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Abstract

Title of Thesis: The Effect of Vertical Implant Position in Relation to Interdental Crestal Bone Height of Adjacent Teeth on Implant Marginal Bone Loss: A Retrospective Radiographic Study

Chao Ji, Master of Science, 2017

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The aim of the study was to investigate the effect of vertical implant position relative to the interdental bone of adjacent teeth on implant marginal bone loss. Electronic Health Records from 2011 to 2016 were screened for subjects with tooth bound single implants. Nobel Ti-Unite implants functionally loaded for over one year were included. The vertical distance from implant platform to interdental bone levels, relative to the adjacent tooth CEJ, and the marginal implant bone level were measured on the insertion and post-treatment radiographs. A total of 178 patients with 213 single implants were included. The overall implant survival rate was 99.1% over an average of 34.8 months follow-up. The mean vertical distance from implant platform to the interdental bone level was 1.28 ± 1.04 mm mesially and 0.83 ± 1.03 mm distally. The mesial platform was consistently deeper than the distal platform, with more bone loss at the mesial surface than the distal surface.

The Effect of Vertical Implant Position in Relation to Interdental Crestal Bone Height of Adjacent Teeth on Implant Marginal Bone Loss: A Retrospective Radiographic Study

by
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Introduction

Background

Dental implants have revolutionized the treatment modalities of modern dentistry with the discovery of osseointegration of titanium chambers in rabbit tibia in 1957. Since Dr. Per-Ingvar Branemark treated the first edentulous patient in 1965 (Brånemark 1983), osseointegrated dental implants have dramatically expanded the treatment options for fully and partially edentulous patients. It is estimated that 450,000 dental implants are being placed every year and the number keeps growing. (Gaviria et al. 2014)

Dental implants were first used to treat fully edentulous patients and have been shown to be highly effective with predictable long-term results. (Adell et al. 1990) Following the Branemark protocol, osseointegrated implants were later used to treat partially edentulous jaws with excellent survival rates and stable crestal bone levels over long-term follow-up. (Lekholm et al. 1999) Single tooth implants have also been proven to be a highly predictable and conservative treatment option, particularly when the adjacent teeth are relatively intact. (Jemt & Pettersson 1993) (Haas et al. 1995)

Early Implant Marginal Bone Loss

However, dental implants are not problem-free. One major and growing problem is the bone loss around dental implants. The stability of peri-implant marginal bone level has long been regarded as one of the criteria of implant success. (Albrektsson et al. 1986; Galindo-Moreno et al. 2015) Crestal bone loss around dental implants can be categorized as early or late bone loss. Early crestal bone loss usually occurs within the first year of function, followed by a minimal rate of bone resorption ($\leq$0.2 mm) annually thereafter. (Albrektsson et al. 1986) Factors affecting early implant crestal bone loss include: surgical trauma, formation of biologic width, and presence of a microgap between the implant platform and abutment. (Oh et al. 2002) (Qian et al. 2012)

Surgical Trauma

It has been demonstrated in an animal model that overheating the bone during implant site preparation contributes to implant failure. The critical temperature was 47°C for 1 minute or 40°C for 7 minutes. (Eriksson & Albrektsson 1984) Furthermore, a net loss of 0.8 mm crestal bone height can be noted six months after the osseous surgery. (Wilderman et al. 1970) Therefore, whenever a mucoperiosteal flap as part of implant placement is raised during implant surgery, crestal bone loss is anticipated.

Formation of Biologic Width

Gargiulo et al evaluated 287 teeth in 30 human jaws and found a consistent dimension of supracrestal tissues, consisting of 1.07 mm connective tissue, 0.97 mm junctional epithelium, and 0.69 mm sulcus depth. This is regarded as the biologic width around natural teeth. (Gargiulo et al. 1961) Similar to teeth, a biologic width exists around dental implants, consisting of junctional epithelium by means of hemidesmosomal attachment and connective tissue with collagen fibers running parallel to the implant surface. (Bauman et al. 1993) Abrahamsson et al found a consistent dimension of biologic width among different implant systems and different surgical protocols, one-stage or two-stage implant placement. The biologic width was on average 3.11-3.50 mm coronal to the crestal bone around implants. (Abrahamsson et al. 1996) Hermann et al found the biologic width around non-submerged one-piece implants to be stable over one-year loading. (Hermann et al. 2000) Berglundh and Lindhe performed two-stage implant surgeries on beagle dogs. They purposefully dissected a significant amount of connective tissue along with periosteum on the inside of the flap during second stage implant surgery of test implants, and performed routine second stage surgery around control implants. After six months a similar dimension of biologic width around control and test implants was found, which consisted of 2.1 mm and 2 mm junctional epithelium, and 1.8±0.4 mm and 1.3±0.3 mm connective tissue around control and test implants, respectively. More importantly, there was consistent a crestal bone resorption observed around test implant whose supracrestal soft tissue thickness was thin (≤2 mm), with consequent angular bone defect formation. (Berglundh & Lindhe 1996) Their findings suggested that a minimum dimension of supracrestal soft tissue is required to protect osseointegration. The crestal bone loss is attributed to the thin soft tissue and the subsequent formation of biologic width around implants. It would be logical to thicken the peri-implant soft tissue to prevent crestal bone loss, as shown by Linkevicius et al. (Linkevicius et al. 2015) Their team thickened the mucosal tissue with allogenic membrane during implant placement and showed significantly less crestal bone resorption over 1 year compared to implants with thin mucosal tissues.

The Microgap Between Implant Platform and Abutment

Conventional Branemark implants involve placement of submerged implants at the bone level before a second stage surgery to connect the abutment over the implants. The connection between implant platform and abutment results in a potential microgap. Single stage non-submerged implant placement with transgingival healing was advocated by Schroeder and his team, and has been shown to have excellent success rate with 8 years follow-up. (Buser et al. 1997) Hermann et al. compared the crestal bone changes between nonsubmerged and submerged implants in canine mandibles, and discovered that submerged implants demonstrate more crestal bone resorption than their nonsubmerged counterpart. (Hermann et al. 1997) They suggested that the location of the microgap of the abutment connection had a significant effect on crestal bone level which is consistently located approximately 2 mm below the microgap. Quirynen and Van Steenberghe have demonstrated that the abutment screws could harbor large amounts of microorganisms over three months. (Quirynen & van Steenberghe 1993) The microgap is proposed to be a source of microbial leakage between the implant platform and abutment of the submerged implants, through which the microorganisms can seep from the abutment screw to the peri-implant tissues.

When moving the implant-to-abutment connection inward toward the center of the implant, the microgap is placed farther away from the surrounding bone and its effect on implant marginal bone loss is reduced. This is referred to as "platform-switched" implants. (Lazzara & Porter 2006) It was demonstrated in a multicenter randomized clinical trial that platform-switched implants maintained or even enhanced the crestal bone level compared to platform-matched implants over one-year period. (Guerra et al. 2014) In a meta-analysis performed, Byrne also showed that platform-switched implants preserved crestal bone height by 0.37 mm compared with platform-matched counterparts. (Byrne 2012)

Peri-implantitis

Late implant bone loss after the first year of function is usually regarded as "peri-implantitis". Peri-implantitis is characterized by an inflammatory process around an implant, which involves both soft tissue inflammation and progressive loss of supporting bone beyond biological bone remodeling. (Anon 2003) The high prevalence of peri-implantitis has shifted the dental clinician's attention from osseointegration to the diagnosis and management of bone loss around dental implants. The prevalence of peri-implantitis ranges from 11.3% to 47.1% among studied subjects. (Koldsland et al. 2010)

In a recent large-scale 9-year retrospective analysis of dental implants of a Swedish population, 45% of the subjects presented with peri-implantitis and 14.5% suffered from moderate to severe peri-implantitis. The implants with moderate to severe peri-implantitis lost an average of 30% of their original bone support at the 9-year follow-up. (Derks, Schaller, Hakansson, Wennström, Tomasi & Berglundh 2016a) Peri-implantitis around anterior implants undoubtedly can cause esthetic problems, including gingival recession and metal display through the gingivae. Posterior implants with peri-implantitis usually come with deep probing depths and consequent maintenance issues. Various risk factors have been proposed for peri-implantitis related bone loss, including smoking, history of periodontitis, diabetes, occlusal overload, residual cement and implant surface characteristics. (Anon 2013a)

Smoking

Smoking is regarded as the most significant risk factor for dental implant failure. (Bain & Moy 1993; Chen, Liu, Xu, Qu & Lu 2013b) It is also related to peri-implant crestal bone loss over short term (1-year), medium term (6-year) and long term (up to 15-year) follow-up. (Peñarrocha et al. 2004; Manz 2000; Carlsson et al. 2000) Lindquist et al pointed out that smoking was the most important risk factor for crestal bone loss around mandibular implants. (Lindquist et al. 1997) DeLuca et al in a 20-year follow-up found smoking to be a significant factor for peri-implant crestal bone loss after the first year of clinical loading, with an average of 0.032 mm more annual bone loss than non-smokers. (DeLuca & Zarb 2006) It was reported in a systematic review by Heitz-Mayfield et al that smokers had an increased risk of peri-implantitis than that of nonsmokers, with odds ratios ranging from 3.6 to 4.6. (Heitz-Mayfield & Huynh-Ba 2009)

History of Periodontitis

Although a number of reviews have shown that periodontally compromised patients have favorable short-term and long-term implant survival rates, they do exhibit greater peri-implant marginal bone loss and higher incidence of peri-implantitis. (Anon 2013c; Schou et al. 2006; Karoussis et al. 2007; Derks, Schaller, Hakansson, Wennström, Tomasi & Berglundh 2016a; Safii et al. 2009) Schou et al reported that patients with periodontitis-associated tooth loss had a significantly higher risk of suffering from peri-implantitis, with a risk ratio of 9 during 10-year follow-up. These patients experienced on average 0.5 mm more peri-implant marginal bone loss over 5 years than patients with non-periodontitis-associated tooth loss. (Schou et al. 2006) Safii et al showed that periodontitis subjects experienced an average of 0.61 mm more marginal bone loss than periodontally healthy subjects in their meta-analysis. (Safii et al. 2009) Heitz-Mayfield et al reported that patients with a history of treated periodontitis had a higher risk of peri-implantitis than those without a history of periodontitis, with odds ratios ranging from 3.1 to 4.7. (Heitz-Mayfield & Huynh-Ba 2009) Patients with a history of chronic periodontitis have greater long-term pocket depth and peri-implant bone loss than periodontally healthy subjects. Karoussis et al pointed out that alterations in clinical parameters around implants in aggressive periodontitis patients may not follow the same pattern as patients with chronic periodontitis. (Karoussis et al. 2007) Kim et al reviewed seven prospective studies in the systematic review, and showed that implants in patients with generalized aggressive periodontitis exhibit significantly greater marginal bone loss than patients with chronic periodontitis in long-term studies. (K.-K. Kim & Sung 2012) The meta-analysis by Monje et al showed that patients with aggressive periodontitis experience more frequent implant failure when compared with those with chronic periodontitis, with a risk ratio of 3.97. (Monje et al. 2014) In a 10-year study of partially edentulous patients with generalized aggressive periodontitis, implants placed in this cohort exhibited higher bone and attachment loss than periodontally healthy patients. (Mengel et al. 2007) Overall, there is limited information regarding the prevalence and incidence of peri-implantitis in individuals with a history of aggressive periodontitis.

Diabetes

Due to few available studies, there is limited evidence of an association of peri-implantitis and diabetes. (Anon 2013b) Moy et al looked into a total of 4680 implants placed in 1140 patients over 20 years and found that diabetes was significantly associated with implant failure with a relative risk ratio of 2.24. (Moy et al. 2005) Systematic reviews have shown that poor diabetic control is associated with an increased risk of developing peri-implantitis. (Renvert & Quirynen 2015; Naujokat et al. 2016) Furthermore, a recent meta-analysis found that the risk of peri-implantitis was about 50% higher in diabetic patients than non-diabetic patients. Among non-smokers, those with hyperglycemia had a 3.39-fold higher risk for peri-implantitis when compared with those with normal glucose level. (Monje et al. 2017)

Occlusal Overload

The relationship between occlusal overload and crestal bone loss remains controversial due to limited animal studies and lack of human clinical studies with a high level of quality. (Naert et al. 2012) In Isidor's monkey study, implant-retained prostheses were delivered in supra-occlusion to induce nonaxial overloaded occlusal forces. 5 out of 8 implants with occlusal overload failed over 4.5 to 15.5 months of function, and one implant had bone loss up to 50%. The remaining two implants with overload, on the other hand, showed increased bone density with highest bone-to-implant contact. (Isidor 1997) This author later stated that no causative relationship could be found, but only an association between occlusal overload and crestal bone loss around implants could be established. (Isidor 2006)

Residual Cement

Cement-retained implant restorations are common in daily practice because of its relative simplicity and better esthetics when compared with screw-retained restorations, particularly for single-tooth implant restorations. (Chee et al. 1999) However, excess cement has been related to crestal bone loss around implants and even implant failure. Although subgingival placement of crown margins of the abutment offers better crown emergence profile, it poses a greater risk of residual excess cement. (Linkevicius, Vindasiute, Puisys & Peciuliene 2011b) Up to 80% of the implants with clinical signs of gingival inflammation were found to have residual cement when evaluated by dental endoscope. The removal of the cement eliminated clinical inflammation among the majority of the implants. (Wilson 2009) Despite the unfavorable effect of residual cement on peri-implant soft tissue conditions, a recent long-term follow up study favored cement-retained restorations from both a biological and clinical aspect. (Nissan et al. 2011) Similar conclusions were drawn in a recent systematic review and meta-analysis, indicating less marginal bone loss around cement-retained restorations than screw-retained ones. (Lemos et al. 2016)

Implant Surface Characteristics

There has been significant advancement in implant surface characteristics since 1965. The quality of the implant surface is associated with bone healing around implants. (Albrektsson et al. 1981) The Branemark team featured smooth, machined surface implants while the Schroeder International Team for Implantology started with a titanium plasma-sprayed roughened implant surface. (Buser et al. 2017) There has been a shift from the use of the original Branemark machined surface implant to a roughened surface implant. This has been supported by various experiments that have shown a positive correlation between implant surface roughness and bone-to-implant contact, as well as the mechanical push-out strength. (Shalabi et al. 2006) Historically, the hydroxyapatite-coated implant surface showed a high roughness with optimal bone-to-implant contact values. However, the dislodgement of the hydroxyapatite coating contributed to significant peri-implant bone resorption and was therefore withdrawn from the market.

(Buser et al. 2017) A moderately roughened surface has become the current trend, with different implant companies featuring different characteristics. Wennerberg and Albrektsson reviewed the implant surfaces of several popular implant brands. Nobel Biocare implants feature the TiUnite surface by anodizing the implant in the phosphoric acid. Straumann SLA implants are sandblasted with large-grit particles followed by an acid-etching procedure. Astra Tech TiOblast implants are blasted with small micron-sized titanium dioxide particles. (Wennerberg & Albrektsson 2010) In a recent meta-analysis, the marginal bone level change after 5 years in function were evaluated for the three most popular implant systems, namely Nobel Biocare, Straumann and Astra implants. There was a statistically significant difference among these three implant systems with regard to the marginal bone level change, with Nobel Biocare implants showing the most significant bone loss over 5 years and greater than Straumann and Astra implants. (Laurell & Lundgren 2011) Kim et al evaluated 979 anodized implants and 1207 sandblasting surface implants, and found that anodized implants exhibited more progressive bone loss than the sandblasted surface implants, with an odds ratio of 4.4. (H.-C. Kim et al. 2017)

Bone Remodeling and Ridge Augmentation

Bone resorption occurs after tooth extraction. (Pietrokovski & Massler 1967) Schropp found 50% ridge width reduction within the first year post-extraction and soft tissue height reduction occurs mostly in the first three months post-extraction and ranges from 0.1 mm to 0.8 mm. (Schropp et al. 2003) In a mongrel dog model, there was substantial reduction in ridge volume six months after a single tooth extraction. A 35% surface area reduction of the coronal portion of the ridge was noted with both horizontal and vertical bone resorption. (Araújo & Lindhe 2009) Araujo and his team compared the buccal and palatal crestal bone height reduction with or without the use of graft materials. After 4 months, they recorded an average of 5.6 mm and 5.8 mm buccal wall reduction in height of test and control groups, respectively, corresponding to 36% and 41% height reduction. Palatal wall height reduction was less, at 13% in both test and control groups. There was a net loss of ridge height by 4.9 mm in the anterior sites, and 3.1 mm in premolar regions. (Araújo et al. 2014) Nevins et al conducted an interesting study of ridge dimension change over a three month period after extraction of teeth with prominent roots. The buccal bone height was measured at the level where the ridge width on cross section measured 6 mm, which was considered sufficient for implant placement. Their study showed 5.24 mm buccal bone height loss without site preservation, and 2.42 mm height loss when sites were grafted with BioOss® xenograft. (Nevins et al. 2006) A recent systematic review showed an average of 3.87 mm reduction in ridge width and 1.67 mm reduction in mid-buccal height clinically. (Van der Weijden et al. 2009) Alveolar ridge preservation is a technique of using bone graft, barrier membrane or a combination of both at the time of the tooth extraction. The horizontal and vertical ridge resorption can be reduced by alveolar ridge preservation, as shown in a recent systematic review and meta-analysis. Avila-Ortiz et al has shown that the alveolar ridge preservation reduces the ridge reduction by 1.89 mm in buccolingual width and 2.07 mm in midbuccal height. (Avila-Ortiz et al. 2014)

In conditions where the existing ridge dimension is insufficient to encase the implant entirely, the application of ridge augmentation can be applied in either a simultaneous approach at the time of implant placement or a staged approach. (Buser et al. 1993) Many studies have shown no difference in survival rates of implants placed in pristine or augmented sites. Buser et al demonstrated in a dog model that all the implants achieved successful osseointegration and functional loading over 12 months in sites with guided bone regeneration (GBR). (Buser et al. 1995) Fugazzotto reported an overall implant survival rate of 97% with a total of 574 implants placed in 302 augmented ridges in a private periodontics practice. (Fugazzotto 1998) A recent retrospective analysis of 10000 implants showed a 96.33% survival rate of implants placed in augmented sites over 20 years, comparable to those placed in native sites. (Knöfler et al. 2016)

Apico-coronal Position of Implant Placement

The recommended depth of implant placement is 3 mm apical to the planned gingival zenith, which allows for the development of an appropriate emergence profile. (COOPER 2008) However, physiologic bone resorption after tooth extraction results in the placement of an implant in a more apical position, due to the pre-existing vertical ridge defect and/or the unevenness of the edentulous ridge. Placing the implant too deep is of concern to clinicians because of anecdotal evidence of maintenance difficulty. (Wadhwani 2013) This is true of the natural dentition as shown by Stambaugh et al that nonsurgical instrumentation is less effective with pockets deeper than 3.7 mm. (Stambaugh et al. 1981) Deeper potential probing depth will harbor more anaerobic gram-negative bacteria which can contribute to peri-implant disease. (Wadhwani 2013) Furthermore, when implants are placed apical relative to the interdental bone of adjacent teeth, an angular bony defect is often created around the implants. In cases of natural teeth, angular bony defects are associated with deep periodontal pockets. (Koop et al. 2012) Teeth with deep pockets have higher risk for periodontal destruction and tooth loss. (Hirschfeld & Wasserman 1978; Kwok & Caton 2007) Moreover, Steffensen and Weber found that the angle of an angular defect around natural teeth was correlated with the radiographic changes in alveolar bone level after modified Widman Flap surgery. Defects with an angle less than 45 degrees showed bone gain while defects with wider angles showed bone loss. (Steffensen & Webert 1989) Reynolds et al also pointed out that narrow intrabony defects around teeth usually responds well to regenerative treatment. (Reynolds et al. 2015) However, apically positioned implants with angular bony defects have not been thoroughly investigated in terms of their marginal bone stability.

To the author's knowledge, there are to date only a few studies that have investigated the effect of the vertical distance from the adjacent teeth and implant platform on the peri-implant crestal bone level. Esposito et al evaluated the marginal bone loss at single Branemark implants and adjacent tooth surfaces. (Esposito et al. 1993) Cardaropoli et al investigated the Branemark implants placed distal to a natural tooth. (Cardaropoli et al. 2003) Both groups concluded that the apico-coronal position of implant platform was not a factor affecting the crestal bone level at either the implant or tooth surfaces over a 3-year follow-up. A prospective study of single Branemark implants demonstrated a correlation between marginal bone loss at tooth surfaces facing the implants and the vertical distance between the levels of implant platforms and cemento-enamel junctions (CEJs) of adjacent teeth during the time of crown cementation through the 1-year follow-up. (Andersson et al. 1995) However, the implants investigated in these studies were Branemark machined surface implants that are rarely used today. Simion et al even suggested that the old machined surface implants were less susceptible to marginal bone loss and thus experienced a lower incidence of peri-implantiits than the roughened surface implants. (Simion et al. 2014) A more recent study by Mailoa et al retrospectively evaluated rough surface implants placed distal to the natural dentition over a period of 4.42 years. More peri-implant bone loss was found when implants were placed deeper than 3 mm from the CEJs of adjacent teeth, compared to those implants with a vertical distance less than 3 mm from the CEJs of adjacent teeth. (Mailoa et al. 2015)

To date, there has been no study to evaluate the influence of the apico-coronal position of roughened surface implants in relation to the interdental bone height on the crestal bone level around implants and adjacent teeth.

Purpose

The purpose of this retrospective radiographic study was to investigate the effect of vertical implant position relative to the interdental bone height of adjacent teeth on the marginal bone loss around implants and adjacent teeth.

Materials and Methods

Data Collection

This retrospective radiographic study was approved by the Institutional Review Board of University of Maryland (HP-00072250). Patient's electronic health records containing the American Dental Association (ADA) code D6010 for implant placement from 2011 to 2016 were originally screened from the University of Maryland School of Dentistry (UMSOD) clinics for subjects with tooth bound restored implants. (Blair 2015)

The following criteria were met to be included in the subject population.

- No uncontrolled systemic condition at the time of implant surgery
- Single implant restoration with natural teeth present on both sides throughout the follow-up period
- The implant was restored with a fixed crown that was functionally loaded for no less than one year.
- Nobel Biocare TiUnite surface implants
- Undistorted and sharp periapical and/or bitewing digital radiographs available at the time of implant placement (T1), crown delivery (T3) and the most recent follow-up (T4) for no less than one year

Subjects/implants were excluded if they had the following conditions.

- Uncontrolled systemic disease or a history of aggressive periodontitis
- Implant-supported crown that had been functionally loaded for less than one year

- Distorted or unclear digital radiographs of the implant, adjacent teeth or the crestal bone level
- Missing radiographs at the time of implant placement, crown delivery and the most recent follow-up
- Implants other than Nobel Biocare TiUnite surface implants

In case the adjacent tooth was extracted after the implant was functionally loaded for one year, the implant was still included when the most recent intraoral radiograph was taken prior to the extraction of adjacent tooth, and fulfilled all the other inclusion criteria.

For patients receiving more than two implants, only the earliest implant placed was included. If more than two implants were placed at the same earliest time point, only one implant was randomly selected.

The following information was collected for each subject and implant.

- Implant type and location
- Gender
- Age at the time of implant placement
- Date of implant placement, second stage implant surgery if necessary, crown delivery and the most recent follow-up with intraoral radiographs taken
- Medical history of diabetes and smoking status
- Dental history, including the reason for tooth loss, history of periodontitis, history of site preservation at the time of extraction, history of bone grafting procedure

either prior to or at the time of implant placement, timing of implant placement, detailed information about the implant placed, loading protocol and type of restoration.

- History of periodontitis: this was determined by reviewing the past history of periodontal treatment, the periodontal chartings and the radiographs. The subject was deemed to have a history of periodontitis if he/she had received scaling and root planning and/or any form of periodontal surgery, and/or periodontal charting exhibiting sites with deeper than 3 mm probing depth, clinical attachment loss and radiographic signs of alveolar bone loss prior to the implant placement. (Armitage 1999)
- History of site preservation: this was determined by reviewing whether such codes as D7953 (Bone replacement graft for ridge preservation), D4263 (Bone replacement graft), D4266 (Guided tissue regeneration – Resorbable barrier) or D4267 (Guided tissue regeneration – Non-resorbable barrier) were put in at the time of tooth extraction D7140 (Extraction, erupted tooth or exposed root) or D7210 (Surgical removal of erupted tooth), and by going through the chart notes.
- History of ridge augmentation procedure prior to implant placement: this was determined by reviewing whether such codes as D7950 (Ridge augmentation graft – edentulous area), D7951 (Sinus augmentation via a lateral window approach), D4263, D4266, D4267 were put in between the time of extraction and implant placement, and by going through the chart notes.

- History of bone graft procedure at the time of implant placement: this was determined by reviewing whether such codes as D6104 (Bone graft inserted at same time of implant placement), D4263, D7952 (Sinus augmentation via a vertical approach), D4266 or D4267 were put in at the time of implant placement, and by going through the chart notes.
- Timing of implant placement: this information was obtained by going through the chart note and comparing the dates of tooth extraction and implant placement
    - Immediate implant placement: same day
    - Early implant placement: 0-3 months after tooth extraction
    - Delayed implant placement: >3 months after tooth extraction
- Detailed information about the Nobel Biocare implant: this information was obtained by going through the chart note and the scanned implant material forms in the electronic health records
- Loading protocol: this information was obtained by going through the chart note and the radiographs
    - Immediate protocol: the provisional restoration was inserted on the same day of implant placement
    - Conventional protocol: no provisional restoration was provided and the final restoration was inserted following a conventional protocol
- Type of restoration: chart notes and radiographs were retrieved to ascertain the type of restoration, screw-retained or cement-retained.

- Intra-oral radiographs of the implants at the time of placement, second stage implant surgery if necessary, crown delivery and the most recent follow-up.

Measurements

All the digital radiographs were exported as jpeg format digital images. The images were evaluated with an open source software package (ImageJ, U.S. National Institutes of Health) on a 13-inch MacBook Pro Laptop. (Mailoa et al. 2015) The images were viewed in full-screen mode for better visualization. Calibration was made with reference to the known implant diameter and length. A built-in digital caliper in the software was used for all linear measurements. Pixel values of a given linear measurement were converted to millimeters after the calibration. The measurements were performed twice at two different occasions, two weeks apart for the evaluation of intra-examiner reliability.

Each time point will include at least one bitewing and/or periapical radiograph. A minimum of three intraoral radiographs were evaluated for each implant. Due to the retrospective nature of the study, the intraoral radiographs were not standardized. Radiographs taken with the best parallelism to the implants and teeth were selected.

The following landmarks were identified (*Figures 1, 2, 3)*:

Point CEJ-m: the distal CEJ of the tooth mesial to the implant. In case of restoration or crown on the tooth, the restorative margin will be used if the distal CEJ is not identifiable on the radiograph.

Point CEJ-d: the mesial CEJ of the tooth distal to the implant. In case of restoration or crown on the tooth, the restorative margin was used if the distal CEJ was not identifiable on the radiograph.

Point IDB-m: the distal crestal bone level of the tooth mesial to the implant

Point IDB-d: the mesial crestal bone level of the tooth distal to the implant

Point PLT-m: the mesial end of the implant platform

Point PLT-d: the distal end of the implant platform

Point BTI-m: the first bone-to-implant contact to the mesial surface of the implant

Point BTI-d: the first bone-to-implant contact to the distal surface of the implant

<u>**Line CEJ-m to CEJ-d:**</u> the line connecting the CEJs and/or restorative margins of adjacent teeth

<u>**Line IDB-m to IDB-d:**</u> the ideal horizontal bone level of the edentulous space without any vertical defect

<u>**Angle-m:**</u> the angle of the mesial implant surface and the crestal bone contour

<u>**Angle-d:**</u> the angle of the distal implant surface and the crestal bone contour

<u>**Distance PLT-IDB-m:**</u> the distance from ***Point PLT-m*** to <u>**Line IDB-m to IDB-d**</u>, indicative of the vertical position of the mesial end of the implant platform in relation to the interdental crestal bone height. It was measured by extending the ***Point PLT-m*** along the long axis of the implant to <u>**Line IDB-m to IDB-d**</u>.

<u>**Distance PLT-IDB-d:**</u> the distance from ***Point PLT-d*** to <u>**Line IDB-m to IDB-d**</u>, indicative of the vertical position of the distal end of the implant platform in relation to the interdental crestal bone height. It was measured by extending the ***Point PLT-d*** along the long axis of the implant to <u>**Line IDB-m to IDB-d**</u>.

Distance PLT-CEJ-m: the distance from ***Point PLT-d*** to **Line CEJ-m to CEJ-d**, indicative of the vertical position of the mesial end of the implant platform in relation to the CEJs of adjacent teeth. It was measured by extending the ***Point PLT-m*** along the long axis of the implant to **Line CEJ-m to CEJ-d**.

Distance PLT-CEJ-d: the distance from ***Point PLT-d*** to **Line CEJ-m to CEJ-d**, indicative of the vertical position of the distal end of the implant platform in relation to the CEJs of adjacent teeth. It was measured by extending the ***Point PLT-d*** along the long axis of the implant to **Line CEJ-m to CEJ-d**.

Distance HD-m: the horizontal distance from the tooth mesial to the implant to the implant platform.

Distance HD-d: the horizontal distance from the tooth distal to the implant to the implant platform.

Distance CEJ-IDB-m: distance from CEJ of the tooth mesial to the implant to the crestal bone level of the tooth, indicative of the periodontal bony support of the tooth mesial to the implant.

Distance CEJ-IDB-d: distance from CEJ of the tooth distal to the implant to the crestal bone level of the tooth, indicative of the periodontal bony support of the tooth distal to the implant.

Distance PLT-BTI-m: the vertical distance between the implant platform to the first bone-to-implant contact at the mesial implant surface

Distance PLT-BTI-d: the vertical distance between the implant platform to the first bone-to-implant contact at the distal implant surface

For radiographs taken at the time of implant placement (T1), crown delivery (T3) and the most recent follow-up (T4), all the points identified: **Angle-m** and **Angle-d**, **Distance PLT-IDB-m** and **Distance PLT-IDB-d** were measured at T3. **Distance HD-m**, **Distance HD-d**, **Distance PLT-CEJ-m** and **Distance PLT-CEJ-d** were measured at any time point of the available radiographs, whichever radiograph gave the best parallelism and undistorted images of the teeth and implant, and preferable a bitewing radiograph. **Distance CEJ-IDB-m**, **Distance CEJ-IDB-d**, **Distance PLT-BTI-m** and **Distance PLT-BTI-d** were measured at T3 and T4. The bone loss between T3 and T4 was calculated as the differences between these four pairs of distances, presented as **ΔCEJ-IDB-m-T43**, **ΔCEJ-IDB-d-T43**, **ΔPLT-BTI-m-T43** and **ΔPLT-BTI-d-T43**.

Statistical Analysis

The mesial and distal aspects of each implant and adjacent tooth were treated as the unit of statistical analysis. Descriptive statistics were prepared for all demographic data at the subject and implant levels (mean ± SD). A multi-level logistic regression model was constructed to evaluate the effect of various subject-related and implant-related factors on the bone loss around implants and adjacent teeth. The following independent variables were analyzed using multi-level analyses:

- History of diabetes
- History of periodontitis
- Smoking status
- Age at which implants were received
- Reasons for tooth extraction

- Time of implant placement
- Length of follow-up
- Platform-switched or platform-matched
- Type of restoration
- Depth of implant platform in relation to interdental crestal bone height and CEJs of adjacent teeth
- Angle of the implant surface and bone contour
- Horizontal distance from implant surface to adjacent teeth

Paired t-test was used to compare the difference between the mean depth of mesial and distal ends of the implant platform, and the difference between the mesial and distal bone loss around implants. A p-value ≤ 0.05 was considered significant.

Intra-examiner reliability was evaluated by conducting Pearson correlation tests on the measurements performed at two occasions. The coefficients ranged from 0.75 to 0.84, suggesting a good correlation between the two measurements.

Data analysis was performed with Dell™ Statistica™ 13.0.

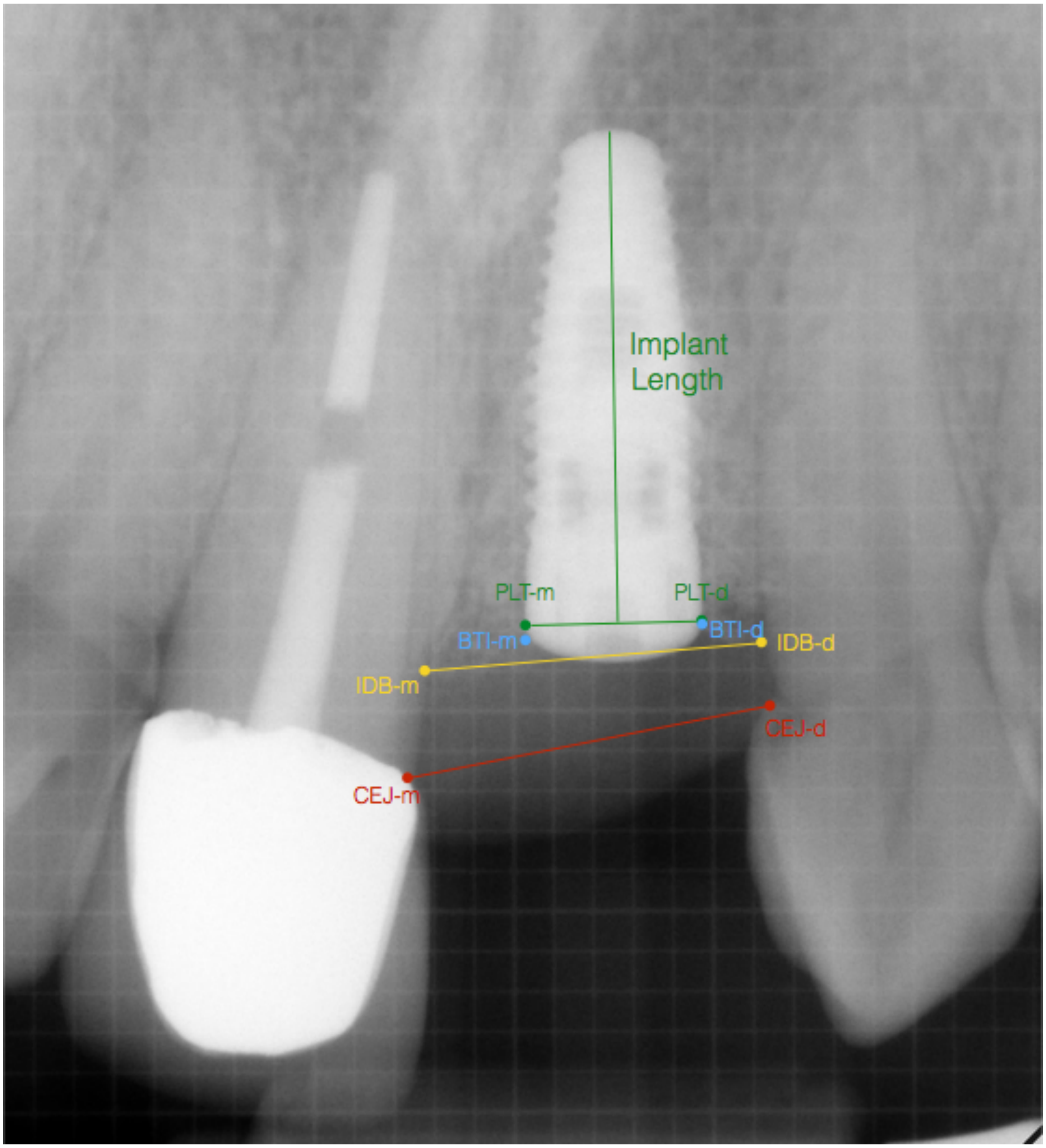

Figure 1: Radiograph taken at the time of #9 implant placement, T1.
Point CEJ-m: the distal CEJ of the tooth mesial to the implant. In this case the crown on the tooth, the restorative margin is used. ***Point CEJ-d:*** the mesial CEJ of the tooth distal to the implant. ***Point IDB-m:*** the distal crestal bone level of the tooth mesial to the implant. ***Point IDB-d:*** the mesial crestal bone level of the tooth distal to the implant. ***Point PLT-m:*** the mesial end of the implant platform. ***Point PLT-d:*** the distal end of the implant platform. ***Point BTI-m:*** the first bone-to-implant contact to the mesial surface of the implant. ***Point BTI-d:*** first bone-to-implant contact to the distal surface of the implant

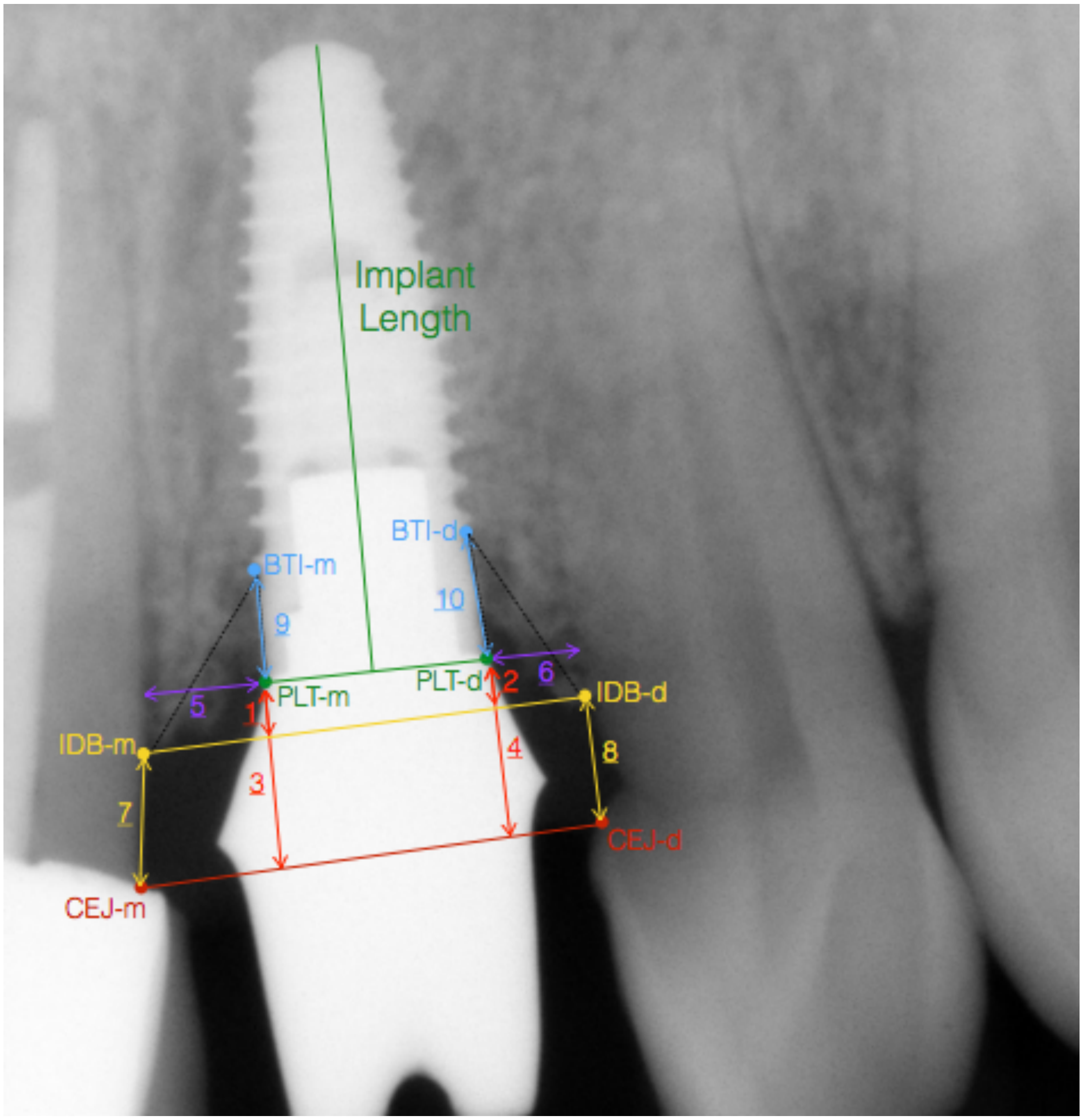

Figure 2: Radiograph taken at the time of #9 crown delivery, T3. ***Point CEJ-m:*** the distal CEJ of the tooth mesial to the implant. In this case the crown on the tooth, the restorative margin is used. ***Point CEJ-d:*** the mesial CEJ of the tooth distal to the implant. ***Point IDB-m:*** the distal crestal bone level of the tooth mesial to the implant. ***Point IDB-d:*** the mesial crestal bone level of the tooth distal to the implant. ***Point PLT-m:*** the mesial end of the implant platform. ***Point PLT-d:*** the distal end of the implant platform. ***Point BTI-m:*** the first bone-to-implant contact to the mesial surface of the implant. ***Point BTI-d:*** first bone-to-implant contact to the distal surface of the implant. **Angle-m (Angle IDB-m – BTI-m – PLT-m):** the angle of the mesial implant surface and the crestal bone contour. **Angle-d (Angle IDB-d – BTI-d – PLT-d):** the angle of the distal implant surface and the crestal bone contour **1. Distance PLT-IDB-m:** the vertical position of the mesial end of the implant platform in relation to the interdental crestal bone height. **2. Distance PLT-IDB-d:** the vertical position of the distal end of the implant platform in relation to the interdental crestal bone height. **3. Distance PLT-CEJ-m:** the vertical position of the mesial end of the implant platform in relation to the CEJs of adjacent teeth. **4. Distance PLT-CEJ-d:** the vertical position of the distal end of the implant platform in relation to the CEJs of adjacent teeth. **5. Distance HD-m:** the horizontal distance from the tooth mesial to the implant to the implant platform. **6. Distance HD-d:** the horizontal distance from the tooth distal to the implant to the implant platform. **7. Distance CEJ-IDB-m:** the periodontal bony support of the tooth mesial to the implant. **8. Distance CEJ-IDB-d:** indicative of the periodontal bony support of the tooth distal to the implant. **9. Distance PLT-BTI-m:** the vertical distance between the implant platform to the first bone-to-implant contact at the mesial implant surface. **10. Distance PLT-BTI-d:** the vertical distance between the implant platform to the first bone-to-implant contact at the distal implant surface

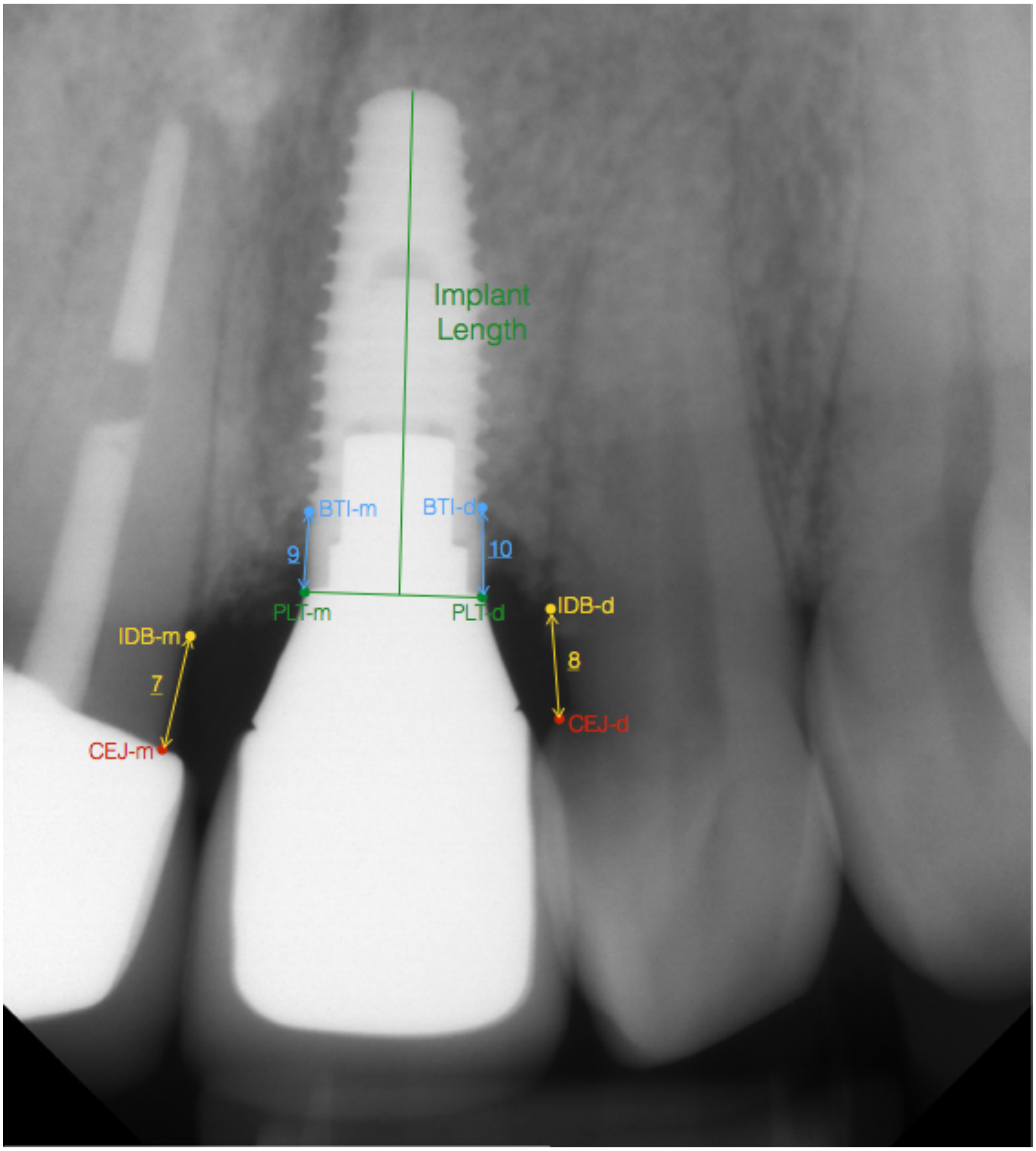

Figure 3: Radiograph taken at the most recent follow up of #9 implant, T4. ***Point CEJ-m:*** the distal CEJ of the tooth mesial to the implant. In this case the crown on the tooth, the restorative margin is used. ***Point CEJ-d:*** the mesial CEJ of the tooth distal to the implant. ***Point IDB-m:*** the distal crestal bone level of the tooth mesial to the implant. ***Point IDB-d:*** the mesial crestal bone level of the tooth distal to the implant. ***Point PLT-m:*** the mesial end of the implant platform. ***Point PLT-d:*** the distal end of the implant platform. ***Point BTI-m:*** the first bone-to-implant contact to the mesial surface of the implant. ***Point BTI-d:*** first bone-to-implant contact to the distal surface of the implant. **7. Distance CEJ-IDB-m:** the periodontal bony support of the tooth mesial to the implant. **8. Distance CEJ-IDB-d:** indicative of the periodontal bony support of the tooth distal to the implant. **9. Distance PLT-BTI-m:** the vertical distance between the implant platform to the first bone-to-implant contact at the mesial implant surface. **10. Distance PLT-BTI-d:** the vertical distance between the implant platform to the first bone-to-implant contact at the distal implant surface

Results

This pilot study reviewed all electronic patient records identified with the ADA code D6010 between 2011 and 2016 with record numbers under #20000. A total of 637 tooth bound single implants were identified. With further screening, a total of 178 patients and 213 single implants fulfilled the inclusion criteria.

Among the excluded 424 implants, 143 implants (33.7%) had insufficient follow-up time, including 5 implants that failed during healing or within one year of function. 39 implants (9.2%) had no radiographs available at the time of implant placement, 28 implants (6.6%) had no radiographs available at the time of crown delivery, 176 implants (41.5%) had no follow-up radiographs, and 10 implants (2.4%) had no radiographs at the time of crown delivery and the follow-up. 11 implants (2.6%) had radiographs that did not fulfill the diagnostic value, including distorted and nonparallel radiographs, radiographs not capturing the implant platform, the implant bone level or the bone level of adjacent teeth. 15 implants (3.5%) were excluded from six patients who have received more than two implants. 2 implants (0.5%) were excluded from one patient who had a history of aggressive periodontitis. (Table 1)

Table 1: Numbers of included and excluded implants and distribution of exclusion categories

Total number of single implants	637
Number of included implants	213
Number of excluded implants	424
Reasons for exclusion	
Insufficient follow-up time	143
No radiograph at the time of implant placement	39
No radiograph at the time of crown delivery	28
No follow-up radiograph	176
No radiograph at the time of crown delivery and the follow-up	10
Radiograph of no diagnostic value	11
Implants from patients receiving more than two implants	15
Implants placed in patient with a history of aggressive periodontitis	2

Patient Demographic Data

There were a total of 178 subjects consisting of 94 males (52.8%) and 84 females (47.2%). The mean age at the time of dental implant placement was 60.6 ± 11.4 years old. The youngest patient receiving dental implants was 21 years old and the oldest was 88 years old. 19 patients (10.7%) had diabetes mellitus. 6 patients (3.4%) were current smokers at the time of implant placement, and 5 patients (2.8%) reported having quit smoking prior to the implant placement. With regard to the history of periodontitis, 39 patients (21.9%) had chronic periodontitis. 35 subjects (19.7%) had two implants included, and the remaining 143 patients (80.3%) had one implant included in the study. (Table 2)

Table 2: Patient Demographic Data

	Patients n=178, (%)
Gender	
Male	94, (52.8%)
Female	84, (47.2%)
Diabetes	
Yes	19, (10.7%)
No	159, (89.3%)
Smoker	
Current smoker	6, (3.4%)
Former smoker	5, (2.8%)
Never smoker	167, (93.8%)
History of periodontitis	
Yes	39, (21.9%)
No	139, (78.1%)
Number of implants included	
One implant	143, (80.3%)
Two implants	35, (19.7%)

Implant Demographic Data

Among the 213 included implants, 128 implants (60.1%) were placed in maxilla, and 85 implants (39.9%) were placed in mandible. 34 (16.0%) were placed in anterior region, including central incisors, lateral incisors and canines. 179 implants (84.0%) were placed in posterior region, including premolars and molars. (Table 3)

The follow-up period ranged from 12 months to 110 months, with an average of 34.8 ± 20.8 months follow-up. Only 2 out of the 213 implants failed and were subsequently removed after one year of loading, resulting in a survival rate of 99.1%. Five implants that failed during the healing period or within the first year of function were excluded due to insufficient follow-up time. Taking into account these five implants with early failure, the cumulative survival rate was 96.8%.

The reasons for tooth loss were generally categorized into four groups: 1. endodontic and restorative reasons, 2. periodontal reason, 3. other reasons, and 4. unspecified reasons. The endodontic and restorative reasons were a non-restorable tooth with deep primary or recurrent caries, horizontal crown/root fracture, cracked tooth, vertical root fracture, periapical radiolucency, root resorption, recurrent endodontic lesion and/or endodontic perforation. A total of 150 teeth (70.5%) were extracted due to the above-mentioned reasons. 9 teeth (4.2%) were extracted for periodontal reasons, including 8 teeth with significant periodontal attachment loss and one tooth with deep caries in addition to periodontal breakdown. Other reasons for tooth loss included 2 implants placed into the space created by orthodontic treatment, and 3 implants placed in previously failed implant site, accounting for a total of 5 implants (2.3%). There were 49 implants (23.0%) placed at sites where the rationale for tooth loss was not recorded in the chart note.

42 sites (19.7%) received site preservation at the time of extraction, while the majority of sites received no grafting procedure during extraction.

16 sites (7.5%) received different kinds of ridge augmentation procedures prior to implant placement, including 7 sites with Guided Bone Regeneration (GBR), 1 site with autogenous ramus block graft, and 8 sites with lateral window sinus augmentation. It is interesting to note that 2 out of 7 sites receiving GBR and 3 out of 8 sites receiving lateral window sinus augmentation had site preservation before the pre-surgical augmentation.

The majority of implants were placed without additional grafting procedures, while 61 implants (28.6%) needed simultaneous bone grafts at the time of placement. Among these implants, bone graft was placed around 51 implants to cover a buccal dehiscence, one implant was placed with simultaneous lateral window sinus augmentation, and another implant was placed with both buccal augmentation and lateral window sinus augmentation. 8 implants were placed with simultaneous vertical sinus augmentation.

With regard to the timing of implant placement, 154 sites (72.3%) had delayed implant placement, 10 implants (4.7%) were placed using the early placement protocol, and 49 sites (23.0%) were immediately placed. Among the 49 immediately placed implants, 29 sites received simultaneous bone graft, and one implant was placed at site #13 with vertical sinus augmentation.

84 implants (39.4%) were placed using a two-stage submerge protocol, while 129 implants (60.6%) were placed with transgingival one-stage healing protocol.

With respect to the implant details, 84 implants (39.4%) were Nobel tapered implants, 81 of which were Nobel Tapered Groovy, 2 were Nobel Tapered Select, and 1 was Nobel Tapered Select PMC. For the 129 Nobel straight implants (60.9%), 83 were Nobel Straight Groovy, 7 were Nobel Speedy, and the remaining 39 were Nobel Active.

With regard to implant diameter, 1 implant (0.5%) was Nobel Active 3.0 mm, 27 (12.7%) were narrow diameter 3.5 mm implants, 99 (46.5%) were regular diameter 4.3 mm implants, 79 (37.1%) were wide diameter 5.0 mm implants, and 7 (3.3%) were Nobel 6.0 mm diameter implants.

For the type of connection, 168 implants (78.9%) had trilobed connections, while 45 implants (21.1%) had conical connections.

51 implants (23.9%) had platform-switched design, while the remaining 162 (76.1%) had matched diameter of the implant platforms and abutments.

Only 5 out of the 213 implants (2.3%) were immediately loaded. Among them, 2 implants were placed at site #8, 2 implants were placed at site #12, and the other 1 implant was placed at site #20.

37 (17.4%) implant-retained crowns were screw-retained, while the majority were cement-retained (82.6%).

Table 3: Implant Demographic Data

	Implants n=213, (%)
Jaw of treatment	
Maxilla	128, (60.1%)
Mandible	85, (39.9%)
Position	
Anterior	34, (16.0%)
Posterior	179, (84.0%)
Survival	
Yes	211, (99.1%)
No	2, (0.9%)
Reasons for tooth loss	
Endodontic and restorative reasons	150, (70.5%)

Table 3 Continued

Periodontal reason	9, (4.2%)
Other reasons	5, (2.3%)
Missing data	49, (23.0%)
Site preservation	
Yes	42, (19.7%)
No	171, (80.3%)
Ridge augmentation prior to the implant placement	
Yes	16, (7.5%)
No	297, (92.5%)
Bone graft at the time of implant placement	
Yes	61, (28.6%)
No	152, (71.4%)
Timing of implant placement	
Immediate	49, (23.0%)
Early	10, (4.7%)
Delayed	154, (72.3%)
Installation procedure	
One-stage	129, (60.6%)
Two-stage	84, (39.4%)
Implant configuration	
Tapered	84, (39.4%)
Straight	129, (60.6%)
Implant diameter	
Nobel Active 3.0 mm	1, (0.5%)
Narrow Diameter 3.5 mm	27, (12.7%)
Regular Diameter 4.3 mm	99, (46.5%)
Wide Diameter 5.0 mm	79, (37.1%)
Nobel 6.0 mm	7, (3.3%)
Implant connection	
Trilobed	168, (78.9%)
Conical	45, (21.1%)
Implant/abutment dimension	
Platform switched	51, (23.9%)
Platform matched	162, (76.1%)
Loading protocol	
Immediate	5, (2.3%)
Conventional	208, (97.7%)
Crown retention	
Screw retained	37, (17.4%)
Cement retained	176, (82.6%)

Vertical Implant Position

The mean vertical distance from the implant platform to the interdental bone level was 1.28 ± 1.04 mm on the mesial and 0.83 ± 1.03 mm on the distal, with a range of -1.1 to 4.7 mm on the mesial and -1.2 to 4.5 mm on the distal, at the time of crown delivery. A negative value indicates the implant platform was coronal to the interdental bone level, while a positive value means an apical positioning of the implant platform in relation to the interdental bone level. The mesial end of implant platform was significantly deeper than the distal end in relation to the interdental crestal bone ($p < 0.01$). (Figure 4)

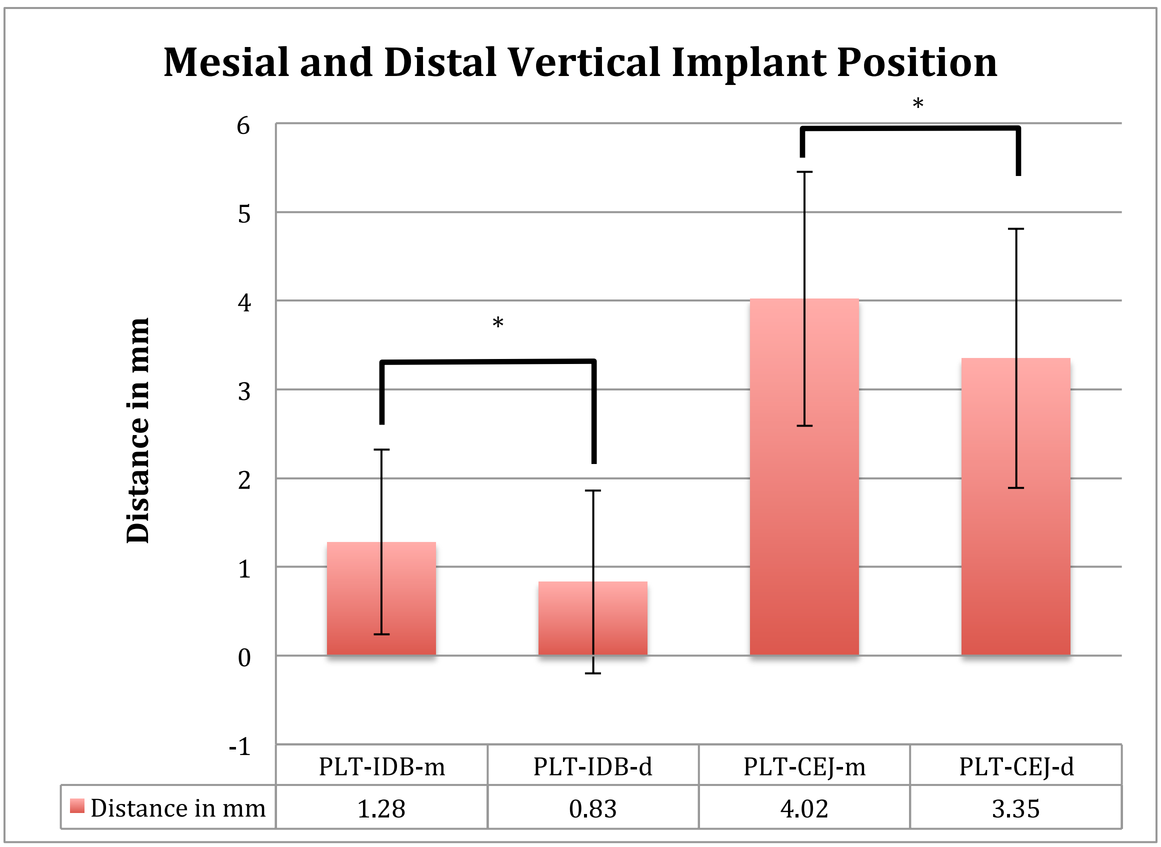

Figure 4: Mean vertical implant position in relation to the interdental crestal bone height and the CEJs of adjacent teeth. **PLT-IDB-m:** the vertical position of the mesial end of the implant platform in relation to the interdental crestal bone height. **PLT-IDB-d:** the vertical position of the distal end of the implant platform in relation to the interdental crestal bone height. **PLT-CEJ-m:** the vertical position of the mesial end of the implant platform in relation to the CEJs of adjacent teeth. **PLT-CEJ-d:** the vertical position of the distal end of the implant platform in relation to the CEJs of adjacent teeth. *p<0.01

Figure 5 shows the frequency distribution of vertical implant position in relation to the interdental bone level. Most of the implant platforms were located equal or within 1 mm below the interdental bone height. The number of mesial ends of the implant platforms placed beyond 2 mm below the interdental bone height was higher than that of the distal platform ends.

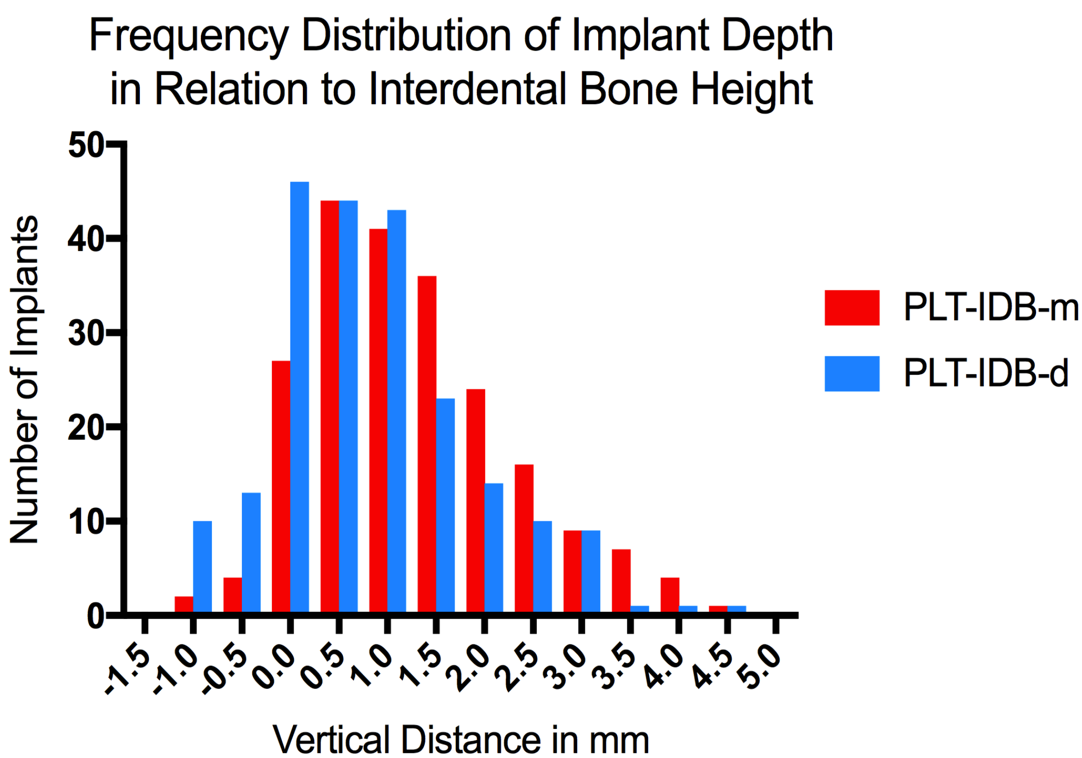

Figure 5: Frequency distribution of vertical implant depth in relation to interdental bone height. **PLT-IDB-m:** the vertical position of the mesial end of the implant platform in relation to the interdental crestal bone height. **PLT-IDB-d:** the vertical position of the distal end of the implant platform in relation to the interdental crestal bone height.

The mean vertical distance from implant platforms to the CEJ of adjacent teeth was 4.02 ± 1.43 mm on the mesial and 3.35 ± 1.46 mm on the distal, with a range of 0 to 9.2 mm on the mesial and -0.3 to 10.5 mm on the distal, at the time of crown delivery. Likewise, a negative value indicates the implant platform was coronal to the CEJs of adjacent teeth, while a positive value means an apical positioning of the implant platform in relation to the CEJ of adjacent teeth. The mesial end of implant platform was significantly deeper than the distal end in relation to the CEJs of adjacent teeth ($p < 0.01$). (Figure 4)

Among the 36 anterior implants, the mean vertical distance from implant platform to the interdental bone level was 1.31 ± 1.08 mm on the mesial and 0.81 ± 0.96 mm on the distal. The mean distance from implant platform to the CEJ of adjacent teeth was 4.10 ± 1.12 mm on the mesial and 3.37 ± 1.29 mm on the distal.

For posterior implants, the mean vertical distance from implant platform to the interdental bone level was 1.27 ± 1.03 mm on the mesial and 0.83 ± 1.05 mm on the distal. The mean distance from implant platform to the CEJ of adjacent teeth was 4.00 ± 1.48 mm on the mesial and 3.35 ± 1.49 mm on the distal.

There was no significant difference between anterior and posterior implants in the aspect of vertical implant position relative to interdental crestal bone height or the CEJs of adjacent teeth.

Horizontal Implant Position

With regard to the horizontal implant position, the implants were on average 3.16 ± 1.38 mm away from the mesial adjacent teeth, and 2.97 ± 1.51 mm away from the distal adjacent teeth respectively. There was no statistically significant difference between the mesial and distal horizontal distances. (Figure 6)

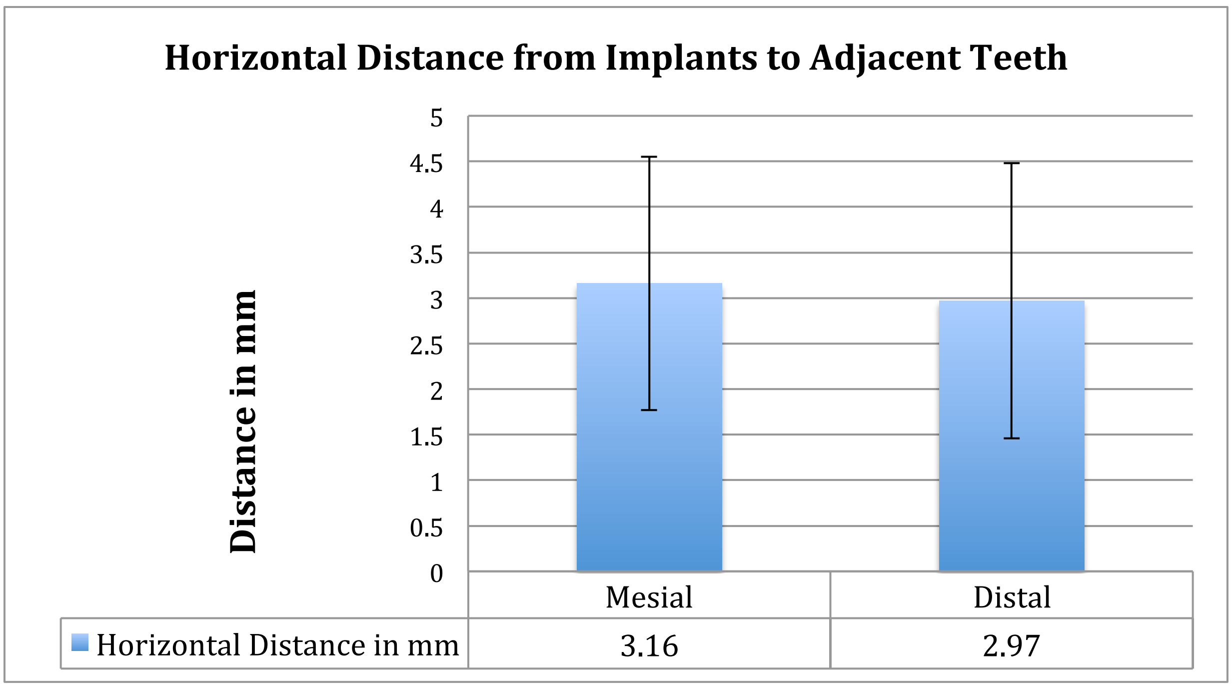

Figure 6: Mean horizontal distance from implants to adjacent teeth.

Angles of the Peri-implant Bony Defects

The average of the angles between the implant surface and the bone contour was 52.3 ± 14.9° (ranging from 14° to 91.5°) and 63.7 ± 17.4° (ranging from 19.5° to 103.7°) at mesial and distal aspects, respectively. The angles of the mesial defects were statistically more acute than those of the distal defect. Both mesial and distal angles were measured at the time of crown delivery. (Figure 7)

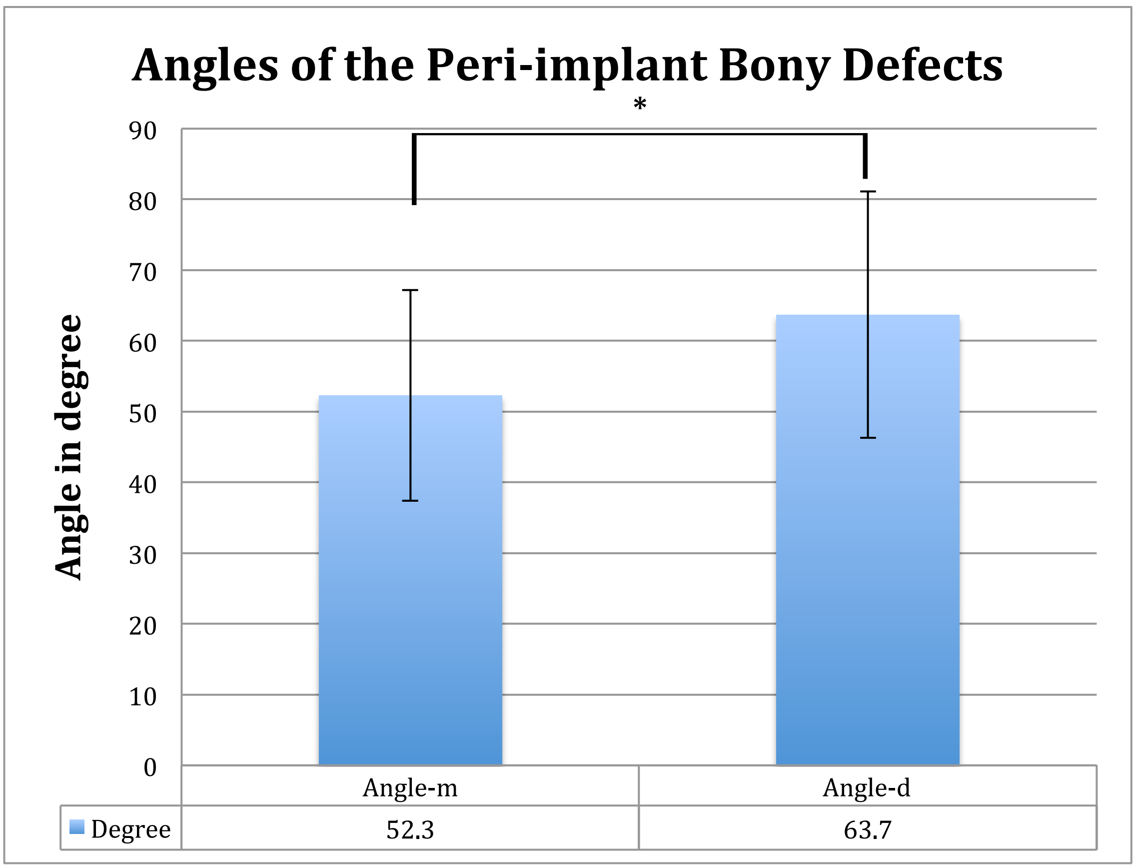

Figure 7: Angles of the peri-implant bony defects. **Angle-m:** the angle of the mesial implant surface and the crestal bone contour. **Angle-d:** the angle of the distal implant surface and the crestal bone contour. * $p < 0.01$

Peri-implant Marginal Bone Level

At the time of crown delivery, the mean bone level was 0.55 ± 0.91 mm apical to the mesial implant platform, and 0.67 ± 0.88 mm apical to the distal implant platform.

At the most recent follow-up, the mean bone level was 1.07 ± 0.84 mm apical to the mesial implant platforms, and 1.10 ± 0.89 mm apical to the distal implant platforms.

The mean bone loss around implants from crown delivery to the most recent follow-up was 0.52 ± 0.75 mm for the mesial aspect of the implants, and 0.43 ± 0.61 mm for the distal aspect of the implants. The mesial bone loss around implants was significantly more than the distal bone loss ($p < 0.01$) (Figure 8)

Figure 9 shows the frequency distribution of peri-implant bone loss after crown delivery. Mesial implant bone loss ranged from -1.7 mm to 4.9 mm, and distal implant bone loss ranged from -0.7 mm to 3.6 mm. The majority of implants had less than 1.5 mm bone loss after crown delivery. Only 15 implants had bone loss beyond 1.5 mm mesially, and 6 implants had bone over 1.5 mm distally from the crown delivery to the most recent follow-up.

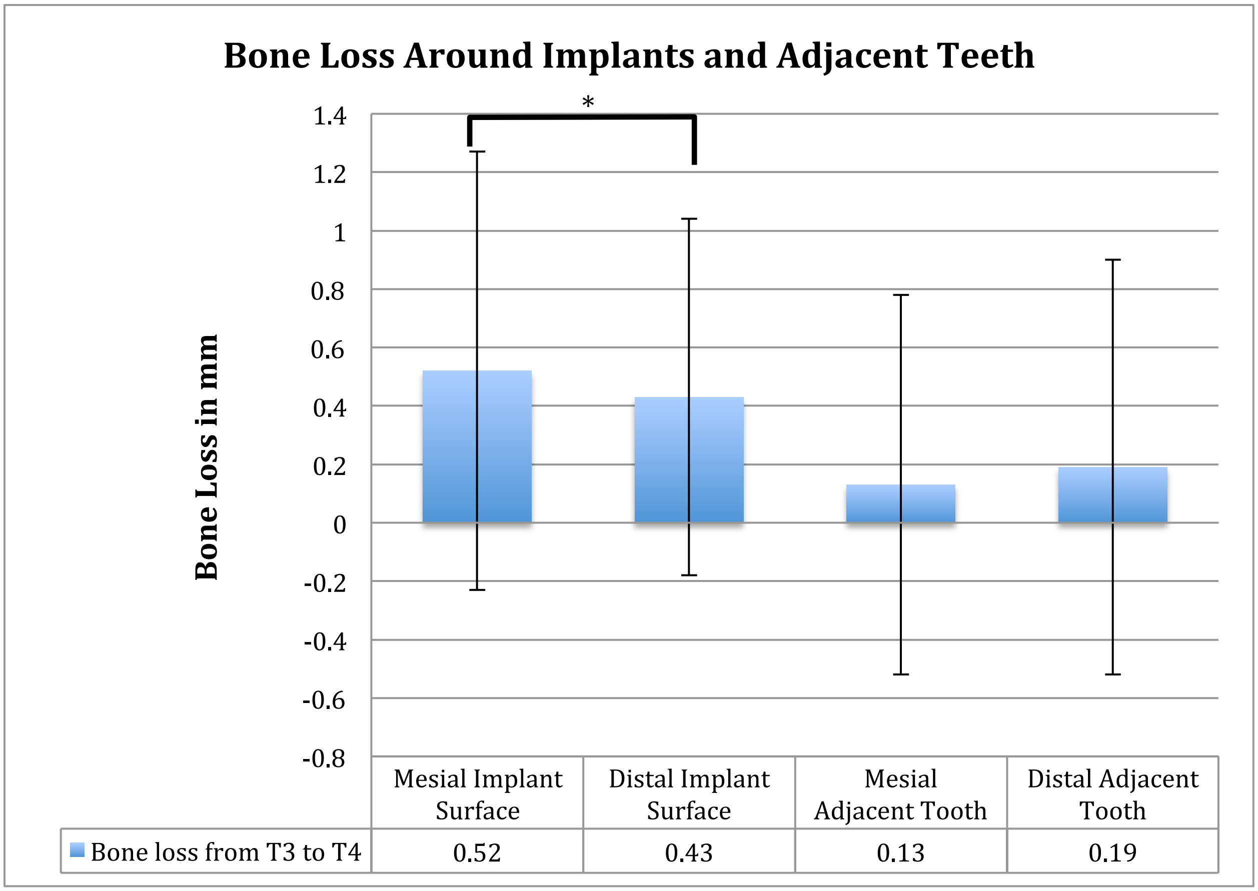

Figure 8: Bone loss around implants and adjacent teeth from crown delivery to the most recent follow-up. *p<0.01

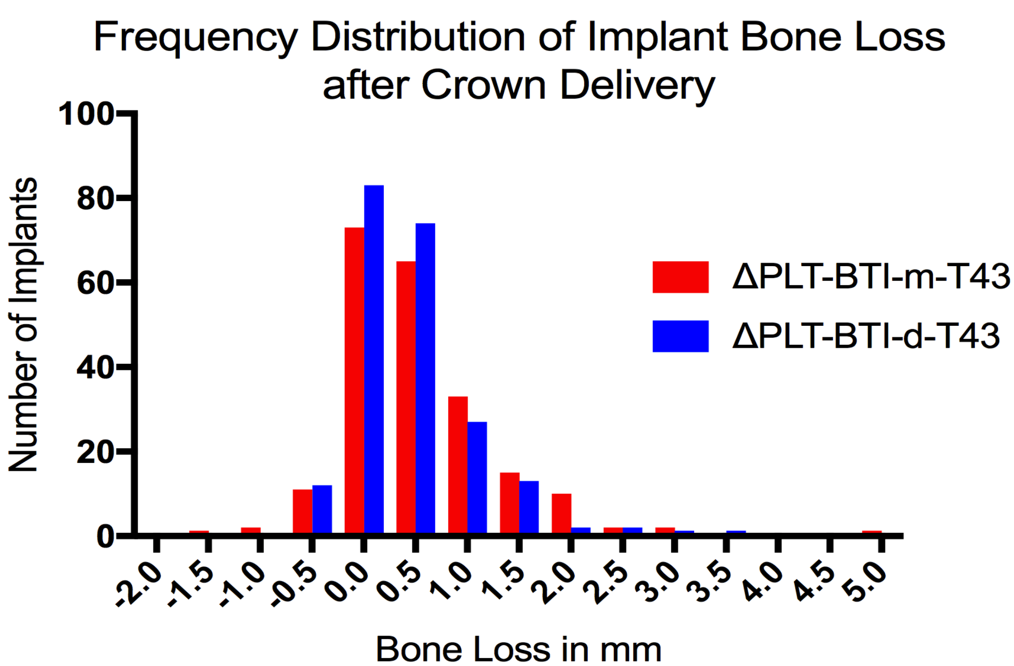

Figure 9: Frequency distribution of implant bone loss after crown delivery.
ΔPLT-BTI-m-T43: Bone loss at the mesial implant surface after crown delivery.
ΔPLT-BTI-d-T43: Bone loss at the distal implant surface after crown delivery.

Bone Level Around Adjacent Teeth

At the time of crown delivery, the bone level was on average 2.73 ± 1.03 mm apical to the CEJs at the mesial adjacent teeth, and 2.30 ± 1.18 mm at the distal adjacent teeth.

At the most recent follow-up, the bone level was on average 2.86 ± 1.08 mm apical to the CEJ at the mesial adjacent teeth, and 2.49 ± 1.27 mm at the distal adjacent teeth.

The mean bone loss around adjacent teeth from crown delivery to the most recent follow-up was 0.13 ± 0.65 mm for the mesial adjacent teeth, and 0.19 ± 0.72 mm for the distal adjacent teeth. There was no statistically significant difference bewteen the mesial and distal bone loss around adjacent teeth. (Figure 8)

Correlation of Patient-related factors and Bone Loss

Diabetes, reasons for tooth loss, smoking status or age at which the subjects received dental implants were not related to the bone loss around implants and adjacent teeth from the crown delivery to the most recent follow-up.

A positive history of periodontitis was associated with greater bone loss at the mesial surface of the implant (r=0.17, $p < 0.05$), as well as to greater bone loss at the distal surface of the mesial adjacent teeth from the crown delivery to the most recent follow-up (r=0.16, $p < 0.05$).

Correlation of Implant-related Factors and Bone Loss

No correlation was found between the following factors and the bone loss around implants and their adjacent teeth, including time of implant placement, platform-switched or platform-matched implants, type of restoration, horizontal distance from implant to adjacent teeth, angles of the peri-implant bony defects and the length of follow-up following crown delivery.

As shown in Table 4, after adjusting for diabetes, history of periodontitis, smoking status, age and the length of follow-up, the implant position in relation to the interdental crestal bone height was positively correlated with peri-implant bone loss both mesially and distally after crown delivery, but was not associated with the bone loss around adjacent teeth. The deeper the implant position was in relation to the interdental crestal bone height, the greater the bone loss observed around the mesial and distal aspects of the implant. The implant position in relation to the CEJs of adjacent teeth was not associated with bone loss around implants or adjacent teeth.

Table 4: Correlation of implant depth and bone loss around implants and adjacent teeth

Implant depth	Bone loss from crown delivery to the most recent follow-up			
	Implant		Adjacent teeth	
	Mesial surface	Distal surface	Mesial to implant	Distal to implant
PLT-IDB-m	r=0.14*	N.S.	N.S.	N.S.
PLT-IDB-d	N.S.	r=0.17*	N.S.	N.S.
PLT-CEJ-m	N.S.	N.S.	N.S.	N.S.
PLT-CEJ-d	N.S.	N.S.	N.S.	N.S.

PLT-IDB-m: the vertical position of the mesial end of the implant platform in relation to the interdental crestal bone height. **PLT-IDB-d:** the vertical position of the distal end of the implant platform in relation to the interdental crestal bone height. **PLT-CEJ-m:** the vertical position of the mesial end of the implant platform in relation to the CEJs of adjacent teeth. **PLT-CEJ-d:** the vertical position of the distal end of the implant platform in relation to the CEJs of adjacent teeth. * $p < 0.05$. N.S.: non-significant

Discussion

The present study evaluated the effect of vertical implant position in relation to interdental crestal bone height of adjacent teeth on implant marginal bone loss.

Out of the 637 tooth bound single implants identified, 424 implants were excluded for various reasons. 41.5% of the implants were excluded due to lack of follow-up radiographs. Patients seeking dental treatment at the dental school come with a specific goal of replacing missing teeth with dental implants instead of comprehensive dental care. Many times after the completion of implant treatment, patients returned back to their original provider outside the dental school. It is therefore not surprising to see such a high percentage of patients and implants without any follow-up appointments. Meanwhile, treatment progress at UMSOD is usually a lot slower than private practice. It is not uncommon to take up to one year after implant placement before the crown is finally delivered. With a longer implant treatment span at UMSOD, about one third of the initially screened implants were excluded due less than one year of follow-up.

The implant survival rate in this cohort was 99.1%. Only 2 out of 213 implants failed after one year of loading. Jemt et al reported a single implant survival rate of 98.5% with three-year follow-up. (Jemt & Pettersson 1993) Haas et al reported a survival rate of 97.4% over 6 years with single-unit implants. (Haas et al. 1995) Both studies evaluated Branemark smooth surface implants. All the implants included in this study were Nobel TiUnite rough surface implants. The higher survival rate of single implants placed and restored at UMSOD clinics in this study may be explained by Jimbo and Albrektsson's review. They assessed 71 studies with 5 years or more of follow-up and reported a higher survival rate of rough surface implants than smooth surface implants, particularly in maxilla with poorer bone quality. (Jimbo & Albrektsson 2015)

Factors Affecting Implant Marginal Bone Loss

Diabetes

The prevalence of diabetes in this cohort was 10.7%, which is similar to the estimated 9.3% prevalence among adults in the United States. (Mealey 2006) Diabetes is a controversial risk factor for implant failure, with arguments from both sides. (Anon 2013a; Chen, Liu, Xu, Qu & Lu 2013a) Oates et al showed a longer healing time for poorly-controlled type II diabetic patients compared to those with good control of diabetes. (Oates et al. 2009)

Subjects with diabetes exhibited similar implant bone loss compared with non-diabetic subjects in this study. Only 10.7% of all the subjects had diabetes. The number of implants received by subjects with diabetes may not be sufficient enough to detect a significant bone loss around implants. Furthermore, the status of diabetes was obtained from the electronic health records at UMSOD clinics. The majority of the data was dichotomous data indicating whether the patients had diabetes or not, but no information was recorded about the diabetic control, eg. Fasting glucose or HbA1c level. It is a common practice at the UMSOD clinics for the patient's glucose level be well-controlled before implant surgery is planned. Therefore, it could be implied from this study that the subjects were well-controlled diabetics and achieved as stable implant marginal bone level as those without diabetes.

Smoking

Smoking has been reported to increase peri-implant crestal bone loss. (Peñarrocha et al. 2004; Manz 2000; Carlsson et al. 2000) However, this present study failed to report greater implant bone loss among current smokers or former smokers. Current smokers and former smokers only accounted for 3.4% and 2.8% of all the subjects in this study. As a result, bone loss may not be detected among such a small sample of implants from subjects who reported to be current or former smokers. Moreover, all the subjects included in this study had intraoral radiographs taken at least one year after the implant restoration, indicating a regular recall regime among the included subjects. This may attenuate the effect of smoking on the implant bone loss. Rinke et al found that patient compliance with supportive periodontal therapy after implant placement experienced lower incidence of peri-implantitis. (Rinke et al. 2011)

History of Periodontitis

This present study showed that subjects with a history of periodontitis had greater bone loss around implants than the periodontally healthy counterparts. This is in concert with other studies. (Anon 2013b; Derks, Schaller, Hakansson, Wennström, Tomasi &

Berglundh 2016b) A recent human study by Koutouzis et al indicated an altered innate immune response after dental implant placement among periodontally susceptible patients. Their team obtained gingival biopsies around implants before and two months after the implant placement. They found that patients susceptible to periodontitis displayed higher levels of innate immune receptor expression and inflammatory infiltrates than periodontally healthy subjects after the implant placement. (Koutouzis et al. 2013)

Considering that there was only one patient diagnosed with aggressive periodontitis, and that aggressive periodontitis may have a higher risk of implant marginal bone loss and implant failure, this patient was excluded from the study.

Number of Implants Each Subject Received

The number of implants included in this study from each subject was limited to two per subject. 15 implants were excluded from six subjects who had received more than two implants. Derks et al showed that patients receiving four or more implants are 15 times more likely to suffer from moderate to severe peri-implantitis. (Derks, Schaller, Hakansson, Wennström, Tomasi & Berglundh 2016a) Patients receiving multiple implants at the same appointment may be more susceptible to implant failure, which may be attributed to operator fatigue in placing multiple implants in a prolonged surgical appointment. Furthermore, many proposed risk factors for peri-implant disease are patient based. By limiting the number of implants included in this study from the same subject, the impact of patient-related factors on the implant marginal bone level can be minimized.

Platform Switch

Platform-switched implants did not differ from platform-matched implants in the implant crestal bone level in this study. There was a total of 213 implants included, among which less than a quarter were platform-switched implants. The average bone loss around implants in this present study was only 0.52 ± 0.75 mm at the mesial surface and 0.43 ± 0.61 mm at the distal surface from crown delivery. Such small sample size and minimal amount of bone loss may not be powerful enough to differentiate the difference in bone level between platform switched and platform matched implants.

Type of Restorations

No difference in implant bone level was found between screw-retained and cement-retained implants. This is also a topic of controversy. Wadwani suggested the association between residual excess cement and peri-implant disease with clinical and radiographic findings of bone loss around implants. (Wadhwani 2013) Histologic evidence of a foreign body reaction to excess cement has been shown by Ramer et al, and the removal of the cement resolved the peri-implant disease in a majority of situations. (Ramer et al. 2014) On the other hand, a recent meta-analysis indicated that cement-retained fixed implant-supported restorations showed statistically less marginal bone loss than screw-retained restorations, although the difference was not clinically significant. (Lemos et al. 2016) With proper design of the abutments and supragingival placement of abutment-restoration interface, the chance of retaining excess cement can be minimized and cement-retained implant restorations do not necessarily lead to more bone loss than screw-retained ones. (Linkevicius, Vindasiute, Puisys & Peciuliene 2011a; Wadhwani 2013)

Horizontal Distance Between Implants and Adjacent Teeth

Horizontal distance was not found to be correlated with the bone loss around implants or adjacent teeth, in contrast to the other studies. (Esposito et al. 1993; Tarnow et al. 2000) The average horizontal distances between implants and adjacent teeth were 3.16±1.38 mm and 2.97±1.51 mm mesially and distally, respectively. A majority of the implants were placed more than 1.5 mm away from the adjacent teeth, which serves as a safe distance to accommodate bone remodeling from the formation of biologic width around implants. (Tarnow et al. 2000)

Vertical Implant Depth

Esposito et al evaluated 71 Branemark machined surface single implants with up to 3 years follow-up, and found that the vertical relation between the implant and CEJs of the adjacent teeth had no effect on the implant marginal bone level. (Esposito et al. 1993) Figure 10 was extracted from their study and showed their method of measuring the vertical distance between implant and the CEJs of adjacent teeth. The illustration of measurement may be true for anterior implants, but should not be used for posterior implants where natural teeth are normally mesially tilted and implants are normally placed in line with adjacent teeth.

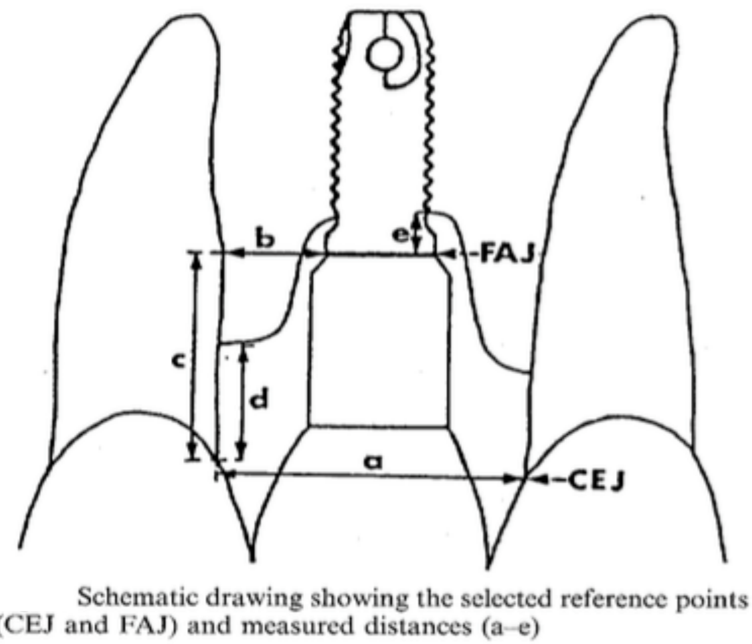

Figure 10: Illustration of the method of measurement in Esposito's study (Esposito et al. 1993)

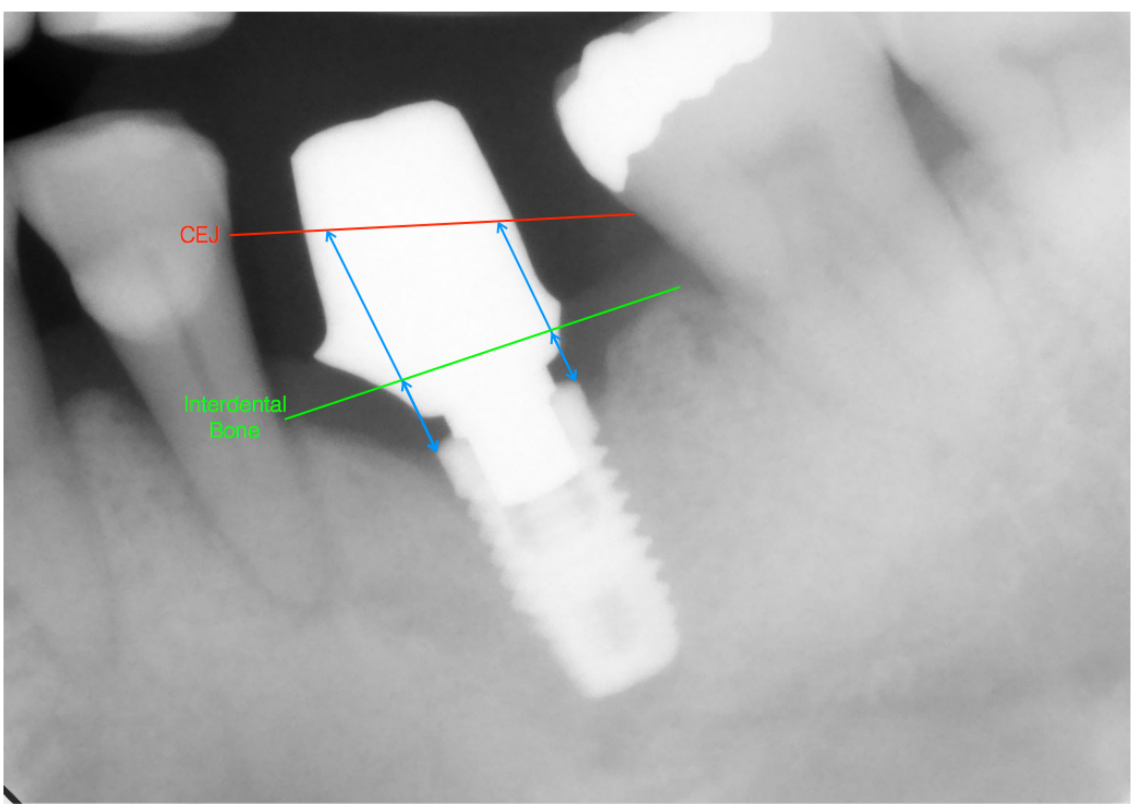

Figure 11: an example of the method of measurement of vertical depth of posterior implants in this study

Figure 11 shows how the radiographs were measured in this study, particularly around the posterior implants. This is a true reflection of clinical settings where posterior teeth have tendency of mesial inclination. Implants are ideally placed parallel to the long axes of adjacent teeth. As a result in this study, the mesial end of the implant platform is consistently deeper than the distal end in relation to both interdental crestal bone height and the CEJs of adjacent teeth, with an average difference of 0.45 mm when the interdental crestal bone height was used as the reference, and 0.67 mm when the CEJs of adjacent teeth was considered. The angles of the mesial peri-implant defects were significantly more acute than the distal angles, which is also a result of the mesially-tilted implants.

It was found in this study that the peri-implant marginal bone loss at the mesial and distal aspects of the implants was positively correlated with depth of the mesial and distal ends of the implant platform to the interdental crestal bone height respectively, although it was a weak correlation ($r=0.14$, $r=0.17$ on the mesial and distal, respectively). Such correlation was not found when CEJs of adjacent teeth were used as reference. This finding was in accordance with Esposito's and Cardaropoli's studies in which the vertical relation between the implant and CEJs of adjacent teeth had no effect on the implant marginal bone level. (Esposito et al. 1993; Cardaropoli et al. 2003)

The mean vertical distance from the implant platform to the interdental bone level was 1.28 ± 1.04 mm on the mesial and 0.83 ± 1.03 mm on the distal, respectively, with a high variance of depth. In other words, the vast majority of the implants were placed within 1 mm below the interdental bone level, and too few implants were placed significantly apical to the interdental crestal bone. Furthermore, there was a minimal amount of bone loss around implants and adjacent teeth. The mean bone loss around the implants after crown delivery was 0.52 ± 0.75 mm on the mesial and 0.43 ± 0.61 mm on the distal aspect of the implants over an average follow-up period of 34.8 months, respectively. Such a small amount of average bone loss around implants within three year's function is in concert with the study by Derks et al. (Derks, Schaller, Håkansson, et al. 2016c) It has been demonstrated that implant bone loss is not linear, and the progression of peri-implantitis accelerates three years after implant function. As a result of implant placement relatively close to the level of interdental bone height, the correlation between the vertical implant position and the implant bone loss was found to be weak.

The weak correlation of vertical implant position relative to interdental bone and the peri-implant bone loss may also be masked by other local confounding factors which were not recorded in this study, including oral hygiene status, the width of keratinized gingiva, or the thickness of supracrestal soft tissue etc. This is an inherent limitation of a retrospective study, but increasing the sample size could reduce such limitation.

Increased crown-to-implant (C/I) ratio results from apical placement of the implants. With the advancement of the knowledge of osseointegration and implant surface treatments, the length of the implants commonly used nowadays is much shorter than the original Branemark guidelines which recommended the use of implants 14 mm in length or longer. The perception is controversial that increased C/I ratio may be detrimental to biologic and mechanical implant success. (Huynh-Ba 2015) A systematic review by Garaicoa-Pazmino et al found that increased C/I ratio is associated with greater implant marginal bone loss. (Garaicoa-Pazmiño et al. 2014) On the other hand, the majority of the opinion papers suggest that C/I ratio does not impact implant survival or peri-implant bone loss. (Huynh-Ba 2015) Furthermore, Quaranta et al showed that unfavorable C/I ratio increases the incidences of abutment loosening and abutment fractures in single implant restorations. (Quaranta et al. 2014) Therefore, apical placement of implants may result in more mechanical complications of implant restorations, in addition to potential increased marginal bone loss.

To the author's knowledge, this was the first study that investigated the effect of vertical implant position relative to the interdental bone of adjacent teeth on implant marginal bone loss. When there is generalized horizontal bone loss around natural teeth, the bone level around the adjacent teeth may be at the same level of the implant platform, and therefore CEJs of adjacent teeth may not reflect any angular defect around the implants. When the interdental bone of adjacent teeth is taken into account, the angular defect formed by the height of interdental bone and the implant can be truly discerned. Such presence of an angular defect around implants may predispose implants to deeper probing depth and consequently higher maintenance difficulties, which may explain why more bone loss was seen with deeper vertical position of implant platform relative to the interdental crestal bone level, and why the bone loss was greater at the mesial aspect of the implants where the implant platform was consistently more apical.

Steffensen and Weber found that the angle of an angular defect around natural teeth was correlated to the radiographic changes in alveolar bone level after modified Widman Flap surgery, with an angle less than 45 degrees showing bone gain while wider defects displayed bone loss. (Steffensen & Webert 1989) However, such correlation between the angle of the angular defect around implants and the bone level was not found in this study. Steffensen's study looked into the bone change after periodontal surgery around natural teeth. This current study only investigated the effect and morphology of such an angular defect on the bone loss over time without any surgical intervention. The depth of the implant platform in relation to interdental crestal bone height of adjacent teeth and the angle of the angular defects around implants may provide additional information in decision making of regenerative or resective therapies in peri-implantitis.

Limitations

There are several inherent limitations for this study. Although the distorted and/or non-parallel radiographs were excluded, the radiographs were not standardized. The implants were placed and restored by clinicians with different levels of experience. Clinical data were not available, oral hygiene status, periodontal conditions of teeth and implants, amount of keratinized tissues and gingival biotype, and may confound the results attained. Further, the follow-up period was not consistent for all the implants.

Future Direction

A larger number of implants, particularly those placed in a more apical position relative to the interdental bone, should be included in this study. A prospective clinical study controlling for confounding clinical factors and standardized radiographs is needed to evaluate the effect of vertical implant position on the implant marginal bone loss over long-term follow-up.

Conclusion

Within the limitations of this retrospective radiographic study, after adjusting for diabetes, history of periodontitis, smoking status, age at which subjects received dental implants and the length of follow-up, the vertical implant position in relation to the interdental bone height of adjacent teeth was positively correlated with the marginal bone loss around implants. The deeper the implant was placed in relation to the interdental bone, the greater marginal bone loss was observed around TiUnite surface implants. History of periodontitis was associated with greater bone loss around implants.

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