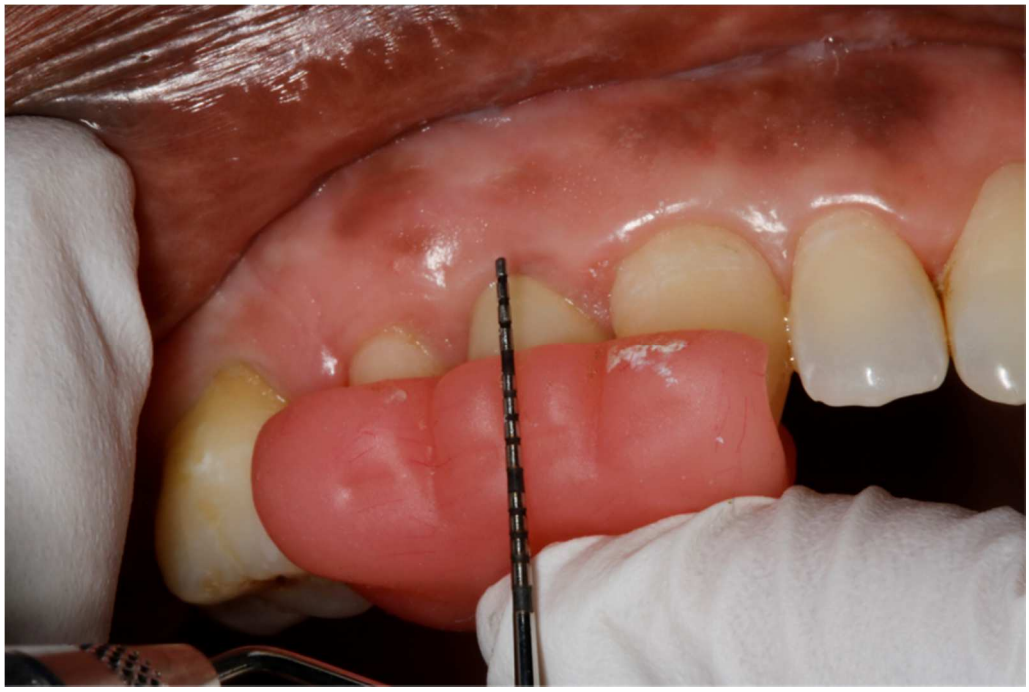


Figure 2. 14. Soft tissue measurements using lab made stent.

CBCT Imaging

All CBCT measurements apart from two were done on CS 3D Imaging Software. Three lines were drawn on the CS 3D Imaging Software for orientation purposes (Fig 2.15). First line was parallel to the implant (A), second line was perpendicular to the implant at the implant-abutment junction (B), and 3rd line was perpendicular to the implant at the gingival margin (C). The landmarks used to do the measurements are seen in Figure 2.15 which were the first bone to implant contact (fBIC), implant platform (IP) and bone crest (BC).

Three vertical measurements parallel to the implant were done (Fig 2.16 and Fig 2.17)

1. Implant platform to gingival margin (IP-GM)
2. Implant platform to bone crest (IP-BC)
3. Bone crest to gingival margin (BC-GM)

Four horizontal measurements parallel to the implant platform were done (Fig 2.16 and Fig 2.17)

1. Soft tissue thickness
    a. At the level of implant platform (ST1)
    b. Directly above the bone crest (ST2)
    c. Midpoint of the BC-GM (ST3)
2. Bone thickness (BT) 1mm apical to bone crest

The next two measurements were done on a different program, ImageJ, since the CBCT software only measures in straight lines. A line was drawn on the CBCT image, which is used as a reference of size on the ImageJ software.

1. Soft tissue Profile (STP) (Fig 2.16 and Fig 2.17)
2. Soft tissue area (AREA) coronal to bone crest with the borders as follows (Fig 2.18 and 2.19)
    a. Bone crest apically
    b. Buccal gingival contour
    c. Soft tissue profile

Presence of bone on the buccal implant platform was assigned as either present or absent. If bone loss was seen on the buccal, the bone loss was measured from the implant platform to the first bone-implant contact.

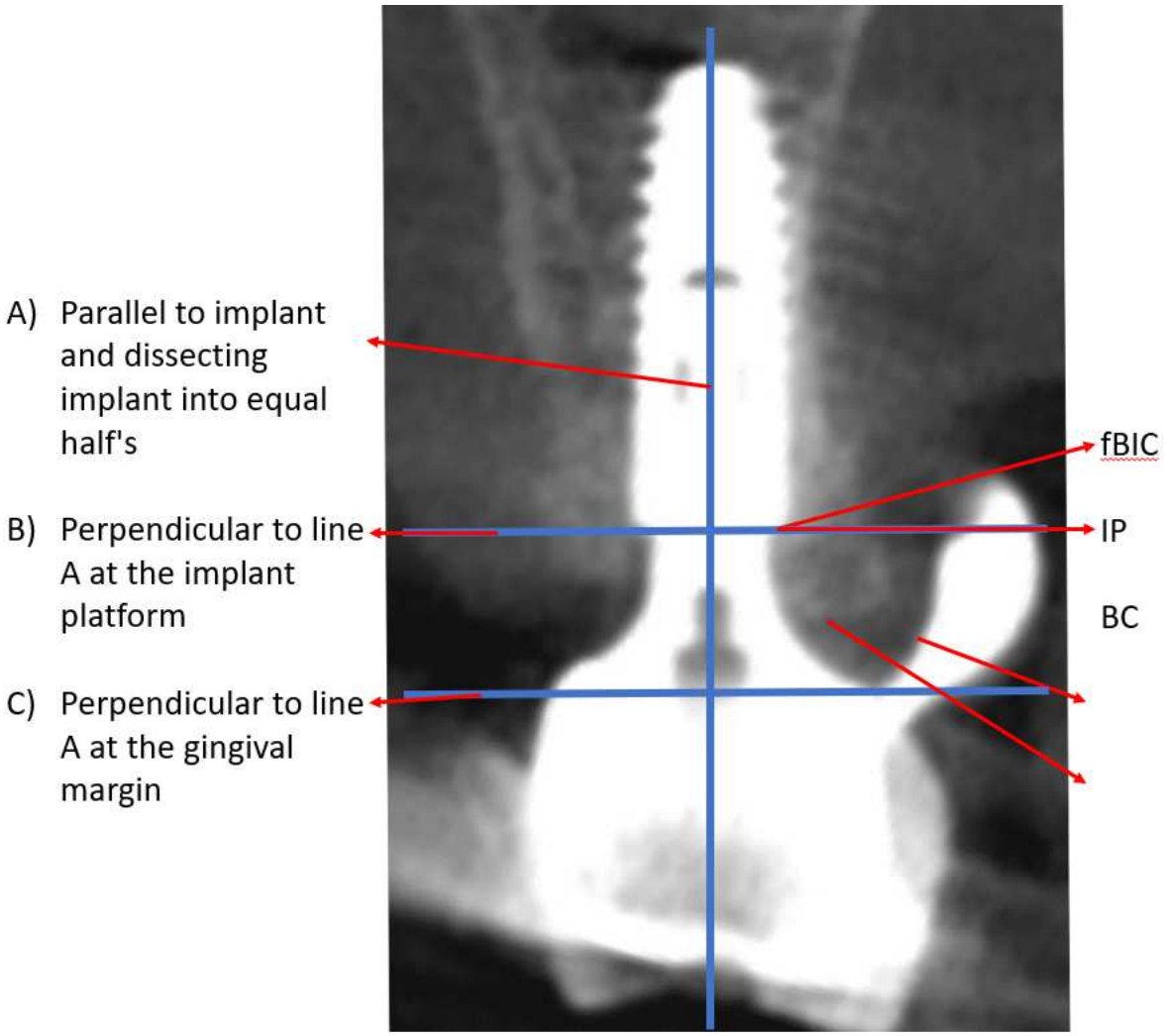


Figure 2. 15. CBCT orientation lines and landmarks; fBIC: first bone to implant contact IP: Implant platform and BC: Bone crest.

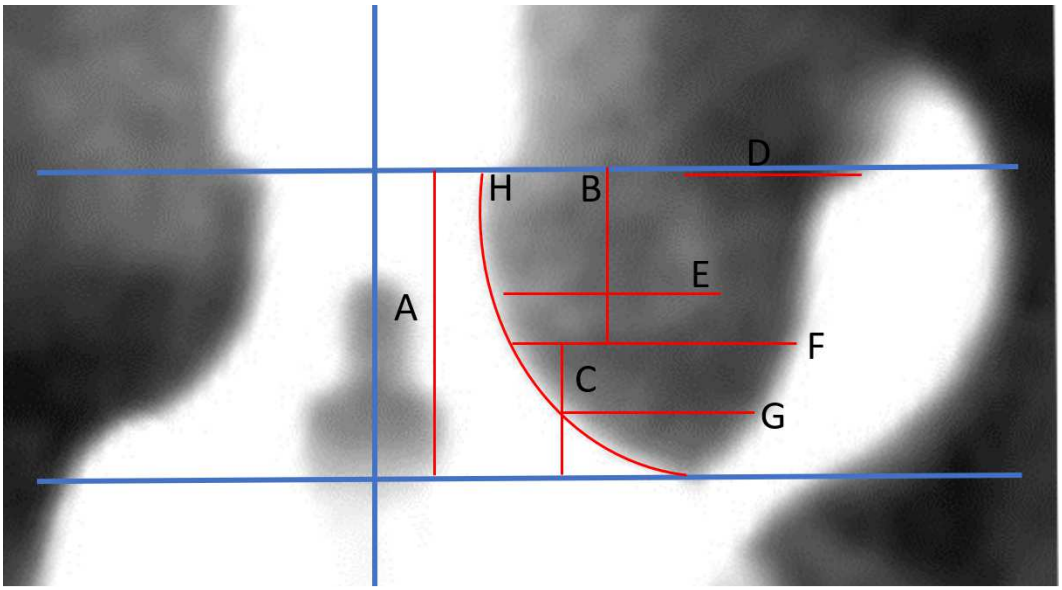


Figure 2. 16. Measurements on the concave abutment. Vertical Measurements A: IP-GM; B: IP-BC; C: BC-GM. Horizontal measurements D: ST1; E: BT; F: ST2; G: ST3. H: STP.

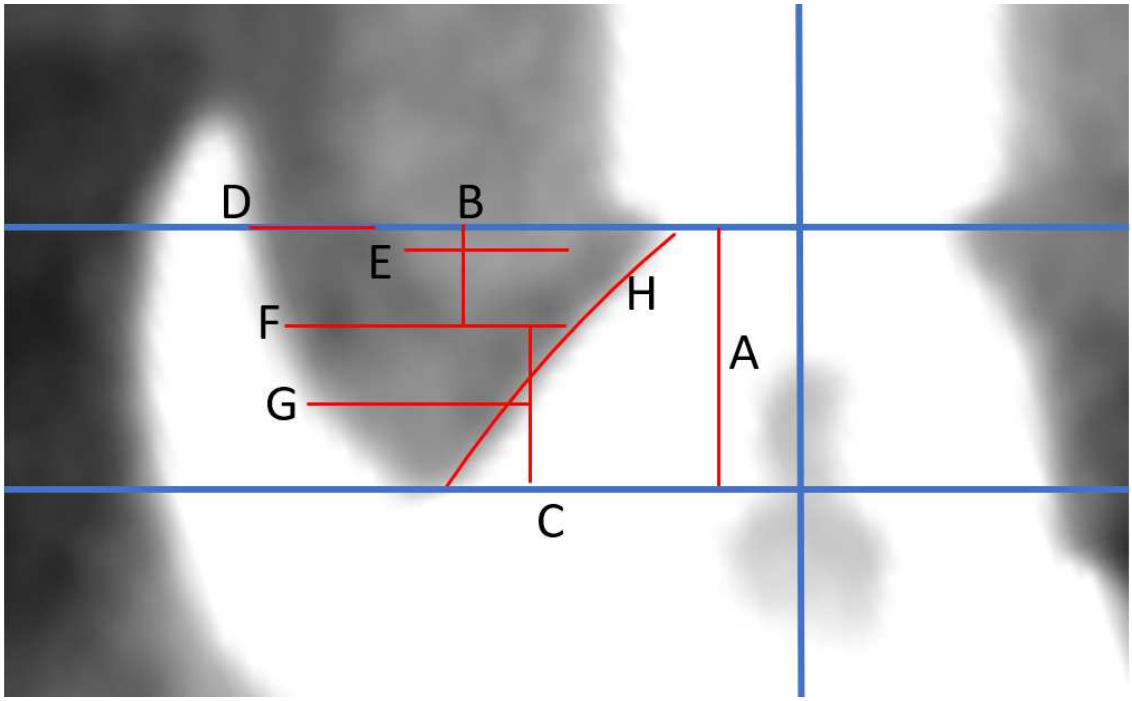


Figure 2. 17. Measurements on the convex abutment. Vertical Measurements A: IP-GM; B: IP-BC; C: BC-GM. Horizontal measurements D: ST1; E: BT; F: ST2; G: ST3. H: STP.

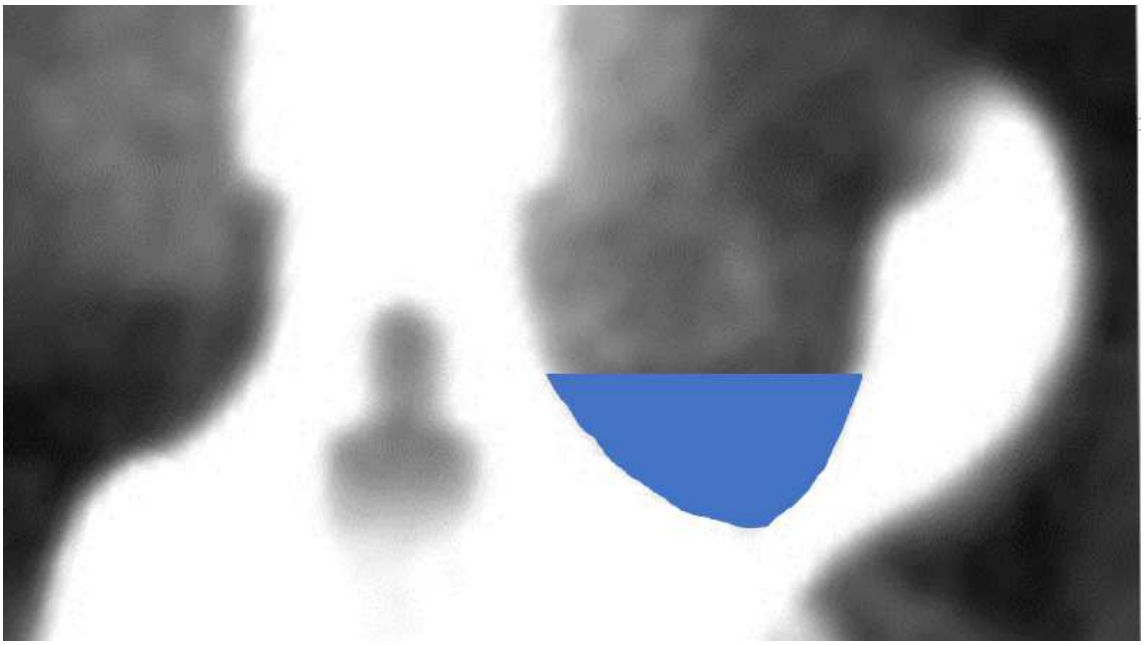


Figure 2. 18. Area measurement on the concave group.

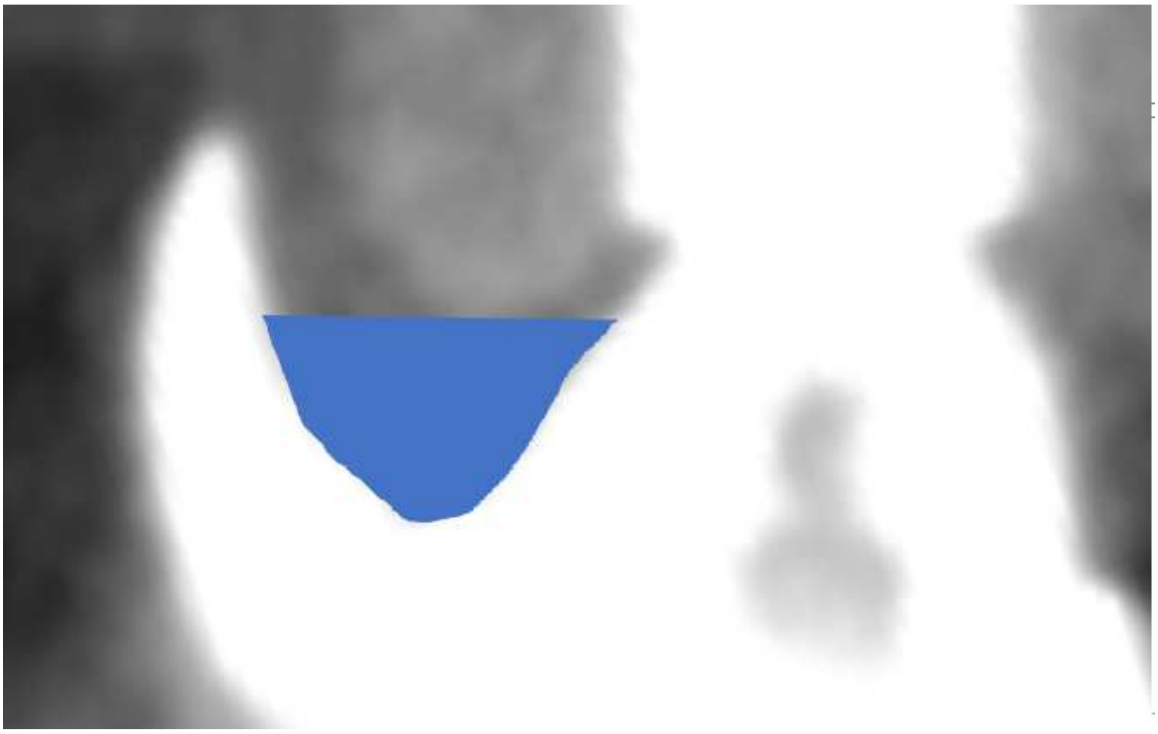


Figure 2. 19. Area measurement on the convex group.

2.6. Data analysis

With an α error of 0.05, the power calculation based on the detection of 0.5 mm difference in mean buccal peri-implant mucosa margin position between groups with a standard deviation of 0.5 mm (Koutouzis, Neiva, Nonhoff, Lundgren 2013), revealed that 14 subjects were required in each treatment group to have a power of 80%.

For description of data mean values, standard deviations (SD) and frequencies were calculated. The primary outcome variable was change of buccal peri-implant mucosa margin position. Fisher's exact test was used to evaluate differences in frequencies of plaque, bleeding on probing and pocket depth categories between treatment groups. A Mann-Whitney U Test used for continuous data. Vertical soft tissue thickness and buccal bone thickness in relation to buccal peri-implant mucosa margin position change was calculated and the correlation was analyzed using Pearson correlation coefficient. Soft tissue CBCT measurements were analyzed using Pearson correlation coefficient. A p-value of <0.05 was considered as statistically significant. All statistical analysis was done using IBM SPSS Statistics for Windows, version 19 (IBM Corp., Armonk, N.Y., USA).

3. Results

3.1. Results comparing concave group and convex group

A total of 28 patients were included in the study, however, two people were excluded because one had to move out and the other had an implant failure within a week. There were no statistically significant variations between the groups in age or the site used (Table 3.1). Thirteen patients with thirteen implants from each group were available for analysis. This reduced the power of the study to 69%.

The average age was 59.08 ± 7.3 years old and 54.62 ± 8.4 years old in the CX and CV Group respectively.

Table 3. 1 Descriptive statistics of the 2 groups.

Group	Number of patients	Age	First premolar site	Second premolar Site
CX	13	59.08 ± 7.3	8	5
CV	13	54.62 ± 8.4	8	5

3.2. Intra-surgical evaluation

The results of the intra-surgical evaluation at the IP visit are illustrated in Table 3.2. Implants at Group CV had slightly greater mean buccal (2.4±0.7mm vs 1.8±1.0mm, p=0.09) and lingual bone thickness (2.3±1.1mm vs 1.6±0.8mm, p=0.06) compared to Group CX. Overall, there were no statistically significant differences between the two groups in terms of mucosal thickness, buccal and lingual bone thickness, and distance from bone crest to implant platform and amount of keratinized mucosa.

Table 3. 2 Descriptive statistics at Surgery (Mean ± standard deviation, in mm).

	CX Group (n=13)	**CV Group (n=13)**	***P*-value**	**95% CI**
Mucosal thickness				
Mean (SD)	2.7 (0.6)	3(1.1)	0.50	(-0.93,0.46)
Min	2	1		
Max	4	5		
Buccal Bone Thickness				
Mean (SD)	1.8(1.0)	2.4 (0.7)	0.09	(-0.94,0.48)
Min	0.5	0.5		
Max	4	3.5		
Lingual Bone Thickness				
Mean (SD)	1.6 (0.8)	2.3 (1.1)	0.06	(-1.53,-0.01)
Min	0.5	1		
Max	3	5		
Buccal Subcrestal Position				
Mean (SD)	1.7 (0.5)	1.7 (0.8)	1	(-0.54,0.54)
Min	1	0		
Max	2.5	3		
Lingual Subcrestal Position	1.1	1.3	0.31	(-0.78,0.32)
Mean (SD)	0.6	0.7		
Min	0	0		
Max	2	2		
Interproximal Subcrestal Position				
Mean (SD)	2.4 (0.7)	2.3 (1.1)	0.85	(-0.71,0.75)
Min	1	0		
Max	4	5		
Keratinized Mucosa Width				
Mean (SD)	2.65 (0.8)	3.69(2.0)	0.09	(-2.28,0.20)
Min	1	2		
Max	4	9		

3.3. Clinical evaluations

The results of clinical evaluations are illustrated in Table 3.3 and Table 3.4. There were no statistically significant differences in the percentage of sites with plaque, BoP (bleeding on probing), PD (probing depth) at T1 and T2 visits between the two groups. There were no statistically significant differences in MP (margin mucosa position) changes between the two groups. For both groups, at the buccal surface a mean decrease

in MP observed from T0-T2 which appears to stabilize after 3 months (Figure 3.1). On the contrary, a mean increase in MP was observed for the interproximal buccal surfaces from T0-T2 (Figure 3.2). In one patient from the Group CX there was a minor exposure of the buccal abutment surface at T1.

Table 3. 3 Frequency (%) of sites with plaque, BoP, PD ≤3mm, 4 to 5 mm and ≥6mm at prosthesis placement (T1) and 1 year following implant installation (T2).

Group/Time	Plaque (%)	BoP (%)	PD≤3mm (%)	PD 4 to 5mm (%)	PD≥6mm (%)
CX Group/T1	9.6	15.4	84.6	14.1	1.3
CV Group/T1	9.6	14.1	83.3	14.1	2.6
CX Group/T2	5.8	16.7	74.4	25.6	-
CV Group/T2	5.8	10.3	66.7	32.1	1.2

In CX Group and CC Group, n=52 for Plaque, n=78 for BoP
CX: Convex, CV: Concave, T1: Prosthesis delivery, T2: 1-year, BoP: Bleeding on probing, PD: Probing depth

Table 3. 4 Mean Changes (SDs) in peri-implant margin mucosa position (MP) and width of keratinized mucosa (KM) (in mm) over time.

	CX Group Mean±SD	**CV Group Mean±SD**	**Mean Difference (CV-CX)**	***P*-value**
MP Mesial T0-T1	0.3 ± 1.1	0.84 ± 0.89	0.54	0.18
MP Mesial T0-T2	0.84 ± 1.21	1.46 ± 0.96	0.62	0.16
MP Mesial T1- T2	0.53 ± 0.51	0.61 ± 0.50	0.8	0.70
MP Distal T0- T1	0.15 ± 1.0	0.61 ± 1.12	0.46	0.29
MP Distal T0- T2	0.46 ± 0.96	0.92 ± 1.18	0.46	0.28
MP Distal T1- T2	0.3 ± 0.48	0.3 ± 0.63	0.00	1.00
MP Buccal T0- T1	-0.76 ± 0.59	-0.53 ± 0.96	0.23	0.47
MP Buccal T0- T2	-0.76 ± 0.72	-0.69 ± 0.85	0.07	0.80
MP Buccal T1- T2	0.0 ± 0.40	-0.15 ± 0.55	-0.15	0.42
MP Palatal T0- T2	-0.30 ± 0.94	0.07 ± 0.64	0.37	0.23
MP Palatal T0- T2	-0.15 ± 0.8	0.15 ± 0.8	0.00	0.33
MP Palatal T1- T2	0.15 ± 0.37	0.07 ± 0.49	-0.08	0.65
KM T0- T1	-0.19 ± 0.80	0.15 ± 1.06	0.34	0.36
KM T0- T2	-0.26 ± 0.72	0.0 ± 1.29	0.26	0.51
KM T1- T2	-0.07 ± 0.27	-0.15 ± 0.37	-0.08	0.55

CX: Convex, CV: Concave, T1: Prosthesis delivery, T2: 1-year, MP: Marginal Position

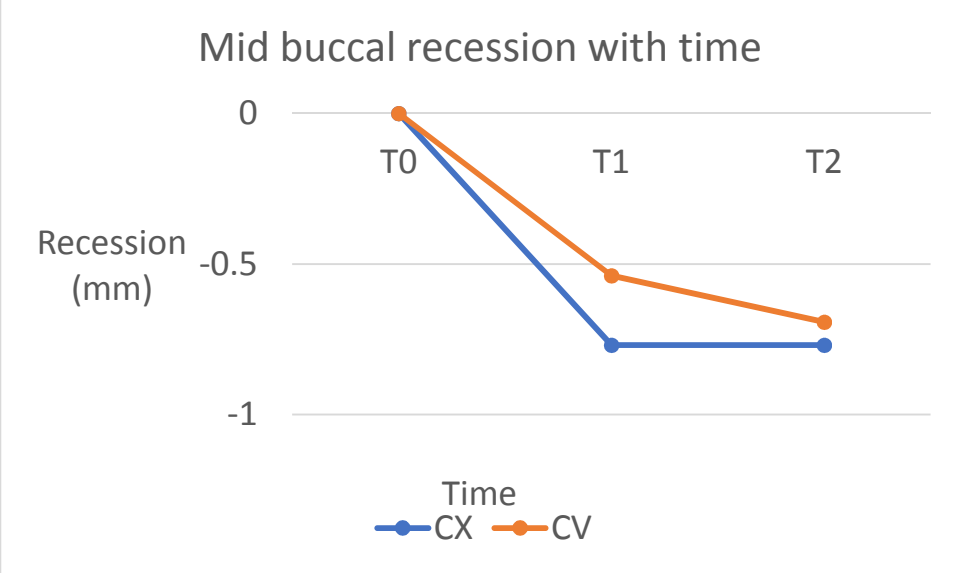


Figure 3.1. Mean mid buccal recession changes with time

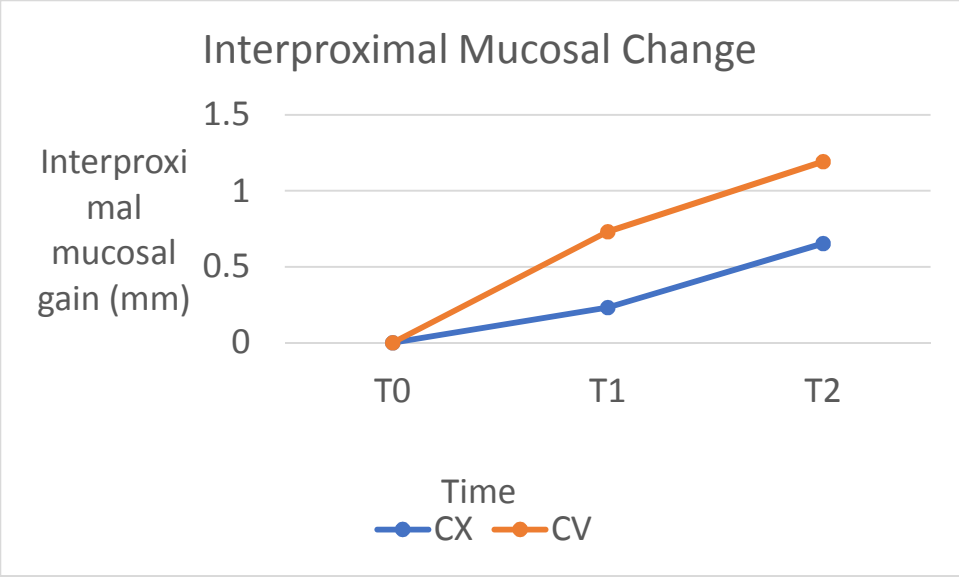


Figure 3.2. Mean buccal interproximal mucosal changes with time

3.3.1 Clinical correlation

The results of correlation analyses are shown in Table 3.5. A Pearson's r data analysis revealed a statistically significant moderate negative correlation between buccal bone thickness and recession T0-T2 (r=-0.425, *P*=0.30). No statistically significant correlation was found between buccal bone thickness and mucosal thickness or mucosal thickness and recession.

Table 3. 5 Clinical correlation between buccal bone thickness, mucosa thickness and recession T0-T2

		Buccal Bone Thickness	Mucosa Thickness	Recession T0-T2
Buccal Bone Thickness	Pearson r Correlation	1	-0.033	-0.425*
	P-value		0.875	0.030
Mucosal Thickness	Pearson r Correlation	-0.033	1	-0.048
	P-value	0.875		0.815
Recession T0-T2	Pearson r Correlation	-0.425*	-0.048	1
	P-value	0.030	0.815	

***** $P \leq 0.05$ Statistically significant difference between CV and CX

3.4. Radiographic evaluation

The mean MBL changes are illustrated in Table 3.6. There were no statistically significant differences in MBL changes at the T0-T1 and T0-T2 between the two groups. The mean SP and changes over time are illustrated in Table 3.7 and Figure 3.3. There were no statistically significant differences in SP at T0 between groups. However, there was a statistically significant difference in SP between CX Group and CV Group at T1 (0.92±0.43 mm vs 1.22 ±0.55 mm, p=0.02) and T2 (0.66±0.39 mm vs 1.16±0.55 mm, p=0.01). In addition, there was a statistically significant difference in the SP change for the interval T0-T2 between CX group and CV Group (-0.66±0.46 mm vs -0.24±0.25 mm, p=0.007).

Table 3. 6 Mean changes (SD) in marginal bone level (in mm) over time.

	T0-T1	T0-T2
CX Mean±SD	0 ± 0	0 ± 0
CV Mean±SD	-0.06 ± 0.24	-0.11 ± 0.40
***P*-value**	0.76	0.76

CX: Convex, CV: Concave, T1:Prosthesis delivery, T2: 1-year,

Table 3. 7 Mean subcrestal implant position and changes (SD) (in mm) over time.

	T0	T1	T2	T0-T1	T0-T2
CX Mean±SD	1.32 ± 0.43	0.92 ± 0.43 *	0.66 ± 0.39 *	-0.40 ± 0.36	-0.66 ± 0.46 *
CV Mean±SD	1.40 ± 0.57	1.22 ± 0.55 *	1.16 ± 0.55 *	-0.17 ± 0.18	-0.24 ± 0.25 *
***P*-value**	0.362	0.02	0.01	0.06	0.007

* $P \leq 0.05$ Statistically significant difference between CV and CX

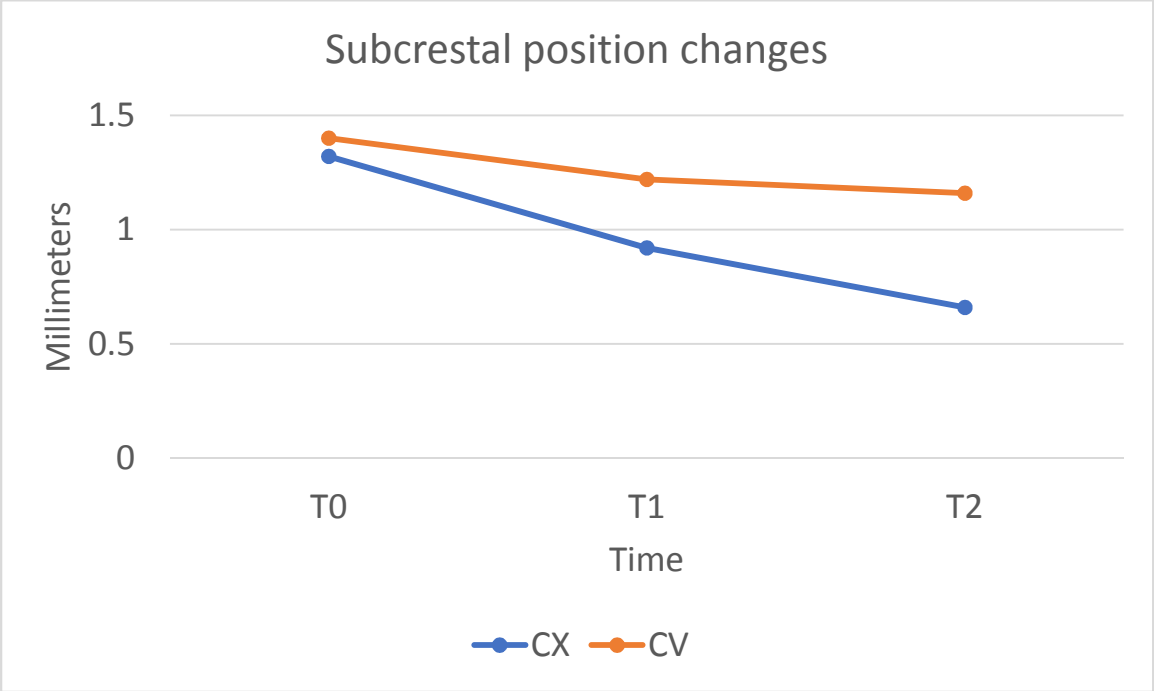


Figure 3.3. Mean subcrestal position changes with time

3.5. CBCT 1-year evaluation

The results of the CBCT evaluation are in illustrated in Table 3.8. There was a statistically significant difference at ST2 between CV and CX Groups (4.08±0.75 vs 3.37 ± 0.81 p=0.03). There was a statistically significant difference at ST3 between CV and CX Groups (2.79 ± 0.66 vs 2.04 ± 0.60 p=0.006). There was a mean difference of 0.71mm and 0.75mm in the ST2 and ST3 respectively. CV Group had a favorable mean difference of 0.22mm in IP-GM, 0.56mm in IP-BC, 0.59mm in BT, 0.68mm in STP and 1.11mm^2 in AREA but these were not statistically significant. CX group had a favorable

mean difference of 0.33mm in BC-GM, and 0.05mm in ST1 but these were not statistically significant.

Table 3. 8 Descriptive statistics with the mean±SD (mm), mean difference (mm) and *P*-value

	Group	Mean ± SD	Mean Difference	*P*-value
IP-GM	CX	3.27 ± 0.78	-0.22	0.621
	CV	3.49 ± 1.34		
IP-BC	CX	0.62 ± 0.57	-0.56	0.125
	CV	1.18 ± 1.12		
BC-GM	CX	2.65 ± 0.84	0.33	0.253
	CV	2.32 ± 0.62		
ST1	CX	1.79 ± 0.55	0.05	0.816
	CV	1.74 ± 0.45		
BT	CX	1.80 ± 0.77	-0.59	0.071
	CV	2.39 ± 0.81		
ST2	CX	3.37 ± 0.81*	-0.71	0.03
	CV	4.08 ± 0.75*		
ST3	CX	2.04 ± 0.60*	-0.75	0.006
	CV	2.79 ± 0.66*		
STP	CX	4.51 ± 0.94	-0.68	0.078
	CV	5.19 ± 0.96		
FirstBiC	CX	0.00 ± 0.00	0.15	0.162
	CV	-0.15 ± 0.38		
PlatBone	CX	0.62 ± 0.51	-0.15	0.416
	CV	0.77 ± 0.44		
AREA	CX	5.66 ± 1.97	-1.11	0.304
	CV	6.77 ± 3.26		

***** $P \leq 0.05$ Statistically significant difference between CV and CX

3.5.1 CBCT correlation

The results of the CBCT correlation of soft tissue are shown in Table 3.9. A Pearson's r data analysis revealed a statistically significant moderate positive correlation between the following, ST1 and AREA (r=0.506, $P \leq 0.005$), ST1 and BC-GM (r=0.456, $P \leq .005$), ST2 and STP (r=0.481, $P \leq .005$), ST2 and AREA (r=0.573, $P \leq .005$), ST3 and AREA (r=0.663, $P \leq .001$), ST3 and STP (r=0.481, $P \leq .005$), STP and AREA (r=0.529, $P \leq .005$), AREA AND BC-GM (r=0.559, $P \leq .005$). Also, a statistically significant strong positive

Pearson's r correlation was found in ST2 and ST3 (r=0.738, $P \leq .001$), No other statistically significant correlations were found.

Table 3. 9 CBCT soft tissue correlation

		ST1	ST2	ST3	STP	AREA	BC-GM
ST1	Pearson r Correlation	1	0.368	0.322	0.313	0.506*	0.456*
	P-value		0.064	0.109	0.119	0.008	0.019
ST2	Pearson r Correlation	0.368	1	0.738*	0.642*	0.573*	0.151
	P-value	.064		0	0	0.002	0.461
ST3	Pearson r Correlation	0.322	0.738*	1	0.481*	0.663*	-0.011
	P-value	0.109	0		0.013	0	0.959
STP	Pearson r Correlation	0.313	0.642*	0.481*	1	0.529*	0.312
	P-value	.119	0	0.013		0.005	0.121
AREA	Pearson r Correlation	0.506*	0.573*	0.663*	0.529*A	1	0.559*
	P-value	0.008	0.002	0.000	0.005		0.003
BC-GM	Pearson r Correlation	0.456*	0.151	-0.011	0.312	0.559**	1
	P-value	0.019	0.461	0.959	0.121	0.003	

***** $P \leq 0.05$ Statistically significant difference between CV and CX

3.5.2 Bone remodeling analysis

Analysis of the mean difference in the surgical bone thickness and implant subcrestal buccal position to the CBCT are shown in Table 3.41. There was a statistically significant change in subcrestal implant position from T0 to T2 of 1.07±0.28mm and 0.52±0.52 for the CX and CV group (P=0.002) respectively with a mean difference of 0.55mm. There was no statistically significant change in buccal bone thickness 1mm apical to the bone crest for both groups.

Table 3. 10 Mean buccal subcrestal implant position changes over 1-year.

	CX Mean±SD	**CV Mean±SD**	**Mean Difference**	**P value**
Bone Thickness	0.05±0.41	0.00±0.70	0.46	0.84
Subcrestal position	1.07±0.28	0.52±0.52	0.55	0.002

***** $P \leq 0.05$ Statistically significant difference between CV and CX

4. Discussion

The results of the present study demonstrated that there were no statistically significant differences in buccal peri-implant margin position between the two groups in 1 year. However, abutment macro-design significantly affected the amount of bone remodeling above the implant platform for subcrestally placed implants. In addition, the abutment macro-design significantly increased the horizontal soft tissue thickness at ST2 and ST3.

Changes in peri-implant mucosa position over time has been evaluated in several studies.[105-108] A trend for mucosal tissue recession has been described with major alterations occurring during the first three months following connection of the transmucosal component of the implant prosthesis complex. Similar findings have been described in the current study for the buccal aspect of the study implants. Buccal mucosal recession was observed from the time of implant installation to final crown delivery at 3 months and at the 12-month follow-up examination. This recession mainly occurred at the first 3 months with minimal changes thereafter. We observed a different pattern for the interproximal surfaces meaning that following surgery; interproximally, there was a coronal migration of the peri-implant mucosa margin over time. Interestingly, it appeared that greater changes occurred at the interval of 3 months to 12 months for the interproximal surfaces compared to buccal surfaces suggesting that healing and maturation of the interproximal supracrestal tissues of the adjacent teeth may have a role on this dimensional difference between the buccal and interproximal surfaces. One of the several challenges evaluating peri-implant mucosa recession after connection of the provisional restoration is the difficulty standardizing the location of the peri-implant mucosa margin following the completion of the surgical procedure. In general, following

placement of an implant in a healed site and connection of a provisional restoration, the mucosa has to be adapted around the provisional restoration.

In the current study, in order to achieve adaptation, it was not uncommon that a small portion of the buccal mucosa had to be excised. Effort was made to avoid advancing the flap too far beyond the abutment-crown margin. In the case that coronal advancement of the buccal flap occurred, one expects greater buccal mucosa recession during the first months of healing.

It has been proposed by Su, et al. that alterations in the subcritical contour of the restoration may modify peri-implant mucosa margin position. In the present study, even though we did not observe any significant differences in the peri-implant mucosa position changes between implants with convex and concave abutment macro-design, the effect of altering the abutment macro-design during treatment was not evaluated. All implants maintained the same abutment during surgical and restorative phases of treatment. [109]

For both treatment groups implant placement was planned and performed following treatment planning guidelines described previously by Buser, et al., with the implant platform positioned 3-4 mm apical to the future crown margin. [8] It is worth noting that all implants from both groups with the exception of one implant at Group CV had their platforms in a subcrestal position at the buccal aspect of the implant. In addition, all interproximal surfaces for implants of both treatment groups had their platforms in a subcrestal position. Thus, one should expect that placement of the implant platform will be at a subcrestal position for at least one surface when treating patients for single tooth replacements. The effect of subcrestal placement on peri-implant bone alterations for the

specific implant system has been evaluated in both animal and clinical studies. [57, 110-113] In general, in those studies, it was observed that subcrestal implant placement can induce greater bone remodeling above the implant platform. However, the first bone-to-implant contact was located consistently at or on top of the implant platform. Observations from previous studies are in agreement with our results which confirm the patterns of bone remodeling for the specific implant system when placed in subcrestal position.

In the current study, comparison of the surgical measurements and 1-year CBCT measurements showed that the subcrestal position of the implant measured at the buccal position had significantly more bone remodeling around the CX group. CX group had 0.55mm (P=0.002) more bone remodeling when compared to the CV group during surgery and after 1 year at the CBCT. This confirms with our radiographical report where we found statistically significant more bone remodeling in the CX group of 0.42mm. This finding is in agreement with the animal studies from Finelle, et al. and Souza, et al. In both studies, healing abutments with different diameters and emergence profiles were used. It was observed that implants connected to abutments with wider diameters and emergence profiles experienced greater bone loss compared to implants connected to abutments with narrower diameters and emergence profiles. In addition, the peri-implant mucosa was established with similar dimensions. [87, 114] The explanation for those observations was when using a wide healing abutment, there is a reduction in the space available for the peri-implant biologic width to establish. In the current study, the diameter of the custom abutments depended the dimensions of the crown. Because all teeth included in the study were upper premolars, no major differences in abutment diameters were expected. This demonstrates that the abutment macro-design can also

contribute to peri-implant bone remodeling. Since implants with convex abutments experienced greater bone remodeling above the implant platform compared to implants with concave abutments might suggest that abutment macro-design can have an effect on establishment of the biologic width and consequently on the amount of bone remodeling. For the CBCT analysis, the bone thickness was larger in the CX group but was not statistically significant. The difference in bone thickness measured 1mm apical to the crest during surgery and 1 year at the CBCT evaluation did not change significantly for both groups (0mm for CV and 0.05mm for CX). This was different to a study by Vera et al. which found that 1mm apical to the implant, 0.62mm of horizontal bone loss occurred. This difference could be attributed to the difference in methodology and/or implant/abutment design. [99] The mean bone thickness at T0 was 2.5mm and 1.9mm for the CX and CV groups respectively. Cho et al. suggested a bone thickness of 1.91mm is recommended to reduce the incidence of bone resorption in the anterior maxilla whereas Spray et al. suggested a minimum bone thickness of 2mm is needed to reduce bone loss. [100] [115]

The effect of abutment design on peri-implant tissue changes has been evaluated in few clinical studies. Patil et al. reported that implants with conventional divergent shape have similar marginal bone level changes and peri-implant mucosa level changes compared to implants with curved and grooved abutments. [91] Katafuchi et al. reported that implants with restorations characterized by wide emergence angle (greater than 30°) and convex profile had higher rate of peri-implantitis compared to implants with a narrow emergence angle (less than 30°) and straight or concave profile. Those findings were attributed to challenges that an over contoured restoration creates on plaque control and peri-implant

maintenance procedures. [116] Interestingly, Sancho-Puchades et al. in a laboratory study reported that abutments with a concave emergence profile and deep crown-abutment margin positions are in greater risk to have cement excess following the crown cementation, which can potentially lead to peri-implant tissue inflammation. [62] In the current study, we did not observe any significant differences in clinical indices between the two groups of implants and any incidence of peri-implantitis. However, one should consider the short-term follow-up time. In the present study, we observed a significant correlation between changes of the buccal peri-implant margin position from T0 to T2 and buccal bone thickness at the time of the surgery irrespective from the abutment macro-design. A positive effect of buccal bone thickness and/or integrity on peri-implant mucosa levels for immediate implants have been reported by Benic et al. [103] However, we did not observe a significant correlation between the mucosa thickness at the time of the surgery and changes of the buccal peri-implant margin position. In the current study, we used a similar way to measure mucosa thickness as previously described by Linkevicius et al. [117] In this study and in subsequent studies, it was demonstrated that mucosa thickness can influence peri-implant bone remodeling and the authors recommended a minimum of 2mm of vertical soft tissue thickness. In our study, the vertical soft tissue thickness measured at T0 was 2.82mm and 3.00mm for CV and CX group respectively. As such, the gingival biotype for all patients except one was determined to be thick (≥2mm) when measured at T0. [118, 119]

In our study CBCT analysis of the horizontal soft tissue thickness was significantly greater at the ST2 and ST3 in the concave definitive abutments. This cannot be attributed to soft tissue biotype as there was no statistically significant difference between the 2

groups in the soft tissue clinical measurements and the ST1 in the CBCT scan. In addition, the vertical thickness of the soft tissue was also similar between the two groups. At ST3 a mean increase in soft tissue thickness of 0.75mm was found for the CV group, meaning a 37% more horizontal soft tissue thickness in the CV group. Whereas in ST2, an increase of 0.71mm was found for the CV group, or a 21% more horizontal soft tissue thickness in the CV group. The difference between the percentage in these 2 areas could be attributed to that there is a greater difference between the width of the healing abutments as you go more coronally, giving more space for soft tissue to take up this space. Also, at ST2, 8 of the 26 implants had the ST2 measured at the implant-abutment interface, which we do not expect to see the difference in soft tissue thickness at this area. There was also an increase in the true height (0.68mm) and area(1.11mm^2) of the CV group but was not statistically significant. The HT and AREA both had moderate correlations to other factors than the ST2 and ST3 which could be the reason why this was not found to be statistically significant. Limited data is available on the effects of horizontal soft tissue thickness on peri-implant soft and hard tissue. In addition, whether horizontal and vertical soft tissue thickness affect the peri-implant hard and soft tissue as two different entities or are a continuation of each other is unknown. However, in our study there was a moderate correlation found between horizontal and vertical soft tissue thickness when measured with the CBCT scan. Peri-implant diseases and conditions consensus report by Berglundh et al indicated that thin soft tissue is one of the risk factors for recession. [120] In immediate implant placement, several studies have associated the risk of thin soft tissue biotype with recession by assessing the thickness using a periodontal probe. The soft tissue thickness was considered thin if the periodontal probe was visible.

[121, 122] However, Cosyn et al found that, even with thick gingival biotype, immediate implants still had mid facial recession. [123]

An in vitro study by Jung et al evaluated different abutment materials under different soft tissue thickness in pigs to assess the effect on the color of mucosa. The study found that at 1.5mm thickness, all materials affected the color change and for 2mm only titanium affected the color. Whereas in thick 3mm thickness, no changes were observed for all materials. [124] Jung et al. evaluated the thickness of the midfacial mucosa 1mm apical to the gingival margin and found it to be 2.6mm in the Porcelain fused to metal group with titanium or gold abutments and 3.2mm in the all-ceramic crowns on aluminum-oxide based abutments. [125] Chang et al. found the horizontal mucosal thickness at the base of the pocket to be 2mm in implants. [126] A study by Benic et al. found the mucosal thickness measured using the application of composite layer on CBCT to be 1.5mm when measured 1mm apical to the gingival margin. In addition, 5 of the 14 implants showed loss of buccal bone on the CBCT. To our knowledge, this is the only study evaluated soft and hard tissue dimensions using the application of a composite layer. The difference in horizontal soft tissue thickness in these studies and our current study can be attributed to the different methodology used. For example, there was a difference in the location of measurement of the horizontal soft tissue thickness. In our study, the mean distance measured from the gingival margin to ST2 and ST3 was measured on average 2.49mm and 1.26mm respectively.

In the present study we avoided any abutment disconnections after the surgical phase of the treatment, in order to maximize peri-implant bone stability. Recent systematic reviews have addressed that topic, pointing out a modest positive effect of non-removal

of the final abutment on peri-implant bone levels. [57, 59] To our knowledge this is the first clinical study utilizing custom CAD-CAM abutments as opposed to prefabricated standard abutments for this application. One major limitation of the study was the loss of two participants, without an increase to the sample size in order to compensate for that. This resulted in reduction of the study power. In addition, comparing the intra surgical data with the CBCT data should be interrupted with caution due to the effect of artifacts.

5. Conclusion

Within the limitation of this study, the following conclusions can be drawn:

1. The null hypothesis was rejected for hard tissue as more bone remodeling was observed for the convex group
2. The null hypothesis was accepted for soft tissue as no difference in peri-implant mucosal position was seen between the two groups.
3. There were no statistically significant differences in buccal peri-implant margin position between the two groups in 1 year
4. There was a statistically significant difference between the subcrestal position of the CX and CV group during the 1-year evaluation (Statistically significant more bone remodeling occurred in the CX group)
5. Horizontal soft tissue thickness was significantly greater at ST2 and ST3 for the CV group in the CBCT analysis
6. There was a statistically significant moderate correlation between buccal bone thickness and recession T0-T2

6. Appendices

Appendix A: Raw Data for descriptive measurements

Patient number	Group 1: Convex 2: Concave	Implant Site	Age	Gender
1	1	13	66	F
2	1	4	60	F
3	1	12	65	F
4	1	13	71	F
5	1	12	63	M
6	1	12	57	F
7	1	12	51	F
8	1	4	52	F
9	1	12	46	F
10	1	5	50	M
11	1	12	65	F
12	1	4	61	F
13	1	12	61	F
14	2	5	36	M
15	2	4	54	M
16	2	5	57	M
17	2	12	50	M
18	2	13	57	F
19	2	5	49	F
20	2	13	61	F
21	2	13	61	F
22	2	4	50	F
23	2	5	63	M
24	2	5	46	M
25	2	12	58	F
26	2	12	68	M

Appendix B: Clinical measurements at surgery (Raw data) 1

Patient number	Group 1: Convex 2: Concave	Mucosal thickness	Buccal plate thickness	Lingual Plate Thickness	KM
1	1	2	1.5	0.5	2
2	1	3	1	2	1
3	1	3	3	1	4
4	1	4	0.5	3	3
5	1	2	2	2	3
6	1	3	1	1	2
7	1	3	1	1	3
8	1	3	4	3	3
9	1	3	1	1	3
10	1	2	2	2	3
11	1	3	3	1	3
12	1	3	2	2	1.5
13	1	2	2	1	3
14	2	5	2	1.5	9
15	2	4	3.5	5	2
16	2	2	2	3	4
17	2	4	0.5	1	5
18	2	3	3	3	2
19	2	4	3	2	4
20	2	1	2	1	3
21	2	2	3	2	3
22	2	3	2	3	2
23	2	3	3	2	3
24	2	3	3	3	6
25	2	3	2	2	3
26	2	2	2	2	2

Appendix C: Clinical measurements at surgery (Raw data) 2

Patient number	Group 1: Convex 2: Concave	Peri-bone implant measurement				Stent measurement on the buccal		
		M	D	B	P	DB	Mid-B	MB
1	1	2	2	2	1.5	4	6	5
2	1	2	1	1	1	4	8	4
3	1	2	2	2	1	7	7	7
4	1	1.5	1	1	1	9	9	9
5	1	3	2	1.5	2	9	9	8
6	1	3	3	1.5	1	6	9	6
7	1	3	3	1	1	9	10	9
8	1	3	3	2.5	1	8	9	9
9	1	3	4	2	2	8	9	9
10	1	3	3	2	2	6	9	9
11	1	3	1	2	1	8	9	8
12	1	2	2	1.5	0.5	5	5	5
13	1	2	2	2	0	7	9	9
14	2	3	2	3	1	7	10	8
15	2	3	3	3	2	5	6	5
16	2	1	2	1	1	5	7	6
17	2	0	0	0	0	4	2	3
18	2	2	2	2	2	4	6	5
19	2	5	3	1.5	2	4	5	6
20	2	1	1	1	1	7	9	9
21	2	3	3	2	2	9	9	9
22	2	2	2	1	2	7	8	8
23	2	3	3	2	2	7	9	7
24	2	2	2	1.5	1	9	11	9
25	2	3	4	2	2	9	9	8
26	2	3	3	2	0	7	8	7

Appendix D: Clinical measurements at the impression visit on the buccal (Raw data) 1

Patient number	Group 1: Convex 2: Concave	Probing depth (PD) measurement			Stent measurement on the buccal		
		DB	Mid-B	MB	DB	Mid-B	MB
1	1	2	1	2	5	7	7
2	1	4	2	2	5	9	5
3	1	3	1	2	5	7	6
4	1	1	1	2	8	11	8
5	1	3	1	2	10	10	8
6	1	2	2	3	5	9	5
7	1	3	1	3	8	11	8
8	1	2	2	3	7	9	7
9	1	3	2	2	8	10	10
10	1	3	2	3	6	10	8
11	1	2	2	2	8	10	8
12	1	3	3	3	5	6	5
13	1	4	4	3	8	9	9
14	2	3	3	3	10	11	8
15	2	3	3	4	4	7	5
16	2	2	1	2	4	8	6
17	2	2	3	3	3	3	3
18	2	3	3	3	4	7	4
19	2	3	2	4	3	4	4
20	2	4	4	3	7	10	8
21	2	3	2	3	9	10	9
22	2	3	1	3	6	7	6
23	2	2	2	3	8	10	5
24	2	3	2	3	8	10	8
25	2	3	2	3	8	10	7
26	2	2	1	2	6	9	7

Appendix E: Clinical measurements at the impression visit on the buccal (Raw data) 2

Patient number	Group 1: Convex 2: Concave	Bleeding on Probing (BOP)			Keratinized Mucosa width on the buccal	Exposed Abutment margin
		DB	Mid-B	MB		
1	1	0	0	0	2	0
2	1	1	0	0	1	0
3	1	0	0	0	3	0
4	1	0	0	0	2	0
5	1	1	0	0	3	0
6	1	0	0	1	3	0
7	1	0	0	0	2	1
8	1	0	0	1	4	0
9	1	0	0	0	4	0
10	1	0	0	0	3	0
11	1	0	0	0	4	0
12	1	0	0	0	1	0
13	1	1	1	1	3	0
14	2	0	0	0	9	0
15	2	1	0	0	2	0
16	2	0	0	0	4	0
17	2	0	0	0	3	0
18	2	0	0	0	3	0
19	2	0	0	1	4	0
20	2	0	1	0	3	0
21	2	0	0	0	3	0
22	2	3	1	3	6	7
23	2	2	2	3	8	10
24	2	3	2	3	8	10
25	2	3	2	3	8	10
26	2	2	1	2	6	9

Appendix F: Clinical measurements at the impression visit on the palatal (Raw data)

Patient number	Group 1: Convex 2: Concave	Probing depth (PD) measurement			Stent measurement on the palatal			Bleeding on Probing (BOP)		
		DP	Mid-P	MP	DP	Mid-P	MP	DP	Mid-P	MP
1	1	2	2	2	5	5	5	0	0	0
2	1	4	2	2	7	8	7	1	0	0
3	1	3	2	3	6	7	6	1	0	0
4	1	3	1	3	9	9	8	0	0	1
5	1	4	2	3	9	9	7	1	0	0
6	1	3	2	3	7	8	6	1	0	0
7	1	5	2	2	7	8	8	0	0	0
8	1	2	2	3	6	8	6	0	0	0
9	1	2	2	3	9	9	8	0	0	0
10	1	4	2	4	5	6	5	0	0	0
11	1	4	3	3	6	7	6	0	0	0
12	1	3	3	3	5	6	5	0	0	0
13	1	3	2	3	8	8	7	0	0	0
14	2	4	4	4	5	7	5	0	0	0
15	2	5	2	2	5	7	5	0	0	0
16	2	3	1	2	11	11	11	0	0	0
17	2	2	2	3	3	3	3	0	0	0
18	2	3	3	3	6	6	5	0	0	0
19	2	3	2	3	5	6	5	1	0	0
20	2	3	2	2	9	9	8	0	0	1
21	2	3	2	2	9	9	8	0	0	0
22	2	3	2	4	6	7	6	0	0	0
23	2	4	2	3	7	9	7	0	0	0
24	2	3	2	3	7	7	6	1	0	0
25	2	3	2	3	5	7	5	1	0	1
26	2	3	1	3	5	7	6	0	0	0

Appendix G: Clinical measurements at the final crown delivery visit on the buccal (Raw data) 1

Patient number	Group 1: Convex 2: Concave	Plaque score on the Buccal, Mesial, Distal, and palatal				Probing depth (PD) measurement		
		M	D	B	P	DB	Mid-B	MB
1	1	0	0	0	0	2	1	2
2	1	1	0	0	0	3	3	3
3	1	0	1	0	0	4	2	3
4	1	0	0	0	0	4	2	4
5	1	1	1	0	0	3	1	2
6	1	0	0	0	0	2	2	3
7	1	0	0	0	0	4	2	3
8	1	0	0	0	0	2	2	3
9	1	0	0	0	0	2	1	2
10	1	0	0	0	0	3	2	4
11	1	0	1	0	0	3	1	3
12	1	0	0	0	0	3	3	3
13	1	0	0	0	0	4	3	3
14	2	0	0	0	0	2	1	2
15	2	0	0	0	0	4	3	3
16	2	1	0	0	0	2	1	3
17	2	0	0	0	0	2	3	3
18	2	1	1	0	0	3	3	3
19	2	0	0	0	0	4	2	4
20	2	0	0	0	0	5	3	4
21	2	0	0	0	0	3	2	3
22	2	1	0	0	0	3	2	3
23	2	1	0	0	0	3	2	4
24	2	0	0	0	0	3	2	3
25	2	0	0	0	0	3	2	3
26	2	0	0	0	0	2	1	2

Appendix G: Clinical measurements at the final crown delivery visit on the buccal (Raw data) 2

Patient number	Group 1: Convex 2: Concave	Bleeding on Probing (BOP)			KM	Exposed Abutment margin
		DB	Mid-B	MB		
1	1	0	0	0	3	0
2	1	0	1	0	2	0
3	1	0	0	0	3	0
4	1	1	0	1	2	0
5	1	0	0	0	3	0
6	1	0	0	1	3	0
7	1	0	0	0	3	1
8	1	0	0	1	4	0
9	1	0	0	1	4	0
10	1	0	0	1	3	0
11	1	0	0	0	2	0
12	1	0	0	0	2	0
13	1	0	1	0	3	0
14	2	0	0	0	8	0
15	2	0	0	1	3	0
16	2	0	0	1	3	0
17	2	0	0	1	3	0
18	2	1	0	1	3	0
19	2	0	0	0	4	0
20	2	1	0	1	3	0
21	2	0	0	0	3	0
22	2	0	0	0	2	0
23	2	0	0	0	5	0
24	2	0	0	0	5	0
25	2	1	0	0	2	0
26	2	0	0	0	2	0

Appendix H: Clinical measurements at the final crown delivery visit on the palatal (Raw data)

Patient number	Group 1: Convex 2: Concave	Probing depth (PD) measurement			Stent measurement on the palatal			Bleeding on Probing (BOP)		
		DP	Mid-P	MP	DP	Mid-P	MP	DP	Mid-P	MP
1	1	2	2	3	5	5	5	0	0	0
2	1	4	2	3	7	8	7	0	0	0
3	1	3	2	4	6	7	6	0	0	0
4	1	3	2	3	8	9	8	1	0	1
5	1	3	2	3	9	9	7	0	0	0
6	1	2	2	3	7	8	6	1	0	0
7	1	3	2	4	7	8	7	0	0	0
8	1	2	2	3	6	8	6	0	0	0
9	1	2	2	2	9	9	8	0	0	0
10	1	6	2	4	5	7	5	0	0	1
11	1	3	2	4	6	7	6	0	0	0
12	1	3	3	3	5	6	5	0	0	0
13	1	3	2	3	8	8	7	0	0	0
14	2	4	3	3	5	7	5	0	0	0
15	2	4	2	4	6	7	6	0	0	0
16	2	2	1	2	11	11	11	0	0	0
17	2	2	2	3	3	3	3	0	0	0
18	2	3	3	3	6	6	5	0	0	1
19	2	6	3	4	5	6	5	0	0	0
20	2	3	2	2	9	9	7	0	0	0
21	2	2	2	2	9	9	8	0	0	0
22	2	3	2	4	6	6	5	0	0	0
23	2	3	2	6	7	9	7	0	0	1
24	2	3	3	3	7	7	6	0	0	1
25	2	2	2	2	5	7	5	0	0	0
26	2	3	1	2	5	7	6	0	0	0

Appendix I: Clinical measurements at the one-year visit on the buccal (Raw data) 1

Patient number	Group 1: Convex 2: Concave	Plaque score on the Buccal, Mesial, Distal, and palatal				Probing depth (PD) measurement			Stent measurement on the buccal		
		M	D	B	P	DB	Mid-B	MB	DB	Mid-B	MB
1	1	0	0	0	0	3	2	3	5	7	7
2	1	0	0	0	0	3	2	2	5	9	5
3	1	1	1	0	0	5	1	3	5	7	6
4	1	1	0	0	0	3	3	3	8	11	8
5	1	1	1	0	0	3	1	2	9	9	7
6	1	0	0	0	0	4	2	4	5	9	5
7	1	0	1	0	0	3	3	3	8	11	7
8	1	0	0	0	0	2	2	4	7	9	7
9	1	0	1	0	0	4	2	3	8	11	9
10	1	0	0	0	0	3	2	4	6	10	7
11	1	1	1	0	0	2	2	3	8	10	7
12	1	0	0	0	0	4	3	3	3	6	3
13	1	0	0	0	0	4	3	4	7	9	8
14	2	0	0	0	0	4	2	3	8	11	7
15	2	0	0	0	0	5	4	5	3	7	4
16	2	0	0	0	0	5	1	3	4	8	5
17	2	0	0	0	0	2	3	3	3	3	3
18	2	0	1	0	0	4	2	3	4	7	4
19	2	0	1	0	0	4	2	4	3	4	3
20	2	0	0	0	0	5	2	3	6	10	7
21	2	0	0	0	0	3	3	3	10	11	9
22	2	1	0	0	0	3	2	4	6	9	6
23	2	1	0	0	0	3	2	4	7	9	4
24	2	0	0	0	0	4	3	4	7	10	7
25	2	0	0	0	0	3	2	3	6	10	6
26	2	0	0	0	0	3	2	3	5	9	6

Appendix J: Clinical measurements at the one-year visit on the buccal (Raw data) 2

Patient number	Group 1: Convex 2: Concave	Bleeding on Probing (BOP)			KM	Exposed Abutment margin
		DB	Mid-B	MB		
1	1	0	1	0	3	0
2	1	0	0	1	2	0
3	1	0	0	0	3	0
4	1	0	0	0	2	0
5	1	0	0	0	3	0
6	1	1	0	1	3	0
7	1	0	0	0	3	1
8	1	0	0	0	4	0
9	1	1	0	0	4	0
10	1	1	0	0	3	0
11	1	0	0	0	3	0
12	1	1	0	0	2	0
13	1	0	0	1	3	0
14	2	0	0	0	8	0
15	2	0	0	1	4	0
16	2	0	0	0	3	0
17	2	0	0	1	3	0
18	2	1	0	0	4	0
19	2	0	0	0	4	0
20	2	0	0	0	3	0
21	2	1	0	0	3	0
22	2	0	0	0	2	0
23	2	1	0	0	5	0
24	2	0	0	0	5	0
25	2	0	0	0	2	0
26	2	0	0	0	2	0

Appendix K: Clinical measurements at the one-year visit on the palatal (Raw data)

Patient number	Group 1: Convex 2: Concave	Probing depth (PD) measurement			Stent measurement on the palatal			Bleeding on Probing (BOP)		
		DP	Mid-P	MP	DP	Mid-P	MP	DP	Mid-P	MP
1	1	3	2	3	5	5	5	0	0	0
2	1	5	2	3	7	8	7	1	1	0
3	1	3	2	3	6	7	6	0	0	0
4	1	3	3	3	8	9	8	0	0	0
5	1	3	2	5	8	8	6	0	0	0
6	1	3	2	3	7	8	6	0	0	0
7	1	2	3	3	7	8	7	0	0	0
8	1	4	3	5	6	8	6	1	0	0
9	1	3	2	4	9	9	8	1	0	0
10	1	4	2	2	5	7	5	0	0	0
11	1	3	3	4	6	7	6	0	0	0
12	1	3	2	3	5	6	5	1	0	0
13	1	5	4	3	7	7	6	0	0	0
14	2	4	5	4	5	7	5	0	0	0
15	2	6	4	5	6	7	6	0	0	0
16	2	3	2	3	11	11	11	0	0	0
17	2	2	2	3	3	3	3	0	0	0
18	2	3	2	3	6	5	5	0	0	0
19	2	4	3	4	5	6	5	1	0	0
20	2	3	2	3	9	9	7	0	0	0
21	2	3	3	3	9	10	9	1	0	0
22	2	4	3	3	6	6	5	0	0	0
23	2	4	2	2	6	9	7	0	0	0
24	2	3	2	3	6	6	5	0	0	1
25	2	3	2	4	5	7	5	0	0	0
26	2	4	2	4	5	7	6	0	0	0

Appendix L: Radiographical analysis (Raw data) 1

Patient number	Group 1: Convex 2: Concave	Radiographic subcrestal position					
		At surgery day		At 3 months		At 1-year	
		Mesial	Distal	Mesial	Distal	Mesial	Distal
1	1	1.81	2.5	0.76	1.09	0.69	0.89
2	1	1.81	1.26	0.96	0.66	0	0.66
3	1	0.75	1.03	1.04	0.94	1.09	0.94
4	1	1.51	1.35	1.51	1.08	0.8	0.8
5	1	1.22	1.08	1.2	0.8	1.2	0.8
6	1	1.26	1.44	0.88	0.66	0	0
7	1	2.32	1.89	2.04	1.71	1.35	1.08
8	1	1.53	1.07	1.1	0.91	0.72	0.66
9	1	1.12	2	0.85	1.38	0.8	1.2
10	1	1.2	0.96	0.76	0.72	0.76	0.72
11	1	1.2	1.01	1.15	0.83	1	0.5
12	1	0.67	1.17	0	0	0	0
13	1	0.7	0.7	0.6	0.3	0.3	0.3
14	2	2.31	2.14	2.31	2.14	2.31	2.14
15	2	2.16	1.4	2.16	1.4	2.16	1.4
16	2	1.3	1.45	0.89	1.15	0.89	1.15
17	2	0	0	0	0	0	0
18	2	1.35	1.47	1.35	1.47	1.35	1.47
19	2	1.46	2.08	1.46	1.98	1.3	1.82
20	2	0.58	0.78	0.58	0.51	0.58	0.51
21	2	2.12	1.91	1.46	1.29	1.2	1.1
22	2	1.18	1.1	1.18	0.89	1.18	0.89
23	2	1.68	1.65	1.4	1.4	1.4	1.4
24	2	1.47	1.44	0.94	1.44	0.9	1.1
25	2	1.5	1.26	1.1	1.13	1.1	1.1
26	2	1.48	1.23	1.2	1.1	0.9	0.9

Appendix M: Radiographical analysis (Raw data) 2

Patient number	Group 1: Convex 2: Concave	Radiographic Bone to first implant contact					
		At surgery day		At 3 months		At 1 year	
		Mesial	Distal	Mesial	Distal	Mesial	Distal
1	1	0	0	0	0	0	0
2	1	0	0	0	0	0	0
3	1	0	0	0	0	0	0
4	1	0	0	0	0	0	0
5	1	0	0	0	0	0	0
6	1	0	0	0	0	0	0
7	1	0	0	0	0	0	0
8	1	0	0	0	0	0	0
9	1	0	0	0	0	0	0
10	1	0	0	0	0	0	0
11	1	0	0	0	0	0	0
12	1	0	0	0	0	0	0
13	1	0	0	0	0	0	0
14	2	0	0	0	0	0	0
15	2	0	0	0	0	0	0
16	2	0	0	0	0	0	0
17	2	0	0	-0.65	-1.15	-1.1	-1.84
18	2	0	0	0	0	0	0
19	2	0	0	0	0	0	0
20	2	0	0	0	0	0	0
21	2	0	0	0	0	0	0
22	2	0	0	0	0	0	0
23	2	0	0	0	0	0	0
24	2	0	0	0	0	0	0
25	2	0	0	0	0	0	0
26	2	0	0	0	0	0	0

Appendix N: CBCT analysis (raw data) 1

Patient Number	Group Number	IP-GM	IP-BC	BC-GM	ST1	BT	ST2
1	1	2.3	0.5	1.9	2	1.3	3.3
2	1	2.1	0	2.1	1.1	0.9	2.5
3	1	3.6	0.7	3	1.4	2.4	3.8
4	1	4.1	0	4.1	2.5	0.7	3.4
5	1	2.5	0.8	1.7	1.2	2.2	3.1
6	1	3.8	0	3.8	2.3	1	3.5
7	1	3	0	3	2.1	1.7	2.6
8	1	3.3	1.8	1.5	1.7	3.3	4.5
9	1	4.1	0.9	3.2	1.3	1	1.7
10	1	3.6	1.2	2.4	2	2.4	3.5
11	1	2.6	0.8	1.8	1.2	2.4	3.2
12	1	2.9	0.2	2.6	1.6	2.1	4
13	1	4.6	1.2	3.4	2.8	2	4.7
14	2	4.9	2.8	2.1	2.1	3.5	4.9
15	2	5.5	2.8	2.7	1.4	4	4.8
16	2	2.6	0.1	2.7	1.3	2.3	4.7
17	2	0.5	-1.2	1.6	2	0.9	2.8
18	2	3.1	1.1	2	1.5	2.4	3.3
19	2	5.2	2.1	3.1	1.8	2.2	4.4
20	2	3.6	0.6	3	2.2	2.8	4.7
21	2	3.9	2.1	1.8	1.2	2.7	3.6
22	2	2.4	0.6	1.8	1.1	1.3	3
23	2	3.9	1.6	2.3	1.3	2.3	3.7
24	2	4	0.6	3.4	2.3	2.4	5
25	2	2.6	1.2	1.4	2.2	1.9	3.8
26	2	3.1	0.9	2.2	2.2	2.3	4.3

Appendix O: CBCT analysis (raw data) 2

Patient Number	Group Number	ST3	STP	fBIC	Bone on platform	AREA
1	1	1.9	4	0	1	5.6
2	1	1.6	2.9	0	0	4
3	1	1.8	5.8	0	1	7.2
4	1	1.7	5	0	0	7.2
5	1	1.6	3.5	0	1	3.2
6	1	2.2	5	0	0	7.5
7	1	1.6	3.6	0	0	4.2
8	1	3.5	5.3	0	1	5.7
9	1	1.4	4.8	0	1	4.5
10	1	2.6	4.4	0	1	5.2
11	1	1.6	3.9	0	1	3.4
12	1	2.3	4.3	0	0	5.7
13	1	2.7	6.1	0	1	10.2
14	2	3.5	6.5	0	1	6.7
15	2	2	6.7	0	1	6.4
16	2	3.5	5	-0.8	0	7.3
17	2	2.8	5.1	-1.2	0	8
18	2	2.2	4.4	0	1	3.4
19	2	3.7	6.6	0	1	11.4
20	2	3.9	4.3	0	1	13.8
21	2	2.5	5.2	0	1	4.7
22	2	2	3.5	0	1	2.8
23	2	2.3	5.1	0	1	6.4
24	2	2.9	5.6	0	0	9.2
25	2	2.3	5	0	1	3.2
26	2	2.7	4.5	0	1	4.7

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