The Effect of Splinted Prosthesis on Posterior Dental Implants on Radiographic Crestal Bone Levels

By

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A thesis submitted in conformity with the requirements for the degree of Masters of Science in Periodontology
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Abstract
This project examined the effect of splinting adjacent dental implants of different designs [Sintered porous surface (SPS), Threaded dual acid etched (THR-DAE), Threaded sand-blasted large grit acid etched (THR-SLA)] placed in posterior sites and compared two intraoral radiographic techniques to assess peri-implant crestal bone levels. 799 implants located in 345 patients qualified and were examined retrospectively using an inclusion criteria of a minimum one year in function and having a recent periapical (PA) and vertical bitewing radiograph (vBW). SPS had less bone loss than THR-DAE and THR-SLA. PA views showed approximately 0.10 mm (Range 0.07-0.40 mm) less crestal bone loss than vBW (P<0.01). Splinted implants had more crestal bone loss (0.30 mm; range 0.16-0.38 mm) than non-splinted implants. 49 implants failed with an overall failure rate of 4.9% with a significant difference in the failure rate of SPS and THR-DAE (P<0.0005) and in the time to fail (P<0.0036).
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Chapter 1
Introduction & Literature Review
Chapter 1: Introduction & Literature Review

Dental implantology involves the use of titanium or titanium alloy tooth root replacements (dental implant fixtures) to support fixed or removable oral prostheses which are meant to restore lost tooth structures. The field has grown exponentially in the past thirty years from experimental and unreliable treatment modalities to a ‘standard of care’ in most clinical situations. The history of dental implant research is long and extensive with a variety of successful and failed materials, implant designs, surgical and prosthetic techniques and clinical applications. Nevertheless, ongoing research is needed to better understand optimal clinical conditions for long-term predictable implant success.

The purpose of this project was to examine retrospectively the performance of endosseous root-form dental implants placed in a graduate teaching facility in posterior jaw locations with or without splinting of adjacent implants at the time of prosthesis fabrication. Implant survival and implant success rates, the latter based on radiographic assessment of crestal bone levels, were determined. In addition, the impact of other clinical parameters including implant length and width, crown-to-implant ratio, history of bone augmentation, implant design, and type of opposing dentition and adjacent tooth structure were analyzed in relation to crestal bone levels. As well, the types of radiograph used to measure crestal bone loss, i.e. periapical and vertical bitewing radiographs were compared for accuracy and distortion of crestal bone level measurements.
I. Splinted vs. Non-Splinted Implant Prostheses

The principal question being addressed in this retrospective clinical study was whether or not splinting of adjacent implants had a significant impact on peri-implant crestal bone loss. Brånemark and his colleagues originally proposed their dental implant device for the restoration of the completely edentulous mandible. Their original design was a fixed splinted prosthesis connected to several implants. Thereafter, dental implants also came to be utilized in partially edentulous patients to support fixed prostheses. The decision whether or not to splint adjacent implants in partially edentulous mouths has always been a source of controversy. Investigators have studied this question with various methods including finite element analyses, photoelastic model analyses and clinical investigations. However, there remains no consensus regarding which prosthetic design (splinted or non-splinted) is superior.

Rationale for Splinting

Splinting crowns on adjacent implants is thought to distribute functional forces applied to implants more uniformly. This reduces potential overloading of crestal bone which may lead to fewer prosthetic and implant complications such as prosthesis loosening, implant fracture and implant failure. Grossman et al (2005) published recommendations on when to splint implants together. It was suggested that implants be splinted if there are a reduced number of natural occlusal stops, steep anterior guidance planes, para-functional oral habits, implants arranged around an arch, implant restorations including canines, fully edentulous maxilla and/or, compromised retention and resistance forms of prosthetic components (to increase retention form for cemented prosthesis).

Misch has also written about the benefits of splinting. He suggested that the use of a splinted prosthesis decreases the number of implants needed with economic implications for the patient. Less prosthetic screw loosening has been reported with splinted prostheses, 8% for splinted vs. 48% for non-splinted (Balshi et al, 1996). Cement-retained splinted prostheses require less strong cement, which in turn allow for future retrievability of the prosthesis (Misch et al, 2005). In addition, a multi-unit prosthesis may be preserved if one of the supporting implants fails and has to be removed.

Unlike teeth, dental implants are unable to move in response to eccentric forces. Forces transmitted to implants have been shown with finite element analysis to concentrate in the
coronal 2 to 3 mm of crestal bone surrounding an implant (Baggi et al, 2008). Overloading forces can cause micro-fractures of crestal bone, mechanical failure and fracture of the implant or fatigue fractures of the prosthetic components (Isidor, 1996). Two posterior implants splinted together may help to protect against the deleterious effects of eccentric loading in the mesio-distal direction, and distribute forces over a greater implant surface area in the bucco-lingual direction.

**Rationale for Not Splinting**

One of the main arguments not to splint adjacent implants is that inter-proximal hygiene may be more difficult to accomplish and require the use of adjunctive oral hygiene aids such as floss threaders and inter-proximal brushes that the patient may not be prepared or able to use. Plaque accumulation between implants will not result in caries; however, plaque and calculus formation may lead to peri-implant mucositis or peri-implant crestal bone loss with subsequent complications (Lindhe et al, 2008). In addition, it has been argued that since the mandible has been shown to deform between 420 µm and 1.06 mm during function (English, 1993; Korioth and Hannam, 1994), restoration of implants with individual crowns may minimize component loosening or fractures as a result of mandibular flexing (Hobkirk and Schwab, 1991). Furthermore, fabrication of a passively seating splinted prosthesis on several implants is more technically difficult to accomplish than is the case with individual implant crowns.

**Literature Assessing Splinted and Non-Splinted Implants**

In a study by Guichet, the effect of splinting and inter-proximal contact tightness between non-splinted implant crowns was investigated (Guichet et al, 2002). As indicated, a common clinical obstacle when restoring multiple implants with a splinted prosthesis is achieving a passive framework fit. A possible solution to this is the use of single unit restorations that are non-splinted. However, non-splinted restorations have numerous inter-proximal contacts that require meticulous adjustments. The importance of achieving a passive ideal contact between implants is more crucial than between natural teeth due to the lack of a periodontal ligament around implants and diminished dynamic response. Guichet investigated three implants restored and loaded either with a splinted prosthesis or with individual crowns of varying inter-proximal contact tightness using an *in vitro* photoelastic model of a human mandible loaded and analyzed
with a polariscope. It was found that individual crowns with heavy inter-proximal contacts showed increased tensile stresses between implants. It was also found that splinted implants distributed occlusal loads more evenly. In addition, off-axis loading of implants was evenly shared in splinted prosthesis. Load sharing in splinted prosthesis was least significantly evident when loads were applied to the posterior terminal implant. It was concluded that individual crowns with excessively tight contacts can produce a similar clinical situation to a non-passively fitting framework in a splinted prosthesis.

Occasionally a splinted implant-supported prosthesis may completely seat on one implant but not fully seat on the other(s). Retrospective studies have failed to demonstrate that mis-fitting prostheses of this type result in differences in crestal bone response compared to implants restored with well-fitting prostheses (Jemt and Book, 1996, Carr et al, 1996). Shalak reported that prosthetic misfits may increase the fatigue of implant components and reduce their critical failure load (Skalak, 1983). In the present study, several implant-supported prostheses were discovered to be incompletely seated and no significant crestal bone loss was observed as a result. However, while a mis-fitting prosthesis may not cause adverse bone reactions under static strain, it may magnify dynamic parafunctional occlusal loads.

Dental implants have been splinted to natural teeth with varying degrees of success and failure. While some authors advocate splinting implants to natural teeth, many studies have revealed long term intrusion of natural teeth that have been splinted to implants (Chee & Mordohai, 2010). Becker outlined methods and techniques for splinting natural teeth to implants and recommended this approach only if needed for cross-arch stabilization (Becker et al, 2000). Although splinting implants to natural teeth is not a common treatment modality in North America, this is often reported in European based literature. The reported rates for prosthetic survival are consistent with published complications for conventional implant supported prosthesis.

A meta-analysis of literature was undertaken by Lindhe et al (1998) in order to estimate survival of implants supporting either fixed partial dentures (IS-FPD) or single crowns in partially edentulous patients. Sixty-six studies published between 1986 and 1996 were retrieved but, only nine studies with single tooth implants and ten studies with IS-FPD met their inclusion criteria. A total of 2686 implants including 570 single crowns and 2116 implants supporting IS-FPD were assessed using a life table analysis. Follow-up times in these studies ranged from 1 to 8 years.
After 1 year, the success rate was 85.7% for IS-FPD and 97.2% for single implants. The survival rate after 6-7 years for IS-FPD was 93.6% vs. 97.5% for single implants. A limitation of this review is that it included studies that were retrospective and prospective in design and only threaded metallic implants were assessed.

A longitudinal study by Naert reported on 1956 implants, of which 846 were in posterior tooth locations, 235 supporting single unit prostheses and 409 supporting IS-FPD (Naert et al, 2002b). The survival rate for implants with IS-FPD was 97.2% after 16 years of function. There was no effect on survival due to implant position (anterior vs. posterior). It was also found that short implant length, high number of implants per patient, low number of implants per prosthesis, implants loaded by acrylic-veneered restoration and implants combined with bone grafting resulted in a higher risk hazard for implant failure (Naert et al, 1995).

Rokni et al (2005) reported data on 199 SPS (sintered porous-surfaced) implants of lengths varying from 7 to 12 mm restored with either splinted or non-splinted prostheses. They observed that splinted implants had greater crestal bone loss by 0.2 mm; and, this difference was statistically significant. Cochran reported data on 596 implants in a 5-year prospective study with non-submerged hollow and solid screw implants (Cochran et al, 2009). Splinted and non-splinted prostheses were assessed. It was found that after 5 years of loading, single implant units experienced 2.64 mm of bone loss while implants in splinted restorations had 2.90 mm of bone loss (cumulative difference of 0.26 mm).

Thus, at least two longitudinal studies have concluded that splinted implant-supported prostheses result in more crestal bone loss than non-splinted prostheses. The amount of crestal bone loss was similar in both studies and included different implant design types. Furthermore, long term survival and success of splinted and non-splinted implants show comparable results.
I. Crestal Bone Loss around Dental Implants

Crestal bone loss around functioning dental implants over time often occurs despite careful surgical and prosthetic protocols. Measuring cumulative peri-implant crestal bone loss in radiographs is a means for researchers and clinicians to evaluate dental implant performance, i.e. success vs. failure. A classic widely quoted paper by Albrektsson (Albrektsson et al, 1986) using data from a large group of patients who had received machine-surfaced, minimally rough threaded endosseous dental implants, suggested that after year one in function, long-term ongoing annual bone loss with successful implants as detected in radiographs should not exceed 0.2 mm/annum. In a 15-year retrospective study with the same implant device, Adell (1985) reported that 1.2 mm of marginal bone loss occurred from the coronal-most thread during the first year of implant function. This was followed by 0.1 mm bone loss annually thereafter with successful implants. However, with the advent of more textured implant surfaces, and modified implant designs, e.g. crestal micro-threads or ‘platform-switching’, this older criterion no longer stands up to scrutiny. Indeed, many newer implant designs show stable bone levels regardless of time in function if optimal treatment has been provided from the outset (Bonde et al, 2010).

Etiology of Crestal Bone Loss

Multiple factors are known to contribute to peri-implant crestal bone loss including surgical and anatomical factors, patient risk factors, ‘biologic width’, implant surface and design factors, and biomechanical factors following the onset of implant function (Ketabi et al, 2010). Surgical and anatomical factors include initial flap design, alveolar ridge bone thickness especially that of buccal bone, one-stage versus two-stage implant placement and bone quality, i.e. density and vascularity. Patient risk factors for unwanted crestal bone loss include smoking and alcohol consumption, history of periodontitis, genetics, diabetes mellitus, poor oral hygiene and inadequate or irregular supportive periodontal care. Factors related to biologic width include the location of the implant fixture-to-prosthetic abutment connection, i.e. micro-gap, use of platform-switching elements, early unwanted exposure of cover screws and implant-to-tooth or inter-implant distances. Implant surface roughness and transgingival collar design can also impact crestal bone levels. And finally, biomechanical factors such as functional over-loading,
prosthetic design, para-functional habits and the presence of prosthetic cantilevers may have significant effects (Ketabi et al, 2010).

**Surgical Trauma**

In an article by Oh et al (2002), several possible etiologies for early peri-implant crestal bone loss were postulated, including surgical trauma as a result of heat from burs during osteotomy preparation. Matthews and Hirsh (1972) had earlier found that bone temperatures increased with increasing force used with surgical burs rather than being related to drill speed. A classic paper by Eriksson and Albrektsson determined that 47°C for 1 minute or 40°C for 7 minutes were the critical temperatures for over-heating bone and impairing osseointegration (Eriksson and Albrektsson, 1984). The crestal bone level of an implant is typically in cortical bone which is less vascular than trabecular bone. Cortical bone is often hard to drill and requires increased drilling force to penetrate and enlarge. Therefore, a combination of drilling force and excessive heat over time in cortical bone can damage the implant osteotomy and inhibit osteogenic healing around the implant.

**Occlusal Trauma**

Occlusal overload of dental implants also is discussed by Oh (Oh et al, 2002). Excessive biomechanical loading can result in implant bending, high compressive stresses on bone surfaces and bone micro-fractures that could precipitate bone remodeling and loss (Rangert et al, 1995). The concept of micro-fractures in bone around dental implants was first described by Roberts (Roberts et al, 1989). It was proposed that high stress-bearing areas such as the crestal bone around dental implants may suffer micro-fractures, bone resorption and the formation of crestal bone craters. Excessive loading might arise from factors such as a large prosthesis supported by 1 or 2 implants in a posterior jaw site, poor vertical alignment of implants, excessive cantilever lengths, discrepancies in dimensions between the occlusal table and implant head, and para-functional habits such as bruxing.

Misch suggested that stresses in peri-implant crestal bone during early implant function may cause micro-fractures and result in the crestal bone loss often seen during year one in function. He suggested progressive loading of implants to avoid early crestal bone micro-fractures and postulated that changes in bone density and strength will occur as a result of loading during year
one leading to alterations in stress-strain relationships and reduced risk of micro-fracture during subsequent years (Misch, 1999a;b).

The impact of occlusal forces on crestal bone levels will be further discussed in a dedicated section in Chapter 1.

**Microbiological and Host Response**

Crestal bone loss also can occur as a result of peri-implantitis, a localized area of bacterially-driven peri-implant crestal inflammation and infection (Mombelli et al, 1987). Peri-implantitis is a site-specific infection with microbial features not unlike those of chronic periodontitis and involves pathogens such as gram-negative anaerobic rods, bacteroids, fusobacterium and spirochetes. Clinical criteria used to diagnose peri-implantitis include radiographic evidence of progressive crestal bone loss, formation of deep peri-implant pockets, bleeding after gentle probing with possible suppuration, mucosal swelling and redness (Mombelli, 1999). This is differentiated from peri-implant mucositis defined by Tonetti and Schmid (1984) as a reversible inflammatory lesion confined to peri-implant mucosal tissues without bone loss. Peri-implantitis is currently under intense investigation as its etiology and pathogenesis share similarities with periodontitis, however treatment is not as predictable.

**Biological Width and Micro-gap**

The implant micro-gap or connection between implant fixture and prosthetic abutment has been linked to crestal bone loss and peri-implantitis as this region of the implant may accumulate significant bacterial deposits (Quirynen et al, 1991). Hermann et al (1997) investigated the effect of micro-gap by comparing 1-piece single-stage versus 2-piece, 2-stage titanium plasma-sprayed threaded implants. They found that bone levels around 1-piece single-stage implants were generally at the level of the smooth-rough (titanium plasma-sprayed) surface junction of the implant. They also found that in conventional 2-stage implants, crestal bone levels consistently were 2 mm apical to the micro-gap.

Platform-switching has been introduced to better accommodate the micro-gap by distancing it from alveolar bone. Lazzara and Porter (2006) coined the term ‘platform-switching’ and proposed the theory behind it. They had observed serendipitously that the inward horizontal repositioning of the implant-abutment interface by using regular diameter (4 mm) prosthetic
abutments on wide-body (5 mm diameter) implants resulted in reduced crestal bone loss. The mismatch had added a horizontal component to the implant surface available for biologic width accommodation, which they propose to be the major driving force behind initial bone remodelling around dental implants (Lazzara and Porter, 2006).

Scarano studied the impact of micro-gaps with 272 titanium 2-piece implants for which prosthetic abutments needed to be removed for a variety of reasons (Scarano et al, 2005). These implants had either screw- or cement-retained prostheses. With screw-retained prostheses, a 60 micron gap was found between the implant and abutment, and actual contact between the implant and abutment was limited to a few areas. Bacteria were present in the micro-gaps and internal threaded portions of the implants. With cement-retained abutments, a 40 micron micro-gap was found but all voids were filled with cement, and no bacteria were found. Since all of these implants had failed, the size of the micro-gaps found may have contributed to implant failure and may not truly represent the micro-gap in successful functioning implants.

The concept of ‘biological width’, i.e. a minimum thickness of mucosal tissue needed to form an effective barrier to protect supporting bone, is known to exist for teeth and has been shown to be true for implants as well (Cochran et al, 1997). Following dental implant placement and exposure to the oral environment, crestal bone remodeling will occur until there is sufficient implant surface exposed to accommodate a linear contact of implant surface-to-soft tissue. For example, Cochran found that after 12 months of loading threaded dental implants in dogs, there was a ‘biologic width’ of 3.08 mm thickness (1.88 mm for junctional epithelium and 1.05 mm for connective tissue) (Cochran et al, 1997). This confirmed earlier studies by Berglundh also in dogs (Berglundh et al, 1991). However, newer implant designs incorporating crestal micro-threads and/or platform-switching appear to reduce the degree of vertical crestal bone loss to accommodate biological width requirements (Arvidson et al, 1998; Chang & Wennström, 2010).

**Implant Design**

Other features of implant design also may impact crestal bone loss. With early dental implant designs the coronal neck region was meant to minimize bacterial plaque accumulation and therefore had a machined and/or polished surface finish (i.e. minimally rough). To further elaborate on this factor, Hermann studied the effect of depth of placement of 1-piece rough-surfaced (titanium plasma-sprayed surface) threaded implants with machined trans-gingival
collar regions. Implants were placed in a dog mandible either with the smooth-rough junction (R/S Jx) at the crest of bone or 1.5 mm apical to the crest. Results showed that after 6 months, implants placed at the bone crest had no change in bone levels. However, it was found that the implants with the R/S Jx subcrestal by 1.5 mm, 1.5 mm of crestal bone was lost so that again, the new crest came to lie at the level of the R/S Jx (Hermann et al, 2000a;b.). As a result, current implant designs often include implant collar finishes such as moderately roughened surfaces (e.g. acid-washed, laser-etched) or even micro-threads in the hopes of allowing some gentle crestal bone loading and avoidance of disuse atrophy that could be promoted with polished collar segments.

It is common to observe bone loss arresting to the level of the first thread of a threaded dental implant. This may be a result of the nature of forces around the implant threads. Cortical bone is the most resistant to compressive loads, 30% weaker to tensile forces, and 65% weaker to shear forces (Reilly and Burstein, 1975). Implants with smooth collar designs only transmit shear forces to bone (Misch, 1999a). Bone loss may stabilize after the first thread becomes exposed because this exposure of the first thread changes the shear forces of the crestal module to compressive force to which bone is more resistant (Misch et al, 2005). Further evidence of crestal bone loss resulting from high localized stresses has been provided by Pilliar (Pilliar et al, 2006). He states that micro-fractures resulting from localized high stress concentrations can cause resorption of crestal bone on compressive surfaces adjacent to threaded implant designs subjected to controlled off-axis implant loading.

Misch has discussed implant thread geometry stating that the functional surface area per unit length of an implant is affected by thread geometry (Misch, 1999a). The functional surface area actively dissipates compressive and tensile non-shear loads through the implant-to-bone interface during loading. For this reason, long (>8 mm designed intrabony length; Renouard and Nisand, 2005) threaded implants generally perform better than short ones (≤8 mm designed intrabony length). There is also a passive surface area, which does not participate in load transfer. The functional surface area of a thread is its bottom aspect as this portion transmits compressive or tensile load. There are three factors contributing to thread geometry. Firstly, is thread pitch which is the distance between adjacent threads. The smaller the pitch, the more threads on the implant body, and therefore more surface area. The second factor is thread shape in which three types are found: V-shape, reverse buttress, and square. The V-shape is used for fixation of
devices such as bone plates, the reverse buttress is flat on top to optimize resistance to pullout loads and the square (power) thread provides optimal surface area for compressive load transmission. The shear force for a V-thread is ten times greater than for a square thread. The reduction of shear loading at the bone-to-thread interface is important in compromised bone strength under high occlusal loads (i.e. posterior regions of the mouth). The thread depth is the third factor helping to define thread geometry and is the distance between the major and minor diameters of the thread. As the thread depth increases the implant surface area increases. Misch advocates the use of various thread designs modified along the length of an implant to give more functional surface area in the regions of highest stress. Therefore, implant design features likely influence peri-implant crestal bone homeostasis after loading.

**Bone Response**

The intrinsic ability of bone adaptation to surrounding structures and forces is described by Wolff’s Law (Wolf, 1986). This concept proposes that changes in bone function are followed by changes in internal structure and external conformation in accordance with mathematical laws. The applicability of Wolff’s law to dental implant and bone interaction has been observed in several ways, including increased bone density around accumulating around loaded implants. It has been estimated that 100 microns of movement can be tolerated before a fibrous tissue repair rather than bone formation and osseointegration will develop (Brunski, 1999). Micromotion is thought to interfere with fibrin clot attachment and organization. This impacts angiogenesis to the healing tissue, which in turn interferes with regenerative cells migrating to the area. Thus, likely it is the absence of excessive micromotion at the bone-implant interface rather than the absence of loading that is critical for osseointegration of a dental implant during initial healing (Szmukler-Moncler et al, 1998).

In summary, crestal bone loss is multi-factorial with factors ranging from surgical placement technique, implant design, thread design, occlusal forces and patient related factors. Therefore, to comprehensively study and quantify the effect of each factor is inherently difficult and multiple modes of investigation are required.
II. Effect of Implant Dimensions on Implant Success & Survival

Accepted implant treatment philosophy and the majority of published literature do not support the routine use of short threaded dental implants when there is more bone available. In a fairly recent review article, Renouard and Nisand (2006) provided a detailed review on the performance of short dental implants and offered an updated definition for ‘short’ as it applies to these devices. A short dental implant is now defined as one with a designed intrabony length, i.e. length meant to remain within bone and provide for long-term osseointegration, of ≤ 8 mm. Early studies found increased failure rates with short implants and linked increased risk of failure to operator learning curves, machine-surfaced implant finishes and/or sites with poor bone density. However, more recent reports with threaded implants having more textured surfaces such as those created by particle-blasting or acid-washing, as well as with SPS implants, indicate survival of short implants comparable with those obtained with longer ones (Anitua et al, 2008; ten Bruggenkate et al, 1998; Kermalli et al, 2008). The present study included a significant number of implants (mostly SPS) that were truly short by the aforementioned definition.

Implant Length

Renouard and Nisand (2006) reviewed 53 papers published between 1990 and 2005 and summarized data from 13 studies with 2072 patients restored with 3173 implants and a mean implant length of 7.9 mm. Follow-up times ranged from zero to 168 months. 9.5% of implants were lost to follow-up and the mean implant survival rate was 95.9%. The worst reported data for 7 mm long threaded machine-surfaced implants was from a study by Wyatt and Zarb (1998) that documented a 25% failure rate. Winkler et al (2000) reported 74.4% survival in their sample of forty-three 7 mm implants of various designs and again concluded that shorter threaded implants tended to fail significantly more often following uncovering and after loading than longer ones. In contrast, Bahat studied 732 threaded machined-surface implants and found that the failure rate for 7 mm length machine-surfaced threaded implants was 9.5% compared to 3.8% for all other implant lengths (Bahat, 1993).

Renouard proposed reasons for increased failure rates with truly short implants such as the use of routine surgical protocols regardless of bone density. For example, the use of a tapping protocol in bone of low density might reduce primary stability especially for shorter implants. More
recent studies showed good results for short implants using an adapted surgical protocol to gain better primary stability, i.e. not using a countersink in bone of lower density (Tawill & Younan (2003); Fugazzotto et al, (2004)). In the twelve papers reviewed by Renouard that reported increased failure rate for short implants, the majority of the papers included only machine-surfaced implants, or machined and hydroxyapatite-coated implants. In the nine papers which reported no influence of implant length, 6 involved textured surface implants primarily of moderate surface roughness while, the other studies used mainly machine-surfaced implants. A study by Herrmann et al (2005) compared shorter implants in jaws with shapes E and D (i.e. highly resorbed) according to Lekholm and Zarb classification (Lekholm & Zarb 1985). It was found that jaw shape and bone quality negatively impacted implant survival since short implants placed in poor quality sites were more likely to fail. It may have been more appropriate to compare short implants placed in sites with poor bone to long implants also placed in sites of less than ideal bone quality, e.g. that require augmentation or pre-implant site grafting. van Steenberghhe et al (1990) concluded that generally longer and wider machine-surfaced threaded implants failed to a lesser extent than shorter standard diameter (i.e. 3.75 mm) implants again with failures being concentrated in patients with poor bone quality.

Renouard and Nisand’s review included studies that reported outcomes with short implants to be comparable to those with long implants. For example, a study of 532 implants in 293 patients treated with 7 to 8.5 mm long threaded implants showed an overall survival rate of 99.2% over a mean follow-up period of 31 ± 12.3 months (Anitua et al, 2008). Similarly, Friberg et al (1991) reported a survival rate for 793 7 mm long Brånemark implants of 94.5% a while, Lekholm et al (1999) reported 10 year study data showing 93.5% survival for 7 mm long Brånemark-type implants. Renouard & Nisand themselves reported mean marginal bone loss of only 0.44 +/- 0.52 mm after 2 years of function for 7 mm long machine-surfaced implants placed using a modified surgical protocol that favored greater initial implant stability (Renouard and Nisand, 2005). A recent review by Romeo et al (2010), confirms the findings of comparable survival for modern implant surfaces and techniques.

As stated above, performance of shorter implants with greater surface textures have sometimes been reported to be better than those with machine-surfaced implants. For example, ten Bruggenkate et al (1998) reported favorable outcomes with 253 6 mm long TPS-coated (titanium plasma-sprayed) implants in 126 patients after 1 to 7 years of function. However, Fugazzotto
reported a 95.1% success rate for single tooth short (primarily 8 to 9 mm long and diameter 4.8 mm) implants placed without countersinking in the maxillary first molar and second premolar location (Fugazzotto et al, 2004). Apropos, past studies have not fairly compared short and long dental implants and for the most part were focused on implant surfaces and designs no longer in widespread clinical use.

The present study focused on implants placed in the posterior maxilla and mandible where bite forces are estimated to be 300% greater compared to anterior jaw segments (Misch, 1999b). Since vertical bone height is often limited by the level of the mandibular neurovascular canal and maxillary sinus, it is common for implant length to be sacrificed due to these anatomical limitations in posterior jaw sites. Studies focusing on implants with modern designs and surgical techniques have reported comparable results compared to standard length implants. Therefore, although shorter implants have less surface area available for osseointegration (Misch, 1999a), with appropriate techniques and implant design, respectable outcomes can be expected.

**Implant Diameter**

The relationship between implant diameter and crestal bone loss has been reported by many studies and results vary considerably. Earlier studies had suggested that wide diameter (≥ 5 mm) threaded implants might be less successful than standard diameter ones. The bicortical (i.e. buccal and lingual) engagement of implant threads likely to occur with wide diameter implants was speculated to compromise healing due to the hypovascularized nature of cortical bone compared to cancellous bone. Ivanoff et al (2000) reported that failures were four times more frequent with wide diameter, bicortically anchored implants. Likewise, Davarpanah et al (2001) reported that placing wide-body implants in narrow ridges (increasing the likelihood of having bicortical contact) also may have led to increased failure rates.

Mordenfeld et al (2004) reported better results with wide diameter implants in the mandible (94.5%) than in the maxilla (78.3%) but this would tend to argue against the idea of bicortical anchorage being the issue. In contrast, Aparicio & Orozco (1998) reported a cumulative survival rate of 97.2% in maxilla and 83.4% in mandible with wide diameter implants. Winkler reported survival rates of 90.7% for 3 mm+ wide and 94.6% for 4 mm+ wide threaded dental implants (Winkler et al, 2000). A more likely reason for wide diameter implants to have increased failure rates may be because they were often used as ‘rescue’ implants and placed into sites where
primary stability could not be achieved with standard diameter implants (Renouard and Nisand, 2006). In addition, wide diameter implants are often placed in the posterior jaws where bone quality may be of lower density and forces are higher. Although wide diameter implants have increased surface area available for osseointegration, localized site factors and surgical technique may contribute to reports of lower survival. In summary, when the dental implant width is selected appropriately to the edentulous ridge, predictable results can be expected.
III. Radiographic Measurement of Crestal Bone Loss

Various radiographic techniques have been described to measure crestal bone levels around dental implants including digital and conventional periapical (PA), horizontal bitewing (hBW) and panoramic (PAN) radiographs as well as cone beam computerized tomography (cbCT) (Bragger et al, 1991; Naert et al, 2002b; Kullman et al, 2007; Wakoh et al, 2006). Changes around implant bone levels may be assessed in relation to stable landmarks such as implant threads, implant-abutment interfaces or collar contours (Bauman et al, 1992). While some authors have specified in their publications the details of a particular apparatus used to obtain standardized radiographs, there is limited evidence available comparing various methods and their accuracy. In the present study, conventional (i.e. non-standardized) PA and vertical bitewing (vBW) radiographs were compared for measuring bone levels and incidence of distortion when assessing peri-implant crestal bone levels.

Measurement techniques for detecting peri-implant crestal bone loss vary by investigator. Studies where one examiner measures all the films typically have that examiner measuring a sample of films multiple times to allow for an intra-examiner reliability test. However a study design with only one examiner may have an opportunity for bias. Study designs that include multiple examiners typically have an inter-examiner reliability co-efficient calculated. Meijer showed that the difference in crestal bone measurements between two observers was 0.1 mm +/- 0.40 mm (Meijer et al, 1992). This was primarily due to discrepancies in defining the crestal bone level.

Literature Regarding Radiographic Evaluation of Crestal Bone Loss

Naert presented radiographic data from a longitudinal evaluation of machine-surfaced, threaded dental implants used in partially edentulous patients. The mean follow up time of implant function was 5.1 years ranging from 1-16 years (Naert et al, 2002a). Radiographs were taken with the paralleling cone technique and measured for crestal bone loss relative to the implant-abutment connection. Measurements were performed under 4X magnification with a digital caliper and film quality was assessed by the absence of blurring of implant threads. The study included implants with prostheses that were any of single crowns, prostheses connected to teeth and implants and implant-supported fixed partial dentures. It was found that single (i.e. non-
splinted) implant crowns did not lead to more marginal bone loss than that seen around splinted implants. The authors included implants in all areas of the mouth and found no difference in bone loss between anterior and posterior jaw sites. There also was no difference in bone loss due to implant length. They found a mean of 1.23 mm loss of bone in the first 6 months with an annual loss thereafter of 0.025 mm confirming earlier reports with the same implant device (Adell, 1985; Albrektsson et al, 1986). More bone loss was seen in the maxilla (greater by 0.31 mm/year in the first year) than in the mandible. Bone gain was seen with 14.57% of implants and 98.75% of implants had less than 3mm bone loss, 92.43% had less than 2 mm and 64% had less than 1 mm. This study by Naert also confirmed results from a study of machine-surfaced, threaded implants by Goodacre. Mean bone loss in the first year was 0.9 mm (0.4-1.6 mm range), and mean annual loss thereafter was 0.1 mm (Goodacre et al, 2003). These investigators found that 1.5% of implants lost more than 2 mm over 3 years, 23% lost 0.1-0.5 mm, 34% had no bone loss and 19% had bone gain.

**Methods for Measuring Radiographs**

Radiographs can be measured by calculating bone loss in terms of the number of threads exposed or in millimetric values from a reference point. When assessing radiographs, they can be measured on plain films with the aid of magnification and conventional rulers or digital calipers. Alternatively, radiographs can be digitalized and measured with computer software that incorporates calibration of known dimensions such as implant length. The implant length as reported by manufacturers must be scrutinized prior to calibration of films. Many dental implant designs incorporate a smooth collar into their implant design and the smooth collar may be considered part of the intraosseous implant length or considered as additional height to the implant length. Furthermore, implant manufacturers may advertise implant lengths in convenient incremental heights, but in actuality they are fractions of millimeters shorter (see Appendix 2).

**Comparison of Radiographic Techniques**

Many published studies lack standardization in radiographic techniques. Smith & Zarb stressed the need for standardized serial radiographs (Smith and Zarb, 1989). They recommended the use of a positioning device to ensure the x-ray beam is at right angles to the long axis of each
implant. Cox and Pharoah (1986) used a film holder device which was screwed directly to an implant after the suprastructure had been removed. A similar device was later used in both animal and human clinical trials of SPS implants (Al-Sayyed et al 1994; Levy et al, 1997). Several methods have been developed to improve and standardize the projection geometry of serial radiographs (Strid; 1985, Larheim et al, 1979; Hollender and Rockler, 1980). The importance of consistent longitudinal radiographs is reported by Sewerin where it was showed in vitro that a 1° deviation between exposures of two sequential radiographs can result in crestal bone levels differing by 0.09-0.25 mm (Sewerin, 1990). Hollender and Rockler (1980) concluded that an accurate interpretation of bone area around implant threads depended on x-ray beam angulations being less than or equal to 9° from a line perpendicular to the long axis of the implant. If the x-ray beam angle is greater than or equal to 13° perpendicular to the long axis of the implant the result is a total overlap of threads. This poses a major difficulty in interpreting radiographs reliably and comparing results longitudinally. Furthermore, there are many exposure and development variables in conventional radiographs that limit the value for longitudinal assessment of subtle alveolar bone changes (Lang and Hill, 1977).

Crestal bone loss measurements can be impacted by the type of film utilized. There are a number of studies in which PA and PAN radiographs were compared for accuracy in measuring crestal bone levels. Kullman compared crestal bone levels of implants using panoramic and intraoral (PA) radiographs of implants in the mandible with two observers and found that while intra-observer agreement was good or very good, inter-observer agreement was only moderately good (Kullman et al, 2007). They found that 7% of radiographs could not be assessed because of film quality and PAN radiographs were as reliable as conventional intraoral radiographs in assessing the point of bone attachment to the implant threads. It was noted that the PAN method gave unreliable magnification and film distortion.

In a study by Penarrocha (Penarrocha et al, 2004) crestal bone loss was measured at the time of loading and 1 year after loading using PAN, conventional PA and digital radiography. Results showed 1.36 mm of bone loss with PAN, 0.76 mm with PA and 0.95 mm with digital PA. In addition, more bone loss was found at maxillary sites and in smokers. The investigators concluded that conventional and digital PA radiographs are more accurate than the PAN technique. In addition, no relationship was found between implant diameter and crestal bone loss, a result which confirms some other studies (e.g. Ivanoff et al, 1999).
Lofthag-Hansen compared PA and narrow-beam PAN radiography and found that there was better agreement in posterior sites (Lofthag-Hansen et al, 2003). However, they did not measure crestal bone loss in millimeters, but rather by the number of threads exposed. Their criterion for an accurate PA was that the implant threads were clearly visible as this suggested that the film was parallel to the implant’s long axis. De Smet found 0.2 mm error between PA and PAN techniques (De Smet et al, 2002). In their study, implants were placed in human cadavers and radiographs taken with conventional and digital PA and PAN. Measurements on radiographs were made using a digital caliper with a 2x magnification. Measurements were also made of actual bone loss around the implant in the cadavers for comparison purposes. Therefore, this is one of the few studies to publish gold standard *in vivo* measurements compared to radiographic measurements. It was concluded that the more accurate radiographic measurements were those made using intraoral films. A later study confirmed these findings that standardized PA were more accurate than PAN or CT in measuring implant length and as a reliable modality for longitudinal and linear distance measurement (Wakoh et al, 2006).

**Digital Subtraction Radiography**

Bragger studied the digital subtraction radiography technique to assess subtle density changes in peri-implant tissues that might provide diagnostic information on implant osseointegration during maintenance phases of patient treatment (Bragger, 1988; Bragger et al, 1991). The major benefit of digital subtraction radiography is that it potentially allows for detection of any changes (gain or loss) in bone density around an implant with time in function. In order to perform digital subtraction radiography, standardized radiographs are required along with computer software to analyze the radiographs. Films can be exposed using customized bite blocks to position the film and this should allow for identical exposure geometry as long as the teeth or implants being radiographed do not change significantly in position over time due to new tooth restorations or extractions. Exposure settings and development or digital capture techniques require careful control.

Bragger measured radiographs taken immediately after implant placement and after 1 year in function (Bragger, 1988). Measurements were made three times from the crest of bone to the implant shoulder and results ranged from -1.72 mm to +1.47 mm of bone remodeling. It was
suggested that this technique is an objective, quantitative and non-invasive method to obtain additional diagnostic information.

In addition to assessing crestal bone loss, observation around the entire implant fixture may reveal presence of health or pathology. A very thin radiolucent zone may be seen around failing or failed implants indicating fibrous encapsulation but may exceed the resolution capabilities of non-standardized radiographs because of overlap of implant structures (Balshi and Mingleedorff, 1977). Brånemark reported that slowly developing implant mobility is generally represented by radiographic crestal bone loss, but sudden-onset implant mobility often demonstrates no radiographic change (Branemark et al, 1977). Strid described the radiographic image of a healthy osseointegrated implant as one where the bony architecture displays horizontal peri-implant trabeculae, individually related to the titanium surface and radiating predominantly from the edges of the fixture threads. Strid reported that in about one-tenth of implants, a thin layer of cortical bone, approximately 1mm thick will surround the implant. Proof of this has been established by computer-aided densitometry which showed increasing peri-implant bone density occurring several years following onset of implant function (Strid, 1985).

**Recommended Clinical Guidelines**

Guidelines recommending the frequency of implant radiography were suggested by Albrektsson et al (1986). The recommendations were for films to be taken 1 week after stage 2 surgery, at the time of prosthesis insertion, 6 months after insertion of prosthesis, annually for 3 years thereafter and if no complications have appeared, then after every subsequent two years. The value of a baseline radiograph at the time of implant placement has been debated in the literature and at the least serves as a baseline record of peri-implant structures and provides medico-legal proof of procedure. Strid recommended that a designated member of the clinical team who has dependable radiographic skills be responsible for the taking of all implant films to improve the comparability of serial radiographs. The machine settings for implant radiography recommended by Strid are no less than 60 kVp, and better to be between 65-70 kVp. It is also recommended that 2 exposures at a 6-12° variance in the horizontal plane (stereoscopic) will help detect bony defects that may be obscured by the implant in a single exposure (Albrektsson et al, 1986).

There are several problems with obtaining reproducible parallel film placement. The most common issue is a shallow mandibular vestibule or palatal vault which impairs proper film
placement. To overcome this problem, Bauman recommended the use of two films, one to capture the entire implant length but not parallel to it and a second film that is parallel only to coronal part of the implant including the crestal bone. Another suggested method is use of a cotton roll between the film holder bite block and the occlusal surface of the teeth if the film length relative to occlusal-vestibular dimension is too big. The second common source of error is the manner in which the patient bites on a film holder bite block. If the patient bites more facially or lingually on the block, the relation of the mandibular teeth relative to the maxillary teeth may cause the film holder to deviate from its parallel position relative to the long axis of the implant.

Therefore, there is an abundance of recommendations reported on literature with very little consensus. This study will attempt to recreate clinical conditions found in a private practice setting and endeavor to elucidate practical techniques with supporting data to aid clinicians with their implant maintenance and recall programs.
IV. Finite Element Analysis of Peri-Implant Force Distribution

Finite element analysis (FEA) is a technique that attempts to understand and further refine dental implant performance. FEA is typically used in industry to create analytical solutions to problems involving complex geometric forms (Geng et al, 2001). Since 1976, FEA has been utilized to simulate the effect of various materials, designs, and forces that affect dental implants (Weinstein et al, 1976). In a FEA, materials are defined by their mechanical properties e.g. Young’s modulus. The types of loads are defined and the problem is solved for each element initially before an aggregate solution can be quantified (Zienkiewicz, 1989). Ongoing research with this methodology has improved in accuracy and now allows for virtual models to be developed that are analogous to clinical scenarios.

Limitations of FEA

The purpose of the present investigation was to assess the effect on crestal bone loss of splinted compared to non-splinted implant prostheses in the posterior maxilla and mandible and several published FEA studies appear relevant to this question. However, the validity of the FEA approach has been questioned by De Tolla who stated that early FEA methods were flawed and plagued with large errors rooted in inaccurate assumptions such as using axially directed static loads, homogenous properties of bone, perfect bonding between bone and implant, improper boundary conditions and two dimensional models (DeTolla et al, 2000). Since FEA models are based on a virtual representation of a clinical scenario, results rely heavily on the quality of data utilized to build the virtual simulation (Brunski, 1992; Geramy and Morgano, 2004).

FEA and Implant Length

One of the goals of many FEA studies has been to investigate stress and strain patterns and concentration areas around implants. Investigators have studied effects of implant length and diameter with various types of prosthetic designs and forces experienced. A recent publication looked at the effects of implant length and diameter prior to and after osseointegration (Georgiopoulos et al, 2007). It was concluded that regardless of the integration phase, as implant length increased, stress on the implant-to-bone interface decreased, and that delayed loading had effects on trabecular bone only, not cortical bone. There was no correlation between the
influence of implant diameter and stress reduction. This study has limitations in that it utilized a two-dimensional FEA model.

In another recent study, five different implant designs were assessed with three-dimensional FEA in the posterior maxilla and mandible (Baggi et al, 2008). The assumptions of complete osseointegration and type II bone were made and various implant types (ITI, Nobel Biocare, Ankylos) with diameters ranging from 3.3 to 4.5 mm and lengths ranging from 7.5 to 12 mm were loaded statically with vertical and horizontal components. Several of the assumptions are considered questionable as assumed factors such as bone quality, level of osseointegration and type of force may not truly replicate in vivo conditions. It was concluded that maximum stress in the peri-implant region was around the implant neck, and that potential overloading could occur with the compression of compact bone and the tension at the junction of cortical and cancellous bone. Increasing implant length was found to improve stress distribution and increasing implant diameter decreased stress values in cortical bone.

Pierrisnard used FEA to study the influence of implant length and bicortical anchorage on peri-implant implant stress distribution (Pierrisnard et al, 2003). The design of the three dimensional FEA model included 3.75 mm diameter implants of various lengths from 6 to 12 mm placed in cortical and cancellous bone and loaded with occlusal forces of 100N at a 30° angle. It was found that coronal cortical anchorage was dominating and that bone stresses were concentrated in that area. The maximum bone stress was constant, and independent of implant length and bicortical anchorage. Stress was always located at the neck level regardless of implant length. Beyond the coronal 4 mm, stress intensity was low and peak stress was positioned at the inferior groove of the first thread. The effect of bicortical anchorage reduced displacement of the implant at the neck level and displacement of the implant was more if it was short. Therefore, it was concluded that long implants are more likely to bend whereas short implants are more likely to rotate.

General principles to guide clinical implant dentistry can be derived from the results and recommendations from several other FEA studies. Factors predicted to affect bone-implant stress distribution using FEA models include implant inclination, number of implants and their location, prosthetic splinting scheme, occlusal surface areas, framework materials and shape of the prosthetic framework (Geng et al, 2001). Canay found that angled implants experience five
times higher compressive stress around cervical bone than non-angled abutments (Canay et al, 1996).

**FEA comparing SPS vs. Threaded Implants**

The present study examined three different implant designs; those being sintered-porous surface (SPS) tapered press-fit implants and two designs of moderately rough-surfaced threaded (THR) implants. A three dimensional FEA study by Pilliar examined the use of completely bonded SPS and machined THR implants when used for orthodontic treatment anchorage and the resulting effects on peri-implant bone (Pilliar et al, 2006). It was found that SPS implants had less stress and a more uniform transfer of the applied forces (300 g lateral force). Peak stresses were twice as high in the most coronal region of threaded implants. Bone stresses at the most coronal thread were 50% higher than the equivalent position for SPS implants. Peak stresses next to threaded implants were more than double those with the SPS design. These findings corresponded to histomorphometric results in animal studies with the same implants (Oyonarte et al, 2005a;b). This study is significant in that it validates a FEA with *in vivo* outcomes and demonstrates differential stress transfer for SPS compared to threaded implants.

**FEA and Posterior Implants**

The focus of the present study was on posterior implants, which are more susceptible to biomechanical problems that can manifest clinically as biological and mechanical failures (Bakaeen et al, 2001). In a three-dimensional FEA study by Geramy and Morgano (2004), scenarios in which a molar tooth was replaced with either one 3.75 mm or one 5 mm diameter versus two 3.75 mm diameter implants also were examined. Implants were loaded with 35N and 70N loads at three different locations on the implant and at different angulations (axial and 15° off axis). The results suggested that a 5mm diameter implant reduced abutment strain by 40% compared to a single 3.75 mm diameter implant. They concluded that a single missing mandibular molar is better replaced with either a wide-diameter implant or two standard diameter threaded implants. Non-axial loading with the double implant design resulted in less micromotion of the crown-implant unit than with the single wide-diameter implant design. In addition, increasing implant width with single implant-supported prosthesis from 3.75 mm to 5 mm may reduce micromotion of the fixture by 50%. Similar conclusions were found in another
FEA by Seong study (Seong et al, 2000). Clinical recommendations by Geramy were to concentrate occlusal forces as close to the bucco-lingual center of the implant by narrowing the occlusal table, to direct maximal intercuspal contacts along the central groove of the crown and to eliminate eccentric occlusal contacts.

**FEA of Splinted and Non-Splinted Posterior Implants**

Many wide body (i.e. 5 mm diameter) implants were included in the present study data set. Several studies have examined wide-body implants using FEA and clinical analyses. Huang et al (2005) studied two adjacent implants of varying sizes in premolar and molar regions with either splinted or non-splinted crowns in a FEA. This study is of interest as this scenario was commonly found in the present study. Implants were modeled as cylindrical roots (not with threaded surface geometry) and in a simulated mandible with cortical and cancellous layers. This study was modeled based on a CT scan of a cadaver mandible with implants in premolar and molar positions. The FEA was validated experimentally via strain gauge measurements on the cadaver mandible. The experimental strains were higher than simulated, and results showed a high correlation. Thus, when a splinted molar crown was supported by either, a wide body or two standard diameter implants, bone stress in the premolar site was decreased by 25%. The wide implant or two splinted implants reduced peak stress in crestal bone by 29-37% compared to a single standard diameter implant. When standard diameter implants were used in premolar and molar regions, there were identical bone stresses whether they were splinted or not. The stress on cortical bone around the first molar implant when splinted with a wide body or two standard diameter implants decreased by about 30% compared to a standard diameter implant in the molar region. Therefore, splinting is significant only if the support of the implant at the first molar region is stronger than that at the premolar site (i.e. a wide body implant). It was concluded that the biomechanical advantages of using a wide diameter implant or two standard diameter implants are almost identical and that the benefit of load sharing by splinted crowns is only significant when the implants in the premolar and molar regions are different sizes.

With the aid of computer simulated clinical conditions, various scenarios have been analyzed and have guided implant design and clinical decision making. The clinical relevance of FEA has been disregarded by many clinicians, however it provides valuable quantitative information and a unique form of analysis that cannot be gather by other means.
V. Clinical assessment of implant - Success vs. Survival

A variety of clinical parameters have been utilized to evaluate long-term implant survival and success. A concise literature review of these various parameters and criteria for both implant survival and implant success are discussed below.

Dental implant survival is defined as continued functionality of the implant in the absence of clinical mobility, radiographic evidence of pathology, unresolved pain, discomfort or infection. Failure is defined as removal of the implant for any reason (Morris and Ochi, 2000). Success has a variety of definitions and typically requires a more stringent evaluation process.

Sennerby & Becker (2000) have addressed this issue suggesting that both the terms ‘success’ and ‘survival’ imply that osseointegration has been achieved and maintained during functional loading. However, they recommend that the term ‘success’ be applied for prospective studies in which all implants are accounted for. All implants would be tested for individual implant mobility, which would include removing all fixed prostheses, and a recent radiograph should show no more than 1 mm of crestal bone loss after the first year of implant function and no more than 0.2 mm per year thereafter. If an author wishes to use a modified success criterion, it should be explicitly stated. The authors also suggested that the term ‘survival’ should be applied to all retrospective studies and include implants that are in the mouth but may not have been tested for mobility or assessed annually for all patients. This criterion is useful for studies that include patients that irregularly return for recall appointments. Survival data should be reported in a life-table analysis and all implants must be accounted for including any implants and patients lost to follow up.

Peri-Implant Hard Tissues

The original criteria for implant success was published by Albrektsson (Albrektsson et al, 1986). A dental implant was considered to be successful when it was individually immobile when tested clinically and had a recent radiograph without evidence of peri-implant radiolucency. In addition, a successful implant could not show more than 0.2 mm of vertical crestal bone loss annually after the first full year of function. And finally, a successful implant could not have persistent or irreversible signs and symptoms of pain, infections, neuropathies, paresthesia or violation of the mandibular canal. To be considered a successful clinical trial outcome, a study group could not
show less than 85% successful implants after 5 years of function or less than 80% successful implants after 10 years. Success values for periods greater than 10 years in function could not be provided at the time of the study as there weren’t sufficient data to support any conclusion. Smith & Zarb (1989) also published suggestions for determination of success rates for dental implants. They concurred with the recommendations of Albrektsson et al (1986) but suggested that implants that are placed but left submerged and are non-functional for various reasons should be excluded in all determinations of success. In addition, complications that were of an iatrogenic nature (e.g. poor surgical placement) and not due to material or design problems were to be considered separately when computing the success rate.

**Periotest®**

Initially, checking implant mobility was simply done crudely with two dental hand instruments. Later, however, the Periotest® (PT) device, a dampening device introduced to measure tooth mobility objectively was used for implants as well (Aparicio 1991; Deporter et al, 2002). The PT is a hand piece that contains a metal slug that accelerates, driven by an electromagnet, towards a tooth or implant. The contact duration of the slug on the tooth or implant surface is measured by PT and quantified in a range of values (-6 to +2). The lower the PT value the more stable the tooth/implant. The test does show decreasing values as time after insertion of an implant increases which is consistent with bone remodeling around an implant. The test has high specificity but low sensitivity.

**Resonance Frequency Analysis**

More recently, resonance frequency analysis (RFA) has replaced the PT in clinical research with implants. It was introduced in 1996 by Meredith and was initially a device that screwed onto the implant or abutment and connected via cables to a monitor. The current design is a wireless machine with an aluminum peg that is screwed into an implant (Meredith et al, 1996). A transducer produces a resonance frequency on the implant which is measured in ISQ (implant stability quotient) units. High ISQ values (e.g. 60 or more) are a sign of a successfully integrated implant. The RFA value is affected by the stiffness of the bone-implant complex, the jaw containing the implant, patient sex, as well as implant diameter and length. In a study by Friberg et al (1999), 75 one-stage implants were assessed with RFA at placement. Several of the
implants showed a dramatic decrease in ISQ values during the study and these changes were linked to excessive loading by a relined denture. However, unloading these implants improved their ISQ values. In another study by Glauser, RFA was performed on 72 immediately loaded implants longitudinally (Glauser et al, 2005). Implants with decreasing stability showed a continuous decrease in ISQ values until clinical failure.

In a review by Aparicio et al (2006), the validity of both PT and RFA tests to estimate the bone-implant contact interface was investigated. Results indicated that without randomized control clinical trial or prospective cohort study designs, both methods have given inconsistent results affected by factors such as bone density, jaw location, abutment length and supracrestal implant length.

**Peri-Implant Soft Tissues**

Researchers have investigated and debated the relevance of peri-implant mucosal health as an indicator of implant success. Early authors questioned the validity of classical periodontal indices and the importance of the peri-implant soft tissue seal (Adell, 1985, van Steenberghe, 1988, Zarb and Symington, 1983, Bauman et al, 1992). Bauman recommended use of a plaque index to monitor oral hygiene as plaque, he felt, was the primary etiologic factor in peri-implant destruction (Bauman et al, 1992). It is only recently, however, that other investigators have reported that the width and thickness of peri-implant keratinized mucosa may be crucial factors in long-term implant health and success (Block et al, 1996; Bouri et al, 2008; Linkevicius et al, 2009). According to Wie, probing depths were the most accurate means of detecting peri-implant destruction (Wie et al, 1979). Probing depths should include measurement of soft attachment levels and be measured relative to a fixed reference point on the abutment or prosthesis. The location of the probe tip penetration around an implant was investigated by Buser and it was found that the mean discrepancy between probe penetration and location of bone margin was 1.17 mm measured 1 year after implantation (Buser et al, 1990). Similarly, Quirynen reported that the probe tip while probing around an implant appeared to stop 1.4 mm coronally to the bone level (Quirynen et al, 1991). However, as happens with natural teeth and probing (Caton et al, 1981), the more inflamed the peri-implant gingiva, the deeper the penetration of the probe. Overall, peri-implant probing depth appears more sensitive to force variation during probing than for similar measurements around teeth (Buser et al, 1990).
In the present study, ‘survival’ was defined as a functioning restored implant present in the mouth free of mobility (tested with two dental hand instruments only and without removing the prosthesis) or sensitivity to percussion. ‘Success’ was based on a radiographic assessment of peri-implant crestal bone levels measured in periapical and vertical bitewing radiographs and required that an implant show no more than 1 mm of bone loss after year one and no more than 0.2 mm annually thereafter. Data collection was complicated by the fact that three different implant designs were involved and they differed in designed intrabony lengths, i.e. the length of implant surface meant to achieve and maintain osseointegration. For example, the THR-SLA implant design had a smooth neck of 1.8 mm length, the SPS implants had a smooth collar of either 1 or 2 mm and the THR-DAE had a machined collar and several machine smooth coronal threads where osseointegration may be possible but not always maintained. Therefore, it was decided that in order to assess fairly the success of these implants the reference point of bone loss would not occur at the implant-abutment interface, rather the length of the smooth or polished coronal portion of the implant collar or neck would be subtracted from the crestal bone loss and the success calculation would be measured.
VI.  *Forces and Peri-implant Bone*

The present study focused on crestal bone loss around implants placed in posterior regions of the mouth. The posterior area of the maxilla and mandible both pose difficulties when placing implants for similar and unique reasons. The bite forces are 300+% more in posterior compared to anterior sites (Misch, 1999b). The result of this increased force transmitted to peri-implant bone can have different effects based on the type and amount of force. Esposito found that late failure of primarily machine-surfaced threaded implants was rarely associated with an infectious factor but rather the combination of poor bone quality and overload was considered to be the leading cause for the late implant failure (Esposito et al, 1997).

Isidor discussed the effect of mechanical stress resulting in strain (deformation) of bone around dental implants (Isidor, 2006). The amount of strain was directly correlated to the stresses applied to the bone and the strain was dependent on the mechanical properties of the bone (i.e. quantity and quality of cortical and cancellous bone).

**Types of Force and Bone Response**

The concept of bone having an intrinsic ability to adapt to forces placed on it is explained by Wolff’s Law. Frost and Isidor explained that the response of peri-implant bone to increased mechanical stresses below a certain threshold will result in strengthening of the bone by increasing the bone density or apposition (Isidor, 2006, Frost, 1992). However, fatigue micro-damage resulting in bone resorption may be the result of mechanical stresses beyond this threshold (Frost, 1992). In a subsequent paper, Frost discussed four types of strains on bone (Frost, 1994). Firstly, if no stress or force is placed on bone, disuse bone resorption may occur. If the load is physiologic then bone homeostasis occurs. A mild overload results in bone mass increasing, and pathologic overloading results in bone damage and subsequent fracturing. Several studies by Piattelli confirm this by showing increase bone density surrounding mechanically loaded implants compared to non-loaded implants in monkeys (Piattelli et al, 1997; Piattelli et al, 1998; Piattelli et al, 1993).
**Excessive Force and Implant Response**

Several studies have tested hyper-occlusion of implants placed in animal models and demonstrated excessive crestal bone loss. In a series of studies by Miyata, high premature contacts of varying amounts were placed on implants in monkeys. The investigators found that the higher the premature contact, the more marginal bone loss, even with only 4 weeks of loading. Bone loss was found when the occlusal contact was high by 180um and 250um (Miyata et al, 1998, Miyata et al, 2000, Miyata et al, 2002).

In a series of studies by Isidor, five implants were placed in the mandible of four monkeys and restored such that 2 implants were occluding in a supra occlusal contact with lateral displacement. The other 3 implants had a cotton cord placed around to increase plaque accumulation and create experimental peri-implantitis. The supra occlusal implants were cleaned, and the others were not. It was found that 5 of 8 implants with excessive occlusal load lost osseointegration in the 4.5 to 15.5 months of overloading. None of the implants with plaque accumulation lost osseointegration although after 18 month there was 1.8 mm of crestal bone loss (Isidor, 1996, Isidor, 1997b, Isidor, 1997a, Isidor, 1998). This is contrary to previous reports that have shown plaque accumulation causes progressive bone loss around implants in monkeys, dogs and microswines. The 5 implants lost to excessive loading had distinct peri-implant radiolucencies. The results of the Isidor’s studies were in conflict with a study by Heitz-Mayfield who performed a similar study in a dog model. The implants were in hyper-occlusion and had mucosal health and the investigators found no effect of high occlusion on marginal bone loss (Heitz-Mayfield et al, 2004). The major difference in these studies was type of animal, amount of bone mineralization near implant and direction of force (Heitz-Mayfield loaded implants in an axial direction whereas Isidor used more deleterious lateral loading).

Brunski attempted to overload implants in a controlled manner with 100N forces for 500cycles/day for 5 days, and histology done 20 days after loading showed that too low a force and/or too short a time had been used for bone to develop a measureable response (Brunski, 1999). A study by Hoshaw loaded implants with 300N tensile force for 1 year. Histology after the loading showed significantly more crestal bone loss in loaded vs. unloaded implants (Hoshaw et al, 1994).

Misch (2005) discussed a positive correlation between occlusal trauma and peri-implant bone loss. He speculated that bone remodeling which occurs at the cellular level is controlled by the
mechanical environment of strain (Misch et al, 2005). One major cause of occlusal overloading is para-functional habits such as bruxism. Several studies have related late implant failures to para-functional occlusion (Balshi and Wolfinger, 1997b, Balshi and Wolfinger, 1997a). Fugazzotto published a retrospective paper of 1472 implants, and found 8 of 11 single terminal abutments failed in patients with para-functional habits. Implants failed in the 2nd molar region where occlusal forces are typically the highest (Fugazzotto, 2001). Moheng and Feryn (2005) concluded that implants are more likely to fail when they are supporting a posterior single tooth or RPD rather than overdenture or complete fixed prosthesis (Moheng and Feryn, 2005). Quirynen reported excessive marginal bone loss and or implant loss in patients with a lack of anterior contacts, the presence of para-functional activities, and/or full-fixed implant-supported prostheses in both jaws (Quirynen et al, 2002, Quirynen et al, 1992). However, Engel (2001) followed 379 patients with implants that had occlusal wear of their prostheses and did not find any significant impact on rate of annual vertical bone loss (Engel et al, 2001).

**Clinical Recommendations to Prevent Overloading**

Since implants are susceptible to overloading, factors contributing to overload are discussed by Kim (Kim et al, 2005). Possible overloading factors include a cantilever that is greater than 15 mm in length in the mandible or over 10-12 mm in the maxilla, para-functional habits, excessive premature contacts, large occlusal table, steep cusp inclination, poor bone density/quality and/or inadequate number of implants to support a large prosthesis. Several methods to reduce potential overload were suggested including a passive fit of the prosthesis, reducing cantilever length, narrowing the bucco-lingual and mesio-distal dimension, reducing cusp inclination, bruxism appliances, eliminating excursive contacts and/or centering occlusal contacts.

**Differential Response of Implants and Teeth to Forces**

Kim published an article outlining occlusal guidelines in implant therapy focusing on biomechanical considerations (Kim et al, 2005). The fundamental differences in how implants and teeth behave and react to forces were discussed. A natural tooth rotates at its center of rotation, typically located in the apical third of the root, upon a lateral load (Parfitt, 1960) and the force is diminished immediately from the crest of the bone along the root (Hillam, 1973). In contrast, an implant lacks a periodontal ligament, and under lateral loading has a high
concentration of forces at the crest of the surrounding bone and allows for minimal rotation or dampening effect (Sekine et al, 1974).

**Local Anatomy Relevant to Posterior Implants**

A paper by Tolstunov outlines distinct implant zones in the jaws and relates implant location to success rate (Tolstunov, 2007). The functional implant zones were based on anatomy, blood supply, pattern of bone resorption, bone quality and quantity and the need for grafting. The author defined functional implant zones (FIZ) as regions in the alveolar jaw where dental implants can be inserted with or without supplemental procedures. Four FIZ were discussed and two of these zones are relevant to the present study. The *sinus zone*, which is located in the posterior maxilla often requires vertical bone augmentation due to sinus pneumatization after loss of posterior teeth. The type of bone in this area also often has poor quality (type 3-4), and the blood supply to this area is primarily from the posterior superior alveolar artery which may be damaged during a direct sinus elevation. The second relevant FIZ is the *ischemic zone*, which is the posterior mandible up to retromolar pad. This zone is confined apically by the inferior alveolar canal and has a heavy masticatory demand during function. The major arterial supply is the inferior alveolar artery and the sublingual branch of the lingual artery. The inferior alveolar artery is responsible for endosteal arterial supply of mandibular dentition. The quality of blood supply is dependent on 4 factors: presence of teeth, patient age, degree of resorption of alveolar bone and presence of systemic disorders. In elderly edentulous patients, the posterior mandible depends mostly on musculo-periosteal small arteries from attached muscles and periosteal membrane for blood supply.

Therefore, the relationship of occlusal force on implant survival and success still remains plagued with contradicting reports and interpretations of clinical findings. The literature regarding peri-implant crestal bone loss appears polarized into groups that view the main etiology as either biomechanical or microbiological. The reality of the matter likely involves a combination of the aforementioned factors interacting to cumulatively produce crestal bone remodeling and loss.
Objective of the Study

1. To compare patterns of crestal bone loss and implant failure around sintered porous-surfaced press-fit dental implants vs. moderately textured threaded dental implants.
2. To compare retrospectively the impact of splinted and non-splinted implant protheses on crestal bone levels.
3. To compare crestal bone level measurements and distortion around dental implants in PA vs. vBW radiographs.

Research Ethics Board Approval

Approval for this retrospective project was given by the Office of Research Ethics, University of Toronto (Protocol# 23692). The study was conducted in accordance with the general guidelines of the Helsinki Declaration as revised in 2000.

Hypothesis of the Study

1. Sintered porous surface (SPS) implants would have less crestal bone loss over time and a similar survival rate as moderately textured threaded (THR) dental implants.
2. Implants supporting a splinted prosthesis would have less crestal bone loss than non-splinted implants.
3. The radiographic assessment of crestal bone levels with vertical bitewing (vBW) radiographs would have less distortion and than those determined from periapical (PA) views.

The null hypothesis was that SPS and THR implants and implants with splinted and non-splinted protheses would have equal patterns of bone loss, and that PA and vBW radiographic views would present similar crestal bone levels.
Chapter 2

Materials and Methods
Chapter 2: Materials & Methods

Patient Group

This retrospective study included patients attending the Oral Reconstruction Center (ORC) clinic of the Department of Periodontology, Faculty of Dentistry, University of Toronto. The patients attended the ORC clinic for treatment of partially edentulous areas using fixed dental implant-supported prostheses. All patients signed the Faculty of Dentistry’s standard “consent to treatment form” and “privacy and consent to personal information collection” form in compliance with current provincial PIPEDA legislation and past Royal College of Dental Surgeons of Ontario privacy guidelines. The inclusion criteria required all implants to have been placed in posterior jaw locations and to have been restored with fixed implant-supported restorations that had been in function for at least 1 year and with a recall radiograph of sufficient quality to assess crestal bone levels.

Surgical and Prosthetic Procedures

All implant procedures were performed in the Oral Reconstruction Center clinic by graduate residents in periodontology or dentists participating in the departmental continuing education programs under the supervision of staff periodontists and/or oral surgeons. Decisions for site development grafting, type of implant, materials used and technique modifications were made by the attending staff. Standard clinic protocols based on published reports were used for all procedures.

Data Collection

Data was collected from patient records and entered into a database (Microsoft Access V.8). The data collected contained information over the period from October 1997 to June 2009. Data was divided into three main categories: patient demographics, implant and prosthetic information and bone grafting information.

Patient demographics included sex and age. Implant information included implant type, dimensions, dates of implant placement, re-entry and prosthesis insertion, type of prosthesis, e.g.
splinted or non-splinted, and adjacent/opposing structures. Bone grafting information included date and type of procedure and materials used.

In addition to data collected from patient charts, a recall program was used to monitor patients’ implants on an annual basis. During these recall appointments, dental hygienists assessed the implants clinically by probing, percussion and detectable mobility or pain and collected radiographs. Radiographs collected included periapical films taken using standard long-cone paralleling technique with an XCP device (Dentsply Rinn ©, Woodbridge, ON) or Snap-A-Ray (Dentsply Rinn ©) and vertical bitewings were taken with either Stick-On bite wing tabs (Pearson ©, Sylmar, CA) or an XCP device (Dentsply Rinn ©). Films were assessed for quality by staff periodontists or periodontal residents present and retaken as needed to ensure that essential structures were present in order to be able to establish current crestal bone levels both mesially and distally. Radiographs were taken using standard settings on D-speed intraoral films (size 2).

Radiographic Analysis

All films were digitalized using the following technique: A Nikon D80 camera with a Sigma 105 mm Macro lens was mounted to a copy stand. A light box with a black filter fitted for a standard size 2 film blocked out all residual light from the light box. The camera was set to black and white, macro mode, ISO Auto, shutter speed Auto, aperture auto, image quality fine, size small. In a dark environment, radiographs were individually photographed and subsequently converted into digital images. The digital picture files were captured in JPEG format.

Digital films were analyzed for crestal bone levels and crown height with the aid of software (Sigma Scan Pro V.4, SPSS Inc., Chicago, Il) to produce millimetric measurements. A sample group of the digitized films was measured both by a staff oral maxillofacial radiologist (EWL) and by the author, a periodontology resident (JYK). Inter-examiner statistics were performed to calculate inter-examiner correlation co-efficient (ICC). Thereafter, the author analyzed the entire sample of films for crown height and crestal bone levels on mesial and distal sides from the implant-abutment interface to the most apical area of bone-implant contact (see appendix for sample image calculation).
Statistical Analysis

Descriptive statistics were performed to calculate patient and implant demographic summary data. The implant data was initially divided into three groups, sintered porous surface (SPS), threaded implants with dual acid etched surface (THR-DAE) and threaded implants with sand-blasted large grit acid-etched surfaces (THR-SLA). An Inter-examiner correlation co-efficient (ICC) was calculated to determine the correlation between an oral maxillofacial radiologist (EWL) and a periodontology resident (JYK) in measuring crestal bone loss on digitalized PA and vBW films.

Analysis of Variance (ANOVA) was used to examine the difference in implant length, diameter, time between implant procedures, effect of crown-to-implant ratio, type of opposing dentition, time to fail by implant type and the type of adjacent structure to the implant. A chi-square test was implemented to test the association of implant type with number of implants per arch, number of implants that are splinted or single and the effect of opposing dentition.

A student’s t-test was used to determine the paired difference between crestal bone loss measured on PA and vBW on both mesial and distal surfaces. An independent students t-test was used for both PA and vBW images of mesial and distal surfaces to investigate possible differences between splinted vs. non-splinted implants and between maxilla vs. mandible.

Kaplan Meier’s survival estimator of time to failure was used to compare the survival distributions between implant types. Correlation analysis was used to determine the association of mesial and distal measures with crown-to-implant ratio by implant type.

Finally, multiple regression analysis was used to model the outcome variable (crestal bone loss) as measured on mesial and distal aspects of implants taken with PA and vBW (four possible outcomes). The variables that were included in the multiple regression analysis were those that with a bivariate analysis had statistical significance of at least P≤0.20. SAS (version 9.1; SAS Institute Inc., Cary, NC) was used for the statistical analysis. A p-value of 0.05 or less was considered statistically significant.
Chapter 3

Results
Chapter 3: Results

Interexaminer Correlation

A set of twenty-five radiographs were measured by two examiners independently and the ICC was calculated. The ICC ranged from 0.86-0.93 out of 1 and was considered highly reliable. Therefore the author was deemed competent to evaluate the entire set of radiographs for the study.

Patient & Implant Demographic Results

This retrospective study initially ran queries from a database containing information regarding dental implant procedures performed in the Oral Reconstruction Center of the Faculty of Dentistry, University of Toronto. Initial queries for posterior implants yielded 1163 dental implants; however, further review of patient charts reduced the number of restored posterior implants available for inclusion to 995. This was due to implants not being restored by June 2008, incomplete information reported in charts, charts that were non-locatable and prosthesis designs that did not qualify for the study (i.e. full arch restoration). Of the 995 implants that qualified, 799 had both PA and vBW radiographs that had been taken at least 1 year after prosthesis insertion. The remainder of the non-included implants were in patients who were either lost to follow-up, implants that had been put to sleep (implants placed and not restored) or failed implants (not present in the mouth) (see Table 1).

Table 1 – Distribution of implants in study

<table>
<thead>
<tr>
<th>Category</th>
<th>Frequency</th>
<th>Percentage</th>
<th>THR-DAE</th>
<th>THR-SLA</th>
<th>SPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualified Implants</td>
<td>799*</td>
<td>80.3%</td>
<td>563</td>
<td>65</td>
<td>171</td>
</tr>
<tr>
<td>Lost to Follow up</td>
<td>135</td>
<td>13.6%</td>
<td>97</td>
<td>9</td>
<td>29</td>
</tr>
<tr>
<td>Failed Implants</td>
<td>49</td>
<td>4.9%</td>
<td>28 (4.27%)</td>
<td>0</td>
<td>21 (10.94%)</td>
</tr>
<tr>
<td>Implants put to sleep</td>
<td>14</td>
<td>1.4%</td>
<td>8</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Total Implants</td>
<td>995</td>
<td>100.0%</td>
<td>8</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>

* 2 implants were observed to be failing and subsequently failed during the data collection phase of the study.
The 799 qualifying implants had been used to treat 345 patients (59.1% Female, 40.9% Male) with a mean age of 59.0 years (Range 29.5-83.7 years). Three different implant designs were included in the study and had various dimensions (see Table 2). There was a statistically significant difference in implant length between SPS and both types of threaded implant (P<0.0001), but no significant differences between the diameters of the three implant systems used.

### Table 2 – Distribution by implant type, length and width

<table>
<thead>
<tr>
<th>Implant Type</th>
<th>Frequency</th>
<th>Percentage</th>
<th>Mean Length (mm)</th>
<th>Length Range (mm)</th>
<th>Mean Width (mm)</th>
<th>Width Range (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS (Endopore®)</td>
<td>171</td>
<td>21.4%</td>
<td>7.20</td>
<td>5.0-9.0</td>
<td>4.34</td>
<td>3.5-5.0</td>
</tr>
<tr>
<td>THR-DAE (Biomet 3i®)</td>
<td>563</td>
<td>70.5%</td>
<td>10.89</td>
<td>8.5-15.0</td>
<td>4.26</td>
<td>3.25-6.0</td>
</tr>
<tr>
<td>THR-SLA (Straumann®)</td>
<td>65</td>
<td>8.1%</td>
<td>10.40</td>
<td>8.0-12.0</td>
<td>4.39</td>
<td>3.3-4.8</td>
</tr>
</tbody>
</table>

Various implant lengths were used in this study and their dimensions are listed in Table 3 by implant type. There was no effect of implant length on crestal bone loss when analyzed with a Generalized Linear Model (GLM), which will be further discussed in a dedicated section.

### Table 3 – Distribution of Implant Length by Implant Type

<table>
<thead>
<tr>
<th>Implant Type</th>
<th>5</th>
<th>7</th>
<th>8</th>
<th>8.5</th>
<th>9</th>
<th>10</th>
<th>11.5</th>
<th>12</th>
<th>13</th>
<th>15</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS</td>
<td>2</td>
<td>150</td>
<td>0</td>
<td>0</td>
<td>19</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>171</td>
</tr>
<tr>
<td>THR-DAE</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>0</td>
<td>250</td>
<td>224</td>
<td>0</td>
<td>59</td>
<td>5</td>
<td>563</td>
</tr>
<tr>
<td>THR-SLA</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>44</td>
<td>0</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>65</td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
<td>150</td>
<td>4</td>
<td>25</td>
<td>19</td>
<td>294</td>
<td>224</td>
<td>17</td>
<td>59</td>
<td>5</td>
<td>799</td>
</tr>
</tbody>
</table>

In addition, an assortment of implant widths was used as shown in Table 4 by implant type. There were no differences in implant widths used and no effect on crestal bone loss according to a GLM.
The implants in this study were placed in posterior maxilla (45.93%) and posterior mandible (54.07%). Implants with a splinted prosthesis comprised 51.2% of implants while 48.8% were supported by non-splinted prosthesis. The most frequent sites for implant placement were the first molar positions, and the least common site was the maxillary second molar position (see Table 5 & Figure 1).

Table 4 – Distribution of Implant Width by Implant Type

<table>
<thead>
<tr>
<th>Implant Type</th>
<th>Implant Width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.25</td>
</tr>
<tr>
<td>SPS</td>
<td>0</td>
</tr>
<tr>
<td>THR-DAE</td>
<td>8</td>
</tr>
<tr>
<td>THR-SLA</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 5 – Distribution of implants by location

<table>
<thead>
<tr>
<th>Implant Location</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>59</td>
<td>7.38</td>
</tr>
<tr>
<td>1.5</td>
<td>51</td>
<td>6.38</td>
</tr>
<tr>
<td>1.6</td>
<td>71</td>
<td>8.89</td>
</tr>
<tr>
<td>1.7</td>
<td>8</td>
<td>1.00</td>
</tr>
<tr>
<td>2.4</td>
<td>45</td>
<td>5.63</td>
</tr>
<tr>
<td>2.5</td>
<td>51</td>
<td>6.38</td>
</tr>
<tr>
<td>2.6</td>
<td>76</td>
<td>9.51</td>
</tr>
<tr>
<td>2.7</td>
<td>6</td>
<td>0.75</td>
</tr>
<tr>
<td>3.4</td>
<td>20</td>
<td>2.50</td>
</tr>
<tr>
<td>3.5</td>
<td>54</td>
<td>6.76</td>
</tr>
<tr>
<td>3.6</td>
<td>114</td>
<td>14.27</td>
</tr>
<tr>
<td>3.7</td>
<td>29</td>
<td>3.63</td>
</tr>
<tr>
<td>4.4</td>
<td>18</td>
<td>2.25</td>
</tr>
<tr>
<td>4.5</td>
<td>55</td>
<td>6.88</td>
</tr>
<tr>
<td>4.6</td>
<td>117</td>
<td>14.64</td>
</tr>
<tr>
<td>4.7</td>
<td>25</td>
<td>3.13</td>
</tr>
</tbody>
</table>
Figure 1 – Distribution of Implants by Location. The most common location for dental implants in this study is the first molar position, with the mandibular jaw having slightly more than the maxilla. The second molar position is the least common area for dental implant placement; this is likely due to anatomical restrictions and adequate function in a shortened dental arch.

The inclusion criteria specified that all implants needed to be restored and in function for at least one year prior to the most recent examination. The time in function (TIF) of an implant was defined as the time of exposure to the oral environment (e.g. the date of placement of a healing abutment until the time data collection was finished - July 1, 2009). The times in function are reported in Table 6. There was a highly statistically significant difference in TIF for SPS compared to threaded implants (P<0.0001).

<table>
<thead>
<tr>
<th>Implant Type</th>
<th>Mean TIF (months)</th>
<th>Range (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS</td>
<td>73.9 (6.2 years)</td>
<td>14.5 - 137.0</td>
</tr>
<tr>
<td>THR-DAE</td>
<td>39.9 (3.3 years)</td>
<td>12.9 - 110.4</td>
</tr>
<tr>
<td>THR-SLA</td>
<td>37.1 (3.1 years)</td>
<td>19.1 - 114.8</td>
</tr>
</tbody>
</table>

**Implant Success Results**

The criterion for success of implants in this study was based on crestal bone loss measured on PA and vBW (see Table 7) radiographs. Mean crestal bone loss values for each implant type were significantly different amongst all three implant types (P<0.0001). SPS had lower crestal bone loss than THR-DAE and THR-SLA. In addition, there was a difference in crestal bone loss...
between the threaded implants. The etiology of this will be discussed further in the discussion section.

The success of implants based on a modified time based Albrektsson criteria is reported in Table 8. The results indicate a very low success rate for implants of all design types. In Table 9, the success criterion was modified to incorporate the varying smooth collar heights in all implant systems and shows a significant difference. The success rate increased by substantial amounts and SPS implants had the greatest success rates where the threaded implants had similar success although lower than SPS. This confirmed the data from Table 7 where not only do SPS have lower crestal bone loss, it also has less loss of bone proportional to its smooth collar height.

Table 7 – Mean Crestal Bone loss by Implant and Radiographic Type

<table>
<thead>
<tr>
<th>Implant Type</th>
<th>vBW – Mesial (mm)</th>
<th>vBW – Distal (mm)</th>
<th>PA – Mesial (mm)</th>
<th>PA – Distal (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS</td>
<td>1.64 (SE=0.062)</td>
<td>1.66 (SE=0.066)</td>
<td>1.51 (SE=0.059)</td>
<td>1.49 (SE=0.059)</td>
</tr>
<tr>
<td>THR-DAE</td>
<td>1.93 (SE=0.034)</td>
<td>2.02 (SE=0.037)</td>
<td>1.88 (SE=0.033)</td>
<td>1.91 (SE=0.033)</td>
</tr>
<tr>
<td>THR-SLA</td>
<td>2.52 (SE=0.100)</td>
<td>2.54 (SE=0.108)</td>
<td>2.15 (SE=0.097)</td>
<td>2.17 (SE=0.097)</td>
</tr>
</tbody>
</table>

Figure 2 – Crestal bone loss by implant type. The difference in crestal bone loss was significant between the three implant designs. There was significantly less bone loss around SPS implants as measured on vBW and PA compared to the THR types, and there was more bone loss around THR-SLA implants compared to the THE-DAE. Note: The pictures of the implants in the background are not to scale, and are intended as a visualization aid only.
Table 8 – Implants Not Successful by Type – Modified Time based Albrektsson (1986) Criteria

<table>
<thead>
<tr>
<th></th>
<th>PA - Mesial</th>
<th>PA - Distal</th>
<th>vBW - Mesial</th>
<th>vBW - Distal</th>
<th>Average</th>
<th>Total</th>
<th>% Not Successful by Implant type</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS</td>
<td>54</td>
<td>49</td>
<td>61</td>
<td>59</td>
<td>55.75</td>
<td>171</td>
<td>32.6</td>
</tr>
<tr>
<td>THR-DAE</td>
<td>400</td>
<td>400</td>
<td>391</td>
<td>402</td>
<td>398.25</td>
<td>563</td>
<td>70.7</td>
</tr>
<tr>
<td>THR-SLA</td>
<td>50</td>
<td>56</td>
<td>58</td>
<td>60</td>
<td>56</td>
<td>65</td>
<td>86.2</td>
</tr>
<tr>
<td>Total</td>
<td>504</td>
<td>505</td>
<td>510</td>
<td>521</td>
<td>510</td>
<td>799</td>
<td>63.8</td>
</tr>
</tbody>
</table>

Table 9 – Implants Not Successful by Type – Modified Time based Albrektsson (1986) Criteria with Allowance of Smooth Collar

<table>
<thead>
<tr>
<th></th>
<th>PA - Mesial</th>
<th>PA - Distal</th>
<th>vBW - Mesial</th>
<th>vBW - Distal</th>
<th>Average</th>
<th>Total</th>
<th>% Not Successful by Implant type</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3.25</td>
<td>171</td>
<td>1.9</td>
</tr>
<tr>
<td>THR-DAE</td>
<td>74</td>
<td>81</td>
<td>88</td>
<td>100</td>
<td>85.75</td>
<td>563</td>
<td>15.2</td>
</tr>
<tr>
<td>THR-SLA</td>
<td>6</td>
<td>6</td>
<td>9</td>
<td>10</td>
<td>7.75</td>
<td>65</td>
<td>11.9</td>
</tr>
<tr>
<td>Total</td>
<td>83</td>
<td>90</td>
<td>101</td>
<td>113</td>
<td>96.75</td>
<td>799</td>
<td>12.1</td>
</tr>
</tbody>
</table>

Splinting vs. Non-Splinted

The main question posed in this study was whether there were differences in crestal bone loss around dental implants when used with splinted vs. non-splinted prostheses. The study included 409 (52.2%) splinted implants and 390 (48.8%) non-splinted implants. Data from three different implant designs showed a consistent trend for splinted implants to have more crestal bone loss (Table 10) than non-splinted implants. Although the data was not statistically significant in all instances, the trend was consistent in all scenarios. It was found that splinted implants had an average of 0.30 mm (Range 0.16-0.38 mm) more bone loss than non-splinted implants. The clinical relevance of 0.30 mm of additional crestal bone loss will be addressed in the discussion section.
Table 10 – Mean Crestal Bone Loss by Implant Type for splinted and non-splinted implants

<table>
<thead>
<tr>
<th>Description</th>
<th>vBW – Mesial (mm)</th>
<th>vBW – Distal (mm)</th>
<th>PA – Mesial (mm)</th>
<th>PA – Distal (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS – Splinted</td>
<td>1.91 (SE=0.164)</td>
<td>1.85 (SE=0.151)</td>
<td>1.73 (SE=0.150)</td>
<td>1.69 (SE=0.148)</td>
</tr>
<tr>
<td>SPS – Non-Splinted</td>
<td>1.53 (SE=0.063)</td>
<td>1.58 (SE=0.066)</td>
<td>1.41 (SE=0.062)</td>
<td>1.41 (SE=0.061)</td>
</tr>
<tr>
<td>SPS – Difference</td>
<td>0.38 (P=0.034, SE=0.144)</td>
<td>0.27 (P=0.096, SE=0.142)</td>
<td>0.32 (P=0.055, SE=0.142)</td>
<td>0.28 (P=0.082, SE=0.136)</td>
</tr>
<tr>
<td>THR-DAE – Splinted</td>
<td>2.07 (SE=0.045)</td>
<td>2.18 (SE=0.042)</td>
<td>1.99 (SE=0.042)</td>
<td>2.08 (SE=0.048)</td>
</tr>
<tr>
<td>THR-DAE – Non-splinted</td>
<td>1.75 (SE=0.049)</td>
<td>1.81 (SE=0.048)</td>
<td>1.73 (SE=0.048)</td>
<td>1.70 (SE=0.041)</td>
</tr>
<tr>
<td>THR-DAE Difference</td>
<td>0.32 (P&lt;0.0001, SE=0.067)</td>
<td>0.37 (P&lt;0.0001, SE=0.064)</td>
<td>0.26 (P&lt;0.0001, SE=0.064)</td>
<td>0.38 (P&lt;0.0001, SE=0.065)</td>
</tr>
<tr>
<td>THR-SLA – Splinted</td>
<td>2.62 (SE=0.139)</td>
<td>2.65 (SE=0.125)</td>
<td>2.22 (SE=0.108)</td>
<td>2.30 (SE=0.091)</td>
</tr>
<tr>
<td>THR-SLA – Non-splinted</td>
<td>2.37 (SE=0.122)</td>
<td>2.35 (SE=0.112)</td>
<td>2.06 (SE=0.170)</td>
<td>1.98 (SE=0.108)</td>
</tr>
<tr>
<td>THR-SLA Difference</td>
<td>0.25 (P=0.210, SE=0.200)</td>
<td>0.30 (P=0.098, SE=0.183)</td>
<td>0.16 (P=0.406, SE=0.192)</td>
<td>0.32 (P=0.025, SE=0.141)</td>
</tr>
</tbody>
</table>

Implant Position

Crestal bone loss values in the posterior maxilla vs. posterior mandible were examined by t-tests which revealed no statistically significant differences.

The effect of an implant being in the most distal location in a quadrant was compared to all other implant locations by implant type (Table 11). The study included 186 restored implants that were in the most distal tooth position. T-tests showed that SPS implants had more crestal bone loss when they were in the most distal tooth position in a quadrant but only on mesial surfaces. THR-SLA and THR-DAE did not show any consistent results related to most distal position.

Table 11 – Effect of last Implant in Quadrant and Crestal Bone loss

<table>
<thead>
<tr>
<th>Description (N=)</th>
<th>vBW – Mesial (mm)</th>
<th>vBW – Distal (mm)</th>
<th>PA – Mesial (mm)</th>
<th>PA – Distal (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS – Not Last Tooth (120)</td>
<td>1.52</td>
<td>1.62</td>
<td>1.42</td>
<td>1.43</td>
</tr>
<tr>
<td>SPS – Last Tooth in Quad (51)</td>
<td>1.92</td>
<td>1.76</td>
<td>1.72</td>
<td>1.64</td>
</tr>
<tr>
<td>SPS – Difference</td>
<td>-0.40 (P=0.0051)</td>
<td>-0.14 (P=0.3286)</td>
<td>-0.30 (P=0.0345)</td>
<td>-0.21 (P=0.1361)</td>
</tr>
<tr>
<td>THR-DAE – Not Last Tooth (446)</td>
<td>1.90</td>
<td>2.01</td>
<td>1.86</td>
<td>1.92</td>
</tr>
<tr>
<td>THR-DAE – Last Tooth in Quad (117)</td>
<td>2.05</td>
<td>2.05</td>
<td>1.95</td>
<td>1.90</td>
</tr>
<tr>
<td>THR-DAE Difference</td>
<td>-0.15 (P=0.1083)</td>
<td>-0.044 (P=0.6376)</td>
<td>0.09 (P=0.2631)</td>
<td>0.02 (P=0.7991)</td>
</tr>
<tr>
<td>THR-SLA – Not Last Tooth (46)</td>
<td>2.51</td>
<td>2.60</td>
<td>2.04</td>
<td>2.22</td>
</tr>
<tr>
<td>THR-SLA – Last Tooth in Quad (18)</td>
<td>2.55</td>
<td>2.38</td>
<td>2.45</td>
<td>2.04</td>
</tr>
<tr>
<td>THR-SLA Difference</td>
<td>-0.04</td>
<td>0.22</td>
<td>-0.41</td>
<td>0.18</td>
</tr>
</tbody>
</table>
Crown:Implant Ratio

The crown-to-implant ratio for SPS implants was found to be significantly larger than that for threaded implant-supported prostheses (Table 12) which was consistent with SPS implants having significantly shorter lengths. There were no significant effects of crown-to-implant ratio on crestal bone loss.

Table 12 – Crown-to-Implant Ratio by Implant Type

<table>
<thead>
<tr>
<th>Implant Type</th>
<th>Crown:Implant PA vBW</th>
<th>Crown:Implant vBW</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS</td>
<td>1.60</td>
<td>1.52</td>
</tr>
<tr>
<td>THR-DAE</td>
<td>1.01</td>
<td>0.93</td>
</tr>
<tr>
<td>THR-SLA</td>
<td>0.79</td>
<td>0.82</td>
</tr>
</tbody>
</table>

The effect of opposing dentition was recorded from vBW and were categorized either as a natural tooth, implant, edentulous, or fixed partial denture. There were no significant differences in crestal bone loss for the various opposing dentition scenarios examined.

Grafting

Many implant sites had received some form of grafting either prior to or simultaneously with implant placement using a variety of techniques. Direct sinus elevation prior to implant placement was performed for 82 threaded implants and Wilcoxon 1-sided and Kruskal-Wallis tests (non-parametric) showed no effect on crestal bone loss compared to non-grafted implants. Indirect sinus elevations were performed for 57 implants of all three types and t-tests showed no effect on crestal bone loss in relation to SPS or THR-DAE implants; however, there was an increased bone loss for THR-SLA (Range P=0.0068 to P=0.0425). Therefore, it is possible that indirect sinus elevations may contribute to crestal bone loss in THR-SLA implants.

Socket preservation grafts at the time of tooth extraction were performed for all implant types and t-tests showed that there was no effect on crestal bone loss. Ridge augmentation procedures prior to and simultaneously with implant placement were also performed for 68 implants of all types and t-tests showed no effect for SPS or THR-SLA; however, there was an effect for THR-
DAE (Range P=0.0006 to P=0.0107). Therefore, it is possible that ridge augmentation procedures may contribute to greater crestal bone loss with THR-DAE implants.

**Lost to Follow up**

The initial data set of patients and implants resulted from our query of how many implants had been placed in posterior maxilla and/or mandible that had been in function for a minimum of one year. Of the 995 implants generated from the database, 135 (13.6%) were lost to follow up for various reasons as listed in Table 13. It is fairly common in long term retrospective studies that patients are lost to follow up (Naert et al, 2002a). An attempt was made to contact every patient earmarked by the database query in order to arrange for a recall examination. The most common reason for a patient being lost to follow-up was that the patient was unwilling to return to the clinic (52.6%). The other common reasons were that patients’ contact information had changed without notice (18.5%) or that the patient has financial balances outstanding for the implant treatment provided (12.6%). A minority of patients was confirmed to have moved away (3.0%) and some expressed dissatisfaction with the treatment/experience and refused to return (3.7%).

<table>
<thead>
<tr>
<th>Reason</th>
<th># of Implants</th>
<th>% of implants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phone number or Address Change (unable to contact)</td>
<td>25</td>
<td>18.52</td>
</tr>
<tr>
<td>Patient is “old/sick/dead”</td>
<td>13</td>
<td>9.63</td>
</tr>
<tr>
<td>Not willing to return, missed appointment</td>
<td>71</td>
<td>52.59</td>
</tr>
<tr>
<td>Moved away</td>
<td>4</td>
<td>2.96</td>
</tr>
<tr>
<td>Owes money</td>
<td>17</td>
<td>12.59</td>
</tr>
<tr>
<td>Not satisfied with treatment/experience</td>
<td>5</td>
<td>3.71</td>
</tr>
<tr>
<td>Total</td>
<td>135</td>
<td>100.00</td>
</tr>
</tbody>
</table>

**vBW vs. PA**

The differences in crestal bone loss measurements determined with PA vs. vBW radiographs were compared and it was found that there were significant differences between PA and vBW radiographic measurements for both mesial and distal surfaces with all implant three types (P<0.0001). Consistently, PA views showed approximately 0.10 mm (Range 0.07-0.40 mm) less crestal bone loss than vBW views (P<0.01).

<table>
<thead>
<tr>
<th>Mesial (mm)</th>
<th>Distal (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA-vBW</td>
<td>PA - vBW</td>
</tr>
<tr>
<td></td>
<td>SPS – Difference</td>
</tr>
<tr>
<td>----------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td></td>
<td>-0.134 (P=0.0003)</td>
</tr>
<tr>
<td></td>
<td>-0.067 (P=0.0120)</td>
</tr>
<tr>
<td></td>
<td>-0.400 (P=0.0010)</td>
</tr>
</tbody>
</table>

**Distortion of Radiographs**

The effect of radiographic distortion was analyzed as well. Each radiograph was graded as either distorted or not based on the appearance of the threads or collar of the implant(s). There was a significant proportion of radiographs with distortions with PAs from maxilla (37.06%) compared to mandible (12.27%) (P<0.0001 Chi-Square) (Table 15). In addition, there was a significant proportion of radiographs with distortions in vBW from maxilla (23.43%) compared to mandible (9.51%) (p<0.0001 Chi-Square test) (Table 16). A comparison of distortion in PAs and vBWs was made and results showed that distortion in a PA did not imply distortion in the corresponding vBW (p<0.0001 McNemar’s test) (Table 17) (see Appendix 3). When a PA was distorted and the corresponding vBW was not, crestal bone loss measured in the PA was 0.21-0.25 mm less than in the corresponding vBW (p<0.0001). In addition, when there was distortion in a PA, the crown height was 1.27 mm taller than that measured in the corresponding vBW (P<0.0001, t-test). When a vBW was distorted and the corresponding PA was not, crestal bone loss measured in the vBW was 0.18-0.25 mm less than that measured in the corresponding PA (P<0.001, t-test). In addition, the crown height measured by vBW was 0.50 mm shorter than by PA when the vBW was distorted. Even when both films were not distorted, the vBWs still showed more crestal bone loss by 0.17-0.25 mm (P<0.0001).

**Table 15 – Radiographic Distortion for PA films by Jaw**

<table>
<thead>
<tr>
<th></th>
<th>No Distortion</th>
<th>Distortion</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Md</td>
<td>379</td>
<td>53</td>
<td>432</td>
</tr>
<tr>
<td></td>
<td>Row % = 87.73%</td>
<td>Row % = 12.27%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Col % = 62.13%</td>
<td>Col % = 28.04%</td>
<td></td>
</tr>
<tr>
<td>Mx</td>
<td>231</td>
<td>136</td>
<td>367</td>
</tr>
<tr>
<td></td>
<td>Row % = 62.94%</td>
<td>Row % = 37.06%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Col % = 37.87%</td>
<td>Col % = 71.96%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>610</td>
<td>189</td>
<td>799</td>
</tr>
</tbody>
</table>

**Table 16 – Radiographic Distortion for vBW films by Jaw**

<table>
<thead>
<tr>
<th></th>
<th>No Distortion</th>
<th>Distortion</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Md</td>
<td>390</td>
<td>41</td>
<td>431</td>
</tr>
<tr>
<td></td>
<td>Row % = 90.49%</td>
<td>Row % = 9.51%</td>
<td></td>
</tr>
</tbody>
</table>
Table 17 – Comparison of Radiographic Distortion for PA & vBW film

<table>
<thead>
<tr>
<th></th>
<th>No Distortion vBW</th>
<th>Distortion vBW</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No distortion PA</td>
<td>520</td>
<td>89</td>
<td>609</td>
</tr>
<tr>
<td>Row % = 85.39%</td>
<td>Row % = 14.61%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Col % = 77.50%</td>
<td>Col % = 70.08%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distortion PA</td>
<td>151</td>
<td>38</td>
<td>189</td>
</tr>
<tr>
<td>Row % = 79.89%</td>
<td>Row % = 20.11%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Col % = 22.50%</td>
<td>Col % = 29.92%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>671</td>
<td>127</td>
<td>798</td>
</tr>
</tbody>
</table>

**Implant Failure Results**

The present study included 995 implants, of which 49 implants failed producing an overall failure rate of 4.9% (survival rate of 95.1%) based on actual implant loss. No THR-SLA implants failed while 21 SPS implants and 28 THR-DAE implants failed (See Table 18). There were statistically significant differences in the failure rates for SPS and THR (P<0.0005) implants and in the time to failure (P<0.0036). The locations of implant failures were compared and no significant site or jaw (maxilla vs. mandible) locations were more likely to fail with either THR or SPS implant types. The data indicated that SPS implants were more likely to fail several years after placement and loading whereas THR-DAE implants were likely to fail in the first 9 months typically failing to osseointegrate.

Table 18 – Implant Failure Data

<table>
<thead>
<tr>
<th>Implant Type</th>
<th># Failed</th>
<th>Relative % Failed</th>
<th>Time to Fail (months)</th>
<th>Failure to Osseointegrate</th>
<th>Failure after Prosthesis</th>
<th>Surgical Placement Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS</td>
<td>21</td>
<td>10.94%</td>
<td>41.00</td>
<td>8 (38.1%)</td>
<td>13 (61.9%)</td>
<td>0</td>
</tr>
<tr>
<td>THR-DAE</td>
<td>28</td>
<td>4.27%</td>
<td>9.58</td>
<td>18 (64.3%)</td>
<td>6 (21.4%)</td>
<td>4 (14.3%)</td>
</tr>
</tbody>
</table>

Table 19 – Summary of the Number of Censored and Uncensored Values

<table>
<thead>
<tr>
<th>Implant</th>
<th>Total</th>
<th>Failed</th>
<th>Censored</th>
<th>Censored %</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS</td>
<td>192</td>
<td>21</td>
<td>171</td>
<td>89.06</td>
</tr>
<tr>
<td>THR - DAA</td>
<td>654</td>
<td>26</td>
<td>628</td>
<td>96.02</td>
</tr>
<tr>
<td>Total</td>
<td>846</td>
<td>47</td>
<td>799</td>
<td>94.44</td>
</tr>
</tbody>
</table>
A Kaplan-Meier survival curve (Figure 3) was calculated to predict future implant failures. This calculation predicted that the survival rate for THR-DAE would be higher than for SPS but the difference was only marginally statistically significant (0.0656). However after 10 months in function, THR-DAE implants appear to have a better survival rate than SPS implants in the study group investigated. It should be noted that follow up data available for SPS implants was longer than for THR, and therefore more opportunity existed to observe long term complications for SPS implants. In addition, there were fewer implants available to report on as the time in function increased past five years. Therefore, late failures in a smaller sample size dramatically decrease the survival probability calculated in the Kaplan Meier survival plot.

**Figure 3 – Kaplan Meier Survival plot by implant type:** long term survival rate of dental implants distinguished by implant type. Only implants with SPS and THR-DAE design types failed. Longer data following SPS implants functioning over time was available and several late SPS failures produced a pronounced decline in the implant survival. Over the first 10 months in function, there is a similar survival trend between the SPS and THR-DAE
implants. The larger number of THR-DAE implants in the sample and lower amount of late failures also contributes to the differential survival rates.

**Effect of Adjacent Structure to Implant**

The effect of adjacent structure (tooth, implant or edentulous space) to an implant was investigated to determine if this played any significant role in crestal bone loss. Each implant type was analyzed in a separate group and it was found that in most instances the adjacent structure was a significant factor in crestal bone loss (ANOVA). In virtually all instances but one, the least amount of bone loss was seen when an implant was adjacent to a natural tooth while, the greatest amount of crestal bone loss occurred when an implant was next to another implant (Figure 4). In some instances, bone loss was similar when an implant faced another implant or an edentulous area. Since the effect of adjacent structures was found to be a significant factor in a bivariate analysis, this effect was combined with the effect of splinted and non-splinted prosthetic type into a statistical model (ANOVA). There was no clear trend and half of the instances displayed border line significant data. Therefore, the impact of adjacent structure and prosthetic design seem to impact crestal bone loss independently.

![Figure 4 – Effect of Adjacent Structure to Implant Crestal Bone Loss by Implant type](image)

The effect of adjacent structures around THR implants demonstrate similar trends where there is less bone loss when the adjacent surface is a natural tooth compared to another implant. The trend is similar for SPS implants with the exception that more bone loss appears near an edentulous surface rather than an adjacent implant.
Table 20 – Bone loss around implants by adjacent structure and implant type.

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<th>SPS</th>
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Multiple Regression Analysis

The variables that were included in the multiple regression analysis were those that had statistical significance with a bivariate analysis of at least $P \leq 0.20$. The outcome measure of the multiple regression analysis was crestal bone loss as measured on mesial and distal aspects of implants taken with PA and vBW (four possible outcomes). The variables included were implant type (SPS, THR-DAE, THR-SLA), prosthesis design (splinted vs. non-splinted), patient sex, opposing dentition (natural, implant, edentulous, FPD), implant position (last in quadrant or not), implant length and diameter, patient age, adjacent structure to implant (tooth, implant, edentulous area) and crown-to-implant ratio. The regression analysis produced a reduced model and for all outcome measures (mesial and distal loss for PA and vBW) included implant type, adjacent structure and prosthesis design as statistically significant ($P < 0.0001$). In addition, in some of the outcomes the patient gender, implant length, crown-to-implant ratio, implant position and age of patient were statistically significant. Based on the $P$-value obtained in the reduced model with and the incidence of a covariate with $P \leq 0.05$ in the outcome measure, the covariates were categorized as either major or minor contributors. Those that were $P < 0.05$ in 3 or more of 4 of the outcome measures were considered major, and the rest with $P < 0.05$ were considered minor contributors. The ultimate result of this study showed that the major factors accountable for crestal bone loss are implant type, prosthesis design and adjacent structure to an implant with minor contributions by implant length, crown-to-implant ratio, implant in the most distal position, gender and age of patient.
Chapter 4
Discussion
Chapter 4: Discussion

The four primary goals of this study were to (A) investigate patterns of crestal bone loss around posterior SPS and THR dental implants, (B) compare the effect of splinted implant-supported prostheses and non-splinted prostheses, if any, on peri-implant crestal bone levels, (C) investigate patterns of implant failures between SPS and THR implants and (D) compare measurements provided by PA and vBW radiographs on crestal bone levels around dental implants. These objectives were examined by retrospectively analyzing patient charts and radiographs that were taken at routine recall appointments in a university clinic setting.

A. Factors Affecting Crestal Bone Loss

The present study assessed crestal bone loss around moderately rough threaded and SPS implants taking into account variables such as implant length and width, splinted and non-splinted prosthesis, crown-to-implant ratio, implant location, adjacent and opposing structures to the implant, and whether auxiliary bone grafting was required. In addition, patient factors such as age and sex were evaluated. Statistical tests were performed to weigh the significance of each factor individually, through a bivariate analysis, after which significant variables were amalgamated in a generalized linear model to quantify relative significance on crestal bone loss.

The data collected was composed of three implant design types (SPS, THR-DAE, THR-SLA) all placed in posterior sites. Significant differences were found when the impact of implant design in relation to crestal bone loss was compared. In general, there was less crestal bone loss around SPS implants compared to THR implants. Furthermore, there was significantly less crestal bone loss around THR-DAA (dual acid-etched) implants compared to THR-SLA (sand-blasted, large grit, acid-etched) implants.

Time in Function

Various theoretical co-factors were assessed to determine the cause of differences between bone levels around the different implant design types. The time in function assessment revealed that SPS implants had been in function significantly longer [73.9 months (range 14.5-137.0 months)] than either of the THR types [THR-DAE =39.9 months (range 12.9-110.4 months), THR-SLA =
37.1 months (range 19.1-114.8 months)]. Classical implant literature has long recognized longitudinal crestal bone loss around machined implants in function and, as a result, also provides for reasonable amounts of observable bone loss in implant success criteria (Albrektsson et al, 1986). However, recent literature has observed that newer implant designs with moderately rough surfaces tend to have noticeable crestal bone remodeling during the initial 6-12 months in function and stable crestal bone levels thereafter compared to traditional machined titanium implants (Chang & Wennström, 2010; Cox & Zarb, 1987). Although this study assessed crestal bone loss using a cross-sectional methodology and not longitudinally over time, the observation of less bone loss around implants that had been in function for longer periods of time, highlights the need to consider factors other than time in function.

**Crown:Implant Ratio**

Another significant difference found between the implant types was the crown height to implant ratio measured and calculated during the radiographic analysis. It was found the SPS implants had a significantly larger crown:implant ratio (1.56) compared to both THR implant types (THR-DAE = 0.97, THR-SLA=0.81). The increased ratio is due primarily to the fact that the SPS implants, which are statistically significantly shorter than both THR types, were placed in sites where there was increased residual ridge resorption requiring a longer crown height to reach the occlusal plane. No significant relationship between crown:implant ratio and crestal bone loss by implant type was found. Furthermore, several recent studies and reviews have confirmed that crown:implant ratio does not impact peri-implant bone levels (Gomez-Polo et al, 2010; Blanes 2009; Birdi et al, 2010). Therefore, the impact of crown:implant ratio does not appear to effect crestal bone levels in SPS and THR implant designs.

**Grafting**

The effect of grafting procedures employed as part of the implant placement technique on subsequent crestal bone loss was also examined statistically as all implant design types had grafted and non-grafted samples. Several grafting procedures were routinely performed either prior to or simultaneous with implant placement including, direct (DSE) and indirect (ISE) sinus elevation, ridge augmentation procedures (RAP) and ridge preservation procedures/socket preservation (RPP) performed at the time of tooth removal. For each implant type, a grafting
procedure was compared to a control group of the same implant type that did not undergo any grafting. The results of this analysis produced inconclusive and inconsistent data trends with sporadic instances of statistical significance. One such finding of statistical significance found a relation between indirect sinus elevation and increased crestal bone loss around THR-SLA implants. There is no supporting literature that reports similar findings and no clinical explanation can be proposed to support this finding. Therefore, there may be a relationship between increased crestal bone loss around THR-SLA implants which were placed in ISE sites. Another significant finding was more crestal bone loss around THR-DAE implants that had ridge augmentation procedures either during placement or subsequently thereafter. The implant design offers an explanation for this phenomenon. Ridge augmentation procedures are typically performed when there is insufficient bone to cover the coronal aspect of an implant, the circumferential bone is very thin, or a dehiscence occurred during implant placement. THR-DAE have a machined collar and several coronal machined threads which have inferior osteoconductive properties then a roughened surface (Davies, 2003). Therefore, attempting to graft bone over a poorly osteoconductive surface can explain this finding. Previous studies, however, have reported that implants respond similarly in grafted sites as in sites with native autogenous bone (Wallace and Froum, 2003). The results of the study are consistent with this position as there was no compelling data to support additional peri-implant bone loss in previously augmented sites.

**Effect of Adjacent Structures**

It was found during statistical analysis that the adjacent structure to an implant (tooth, implant or edentulous area) influenced crestal bone when analyzed as an individual factor (ANOVA) and when included in the multiple regression analysis. It was found that regardless of the implant type, there was less bone loss when the surface adjacent to the implant was a natural tooth. Furthermore, increased crestal bone loss was observed when a threaded implant was adjacent to another implant. In the SPS group, there was a trend for the most bone loss to be when the adjacent structure was an edentulous area as opposed to an implant or tooth. While not all instances were statistically significant, this is an overall trend that can be clinically interpreted and is relatively consistent between implant systems. Furthermore, these results confirm well known established findings that implant bone levels can stabilize at closer distances to natural
teeth compared to other implants (Tarnow, 2000; Cardaropoli et al, 2003; Chang & Wennström, 2010; Martin et al, 2009). This study did not take into consideration the horizontal distance of the implant to the adjacent structure. However, it is interesting to note that regardless of implant design, there was a consistency in the reaction to adjacent structures.

**Smooth Collar Height**

The three different dental implant designs that were assessed in this study all incorporated a machine-surfaced (smooth) transgingival collar segment with varying collar heights. The smooth collar height was smallest for SPS implants and greatest for THR-SLA implants, the latter being intended for single-stage implant placement with the coronal platform residing in the soft tissue. The THR-DAE implant design incorporated a machined smooth collar that continued apically to the first three threads before the acid etched roughened surface started. During radiographic analysis, it was a common observation for crestal bone levels adjacent to THR-SLA and SPS implants to be located approximately at the level of the junction between smooth collar and textured implant surface. This compliments results obtained in a recent study that evaluated crestal bone levels comparing implants with rough and smooth collars (Stein et al, 2009), as well as classical studies by Hermann (Hermann et al, 2000a;b). On the other hand, crestal bone levels around THR-DAE implants tended to be located at the level of the first or second implant thread. The smooth collar component of each implant design appears to correspond with the respective quantity of crestal bone loss by implant type.

The data supports the view that machine-surfaced finishes and collar heights both influence crestal bone levels due to inadequate retention of the fibrin clot and subsequent de novo bone formation by contact osteogenesis (Davies, 2003). An alternative explanation to the loss of crestal bone around machined collars has been postulated by Wiskott & Belser (1999). They explain bone loss around polished implant collars to be a combination of several factors that include the influence of surface texture on cellular positioning and bone healing, and inadequate stimulation or force transferred to adjacent bone resulting in disuse atrophy. A contributing factor driving crestal bone loss may be the formation of the ‘biological width’. This phenomenon has been observed to be a 1-2 mm area of peri-implant connective tissue that separates the sulcular epithelium from the bone crest (Berglundh & Lindhe, 1996; Deporter et al,
Implants placed with the smooth collar flush with the crest of bone may lose crestal bone in order to accommodate biological width formation. The implant success calculations of the three designs magnified the impact of the smooth collar design element on crestal bone loss. There are several recommended success criteria for threaded dental implants, which are based on observations of the original machine-surfaced, threaded Brånemark-type dental implant (Albrektsson et al 1986). The recommended dental implant success criteria for crestal bone loss was one that showed no more than 1 mm of crestal bone loss in year one of function and no more than 0.2 mm annually thereafter (Sennerby & Becker, 2000). The present study initially utilized this time-based allowance for crestal bone loss as a measure of success. However, when this single scale of allowable bone loss was utilized with the three implant designs studied, the data indicated that approximately 510 of 799 implants (~64%) were classified as unsuccessful although they were surviving and functioning normally. The implant designs in this study are different than the original Brånemark-type implant that the success criterion was based on. The relevance of the modified Albrektsson time based success criteria may not be appropriate for implants different than the original Brånemark-type. Therefore, in order to assess and compare the three implant groups under study, an allowance for smooth collar height was built into the equation and a new success criterion was created. This new criteria defined a successful implant as one with no more than 1 mm of bone loss after year one in function or 0.2 mm per year thereafter, and the length of the smooth or polished coronal portion of the implant collar or neck would be subtracted from the crestal bone loss. When the data was re-analyzed with the adjusted equation, it indicated that approximately 97 of 799 (~12%) implants were considered unsuccessful. Although this is still a high percentage of unsuccessful but surviving implants, the adjustment for smooth collar height in the equation proved a valuable component for a more realistic success criterion. The SPS implants were significantly more successful compared to both threaded implant systems when evaluated on a time based allowance of crestal bone loss. Therefore, the cause of the differential bone loss between implant systems was more likely due to the smooth collar component rather than the time in function, crown:implant ratio, grafting procedures, or implant dimensions. This may have been modified by formation of biological width by the soft tissue and stress shielding.
B. Effect of Splinted Prosthesis

The effect of splinted implant prostheses on crestal bone loss was also assessed. The results showed that splinted implants consistently lead to greater (0.3 mm) crestal bone loss than non-splinted implants regardless of implant type. Although the statistical significance of these differences in bone loss was high, the likelihood that the differences would have clinical impact may be small. The multi-factorial nature of crestal bone loss (Ketabi et al, 2009) and the limitations of a retrospective study design might also be argued to reduce the clinical importance of the principal finding. Nevertheless, other investigators have published similar findings with regards to the effect of splinting of implants (Rokni et al, 2005; Cochran et al, 2009) with similar implant systems in anterior and posterior locations in the mouth. It is not clear why splinted implants show greater crestal bone loss than non-splinted implants although various explanations have included less hygienic prosthetic design (Grossman et al, 2005) and stress-shielding of crestal bone (Pilliar et al, 1979). A splinted fixed prosthesis inherently creates an area that is difficult to maintain with routine oral hygiene including brushing and flossing. The interproximal area can act as a food trap and a nidus for plaque and bacterial accumulation. The use of adjunctive interproximal oral hygiene aids would be required to keep the area clean in addition to regular professional dental cleanings. Accumulation of bacterial and plaque would result in peri-implant mucositis, which may progress to peri-implantitis and subsequent bone loss around the implant (Lindhe et al, 2008). Furthermore, an alternative and complementary explanation involves the concept of stress shielding, whereby the bone and implant flex differently during function creating zones of unloading in the osseous tissue (Pilliar et al, 1979). This results in inadequate stimulation and subsequent bone atrophy. However, there were several implants observed in this study that were placed and submerged for several years without any loading and suffered no bone loss. The peri-implant bone was neither loaded nor stimulated sufficiently to maintain bone according to the concepts proposed by Wiskott and Pilliar (Wiskott & Belser, 1999; Pilliar et al, 1979).

Although the clinical significance of 0.3 mm additional bone loss from splinting implants together is minor, the clinical relevance of splinting implant prosthesis is important from the aspect of implant survival. In the present study, 66% of restored implants that failed had not been splinted regardless of implant type. While the sample of failed implants that were restored is small (n=19), the trend is a point of interest. Literature comparing moderately rough implant
survival of splinted and non-splinted prostheses is sparse (Lindhe and Burglundh, 1998). However, recommendations for splinting and not splinting implants have been reported (Grossman et al, 2005). Although these recommendations appear to be based on principles from conventional fixed prosthodontics, they do not appear to be based on literature and are anecdotal. Based on results from this study, it is recommended to splint adjacent implants together where possible for the following reasons. Splinting improves force distribution around peri-implant bone which decreases the chance for microfractures and progressive bone resorption. In addition, splinted implant supported prosthesis may be retrieved, modified and salvaged in the event a non-strategic implant is lost in the future. This benefits the patient with improved comfort and function in the event of an implant failure and saves the patient the financial burden of a new prosthesis. Splinting implants together allows for larger spans of teeth to be supported by fewer strategically placed implants, which is a financial benefit for the patient. Furthermore, clinicians can be comforted that the difference in crestal bone loss between splinted and non-splinted prostheses is clinically negligible regardless of implant type.

Multiple Regression Analysis of Crestal Bone Loss

Multiple regression analysis produced a reduced model that ranked the most influential factors for the outcome measure of crestal bone loss. The most significant (P<.0001) factors included implant design type, adjacent structure and prosthesis design. Other factors found to affect crestal bone levels to a lesser degree were patient gender, implant length, crown-to-implant ratio, implant position and age of patient. As the effect of adjacent structures on implants was not the primary focus, the results of the statistical analysis should be interpreted with the inherent limitations of this study, which is discussed below.

C. Implant Failure

Many studies lack a significant amount of implant failures to assess aetiology of failure due to small sample sizes and short follow up time. Implant failures occur for a variety of reasons and it is not uncommon for an implant to fail without any apparent reason. This study was performed in an educational institutional setting and followed a large number of implants, a portion of which was tracked for approximately 10 years. Implants were placed primarily by residents in periodontology and continuing education students. Due to the large sample size and observation
period, this study had the benefit of assessing 49 implant failures. Efforts were made to collect and thoroughly review the circumstances surrounding each failure and attempt to identify the causes.

**Patterns of Implant Failure**

The failures occurred for a variety of reasons, which were grouped in the following categories: (i) failure to osseointegrate prior to loading; (ii) failure after mechanical loading; and (iii) operator surgical placement error where several implants were removed relatively soon after placement prior to any chance for osseointegration. Of the three implant design types investigated in this study, no THR-SLA implants failed and 21 SPS implants and 28 THR-DAE implants failed, respectively. The overall failure rate was 4.9% and the relative failure rates were 10.94% for SPS and 4.27% for THR-DAE implants. The SPS implants tended to fail after a period of prosthetic loading, whereas the THR-DAE implants tended to fail prior to loading. This confirms the findings from Winkler that shorter threaded and HA coated press fit implants tended to fail significantly more often following uncovering and after loading than longer implants (Winkler et al, 2000). However, this study only included implants that were in function for at least three years and, therefore, early failures were not assessed.

**SPS Failure Trends**

Two thirds of the failed SPS implants in our study occurred after prosthetic loading. The Kaplan-Meier survival curve (Figure 3) demonstrated different failure tendencies for SPS and THR-DAE implants. For the first 10 months in function, the failure rate between implant types appeared similar. As the follow up time increased, no more THR-DAE implants were in function for a comparable amount of time to SPS implants. In addition, fewer SPS implants were available for monitoring and several SPS implants had late failures. This caused the survival curve to drop and exacerbate the survival curve difference seen after 10 years in function.

The SPS implants were typically placed in areas of more severe ridge resorption where threaded implants of standard dimensions could not be placed. These difficult sites were typically challenging for implant placement due to lack of quality and quantity of bone and, therefore, may account for increased SPS failures. However, studies have reported SPS implant survival rates comparable to THR implants (Kermalli et al, 2008; Deporter et al, 2005) in areas of
reduced bone volume and quality. Several patients had cluster failures as they lost several implants in a localized area. The study found that 52% of SPS implant failures occurred in 33% of patients with a failed implant. These patients exhibited lower compliance demonstrated by irregular attendance at routine recall examinations. Cluster failures have been observed in literature, and one study found that 57% of implant failures occurred in 33% of patients (Schwartz-Arad et al, 2008).

**THR-DAE Failure Trends and Experience of Implant Surgeon on Implant Failure**

In the university implant training program where this study was conducted, students typically gain initial experience by placing threaded implants and then SPS implants in the later part of their residency. Several implants were removed shortly after placement due to iatrogenic error (i.e. nerve impingement, poor positioning) and can be definitively categorized as operator error. As a result, early threaded implant failures may have been caused by operator error. In addition, SPS implants were commonly used in more challenging situations and were typically placed under closer supervision, which may account for fewer early failures. However, some implants placed may have suffered iatrogenic damage during placement (i.e. overheating site, dull burs, contamination, prolonged surgery) and resulted in fibrous encapsulation rather than osseointegration. This would have only been recognized several months after placement when the implants were re-entered or during prosthetic fabrication. Several conflicting studies have been published on the notion that novice clinicians tend to have increased implant failures. Lambert reported that implants placed by inexperienced surgeons (<50 implants) failed twice as often as those placed by experienced surgeons (Lambert et al, 1997). Another study reported that the experience of the surgeon plays an important role in determining survival rates of unloaded implants (Preiskel & Tsolka, 1995). In contrast to these reports, a university study reported that surgical experience does not influence implant survival and observed implant survival rates of 96% in cases where surgery was carried out by faculty-student teams (Kohavi et al, 2004). Furthermore, Melo found that there was no statistically significant difference in implant survival rates when the level of training was compared for oral surgery residents (Melo et al, 2006).
Other Failure Trends

Several implants with suspicion of failure underwent exploratory surgeries and were found to have mobility with fibrous encapsulation. This occurred with implants (both SPS and THR-DAE) that were either submerged at placement or exposed with healing abutments. Other trends were investigated to elucidate possible causes for failure. No particular location or arch appeared to contribute to failure and there were no more failures in grafted sites than in non-grafted sites. It was found that two thirds of restored implants that failed were restored with a single tooth prosthesis compared to splinted implant failures.

Patient systemic conditions and precarious habits such as smoking and alcohol consumption were assessed. Several patients with multiple implant (cluster) failures tended to have non-compliant behavior, including smoking greater than ½ pack of cigarettes a day or drinking 4 or more alcoholic beverages (Heitz-Mayfield & Huynh-Ba, 2009; Ekfeldt et al, 2001). Although these findings were common in several patients, they may simply be coincidental as these patients had different implant types fail during different periods of healing and treatment.

D. Radiographic Analysis

Difference between vBW and PA measurement

This part of the study examined the type of radiograph used to measure crestal bone loss by comparing vertical bitewing (vBW) to periapical radiographs (PA). The effect of radiograph type on crestal bone loss measurements produced statistically significant results. Currently, long cone periapical radiographic technique is commonly reported for assessing mesial and distal crestal bone levels around dental implants (Cox and Pharoah, 1986). The results of the study found that vBW consistently indicated 0.1 mm greater crestal bone loss than PA. This confirms the results of Sewrin in an in vivo setting where deviation between two exposures (i.e. PA and vBW) resulted in approximately 0.1 mm difference in crestal bone levels (Sewerin, 1990).

Distortion of Radiograph

The frequency of distortion was also assessed and there was significantly more distortion when radiographs were taken in the maxilla than the mandible. This was observed when comparing radiographs taken in the maxilla (vBW Distortion = 23.43%, PA Distortion = 37.06%) and mandible (vBW Distortion = 9.51%, PA Distortion = 12.27%) and examining the incidence of
thread overlap and distortion. A shallow or restrictive maxillary palatal vault and the manner in which a patient bites a film holder are likely to contribute to off-axis film placement with subsequent radiographic distortion (Baumann et al, 1992).

There was a statistically insignificant trend for more distortion with the PA technique compared to the vBW technique. The 0.1 mm difference in bone loss in vBW may be attributed to less distortion of the film and parallel placement with the long axis of the implant at the crown-to-implant interface. The implant-bone interface in a distorted film would likely show overlapping bone and as a result falsely appear as less crestal bone loss. This can be proven by examining the extreme example for the results of a distorted PA and an undistorted vBW. When a PA was distorted and the matching vBW was not, crestal bone loss and crown height measured in the PA was 0.21-0.25 mm less and 1.27 mm taller than in the corresponding vBW. This demonstrates that, throughout a radiograph, the distortion increases towards the periphery, which is likely due to a film that is stretched and bent because of the palate or floor of the mouth. Furthermore, despite calibration of the radiograph with the known dimension of the implant, if the periphery of the film is bent and stretched, the measurements will only be accurate when they are in close proximity to the area of calibration.

**Clinical Application of Radiographic Analysis**

In a practice setting, conventional radiographs taken to assess crestal bone levels are typically not digitalized and measured with computer software. The more common approach is to estimate bone level by counting the number of threads that are not completely covered by bone or, in the case of SPS implants, where the crest bone is in relation to the machined collar-to-sintered surface junction. This technique has limitations associated with it, including the necessity for sharp distinct implant threads visible on the radiograph. The apparent density of peri-implant bone can be affected by settings on the radiographic machine and by the developing techniques. In addition, each threaded implant system differs in thread design and thread pitch (spacing between threads). For example, the thread pitch on THR-SLA is 1.25 mm, whereas the thread pitch on THR-DAE varies between 0.6-0.9 mm. This type of analysis cannot be performed on SPS implants as they have no threads. Therefore, loss of crestal bone below two threads in one implant type could be double that of another threaded implant type in terms of actual millimetric bone loss. If a clinician wishes to estimate crestal bone levels by counting
threads exposed, then detailed knowledge of thread pitch, fixture height and quality radiographs taken over a period of time are recommended. Therefore, to facilitate thread counting, our recommendation for the decision to take a vBW or PA depends on which view produces sharpness of the threads on the radiograph.

There are benefits to taking several radiographs of different types and at different angles to assess structures and find abnormalities. Throughout this study, there were several occurrences of prosthetic crowns and bridges that were not fully seated on the implant fixture, which could only be detected in certain views. In clinical practice, it is not common to take several radiographs at every recall appointment because of the impact of the additional radiographic dosage on the patient and the additional chair time required. However, it may be justified to take a PA and vBW immediately at the day of prosthesis insertion (i) to ensure the superstructure is completely seated, (ii) assess peri-implant structures, and (iii) determine which radiograph type produces the best quality image without any thread distortion for future follow up.

**Summary of Radiographic Analysis**

The results of this study indicated three significant findings. First, a distorted PA can show up to 0.25 mm less bone loss than a vBW that displays sharp threads. The same can be said for the converse scenario where a vBW is distorted and a PA displays sharp threads. Second, regardless of the arch, the first type of radiograph that should be taken is a vBW to ensure the least amount of distortion. If this view produces a distorted image then a PA should be taken and has a high likelihood of not being distorted (see Appendix 3). Finally, the difference between the two intraoral views (PA and vBW) resulted in an average difference of 0.1 mm in crestal bone levels. Therefore, clinicians need not worry about the difference in accuracy of the two films, rather the quality and distinction of their contents.

**Study Limitations**

It is recognized that the retrospective study design had inherent flaws coupled to its methodology. Data collected relied on previous chart entries by multiple clinicians. Additional variables such as smoking status and an updated comprehensive review of medical conditions that might affect implant status could not be assessed due to inconsistent charting.
In addition, crestal bone loss around an implant occurs in a three-dimensional manner, while radiographic assessment with conventional intraoral films only allow the assessment of mesial and distal surfaces and do not allow for assessment of buccal and lingual crestal bone levels. With the advent of cbCT technology, circumferential crestal bone levels are now more accurately measured and are being reported in recent literature (Naitoh et al, 2005).

Furthermore, clinical measurements of peri-implant soft tissue bio-type and thickness in addition to plaque and signs of inflammation were not recorded and assessed during this study. The multifactorial nature of crestal bone remodeling and loss around implants poses inherent difficulties to study. No particular element is the definitive cause of crestal bone loss; rather there are multiple components that contribute in aggregate.

A significant limitation of the present study was the inability to prospectively record details regarding the surgical placement technique used for each implant. All implants were assumed to have been placed according to manufacturer’s directions. However, it was not always possible to determine whether or not implant placement was ideal, i.e. fully submerged, level with crestal bone, or supracrestally placed. Unfortunately, immediate post-op radiographs after implant placement were not always taken, as the depth of original implant insertion does affect the amount of crestal bone remodeling seen. Therefore, there may be an initial amount of bone loss around an implant at baseline that is not accounted for in this analysis.

Another confounding factor which was not assessed was the history of periodontal disease and periodontal status of the adjacent tooth. These factors, each of which may contribute to crestal bone loss may be further influenced by embrasure space, interdental contact area, interproximal food traps and patient oral hygiene, were not assessed.

Overall, several significant findings were discovered that resembles results published by others. The impact of implant design, type of prosthesis and adjacent structure were found to be the most influential for crestal bone loss. These findings can be directly applied to clinical practice in which a clinician can assess a clinical situation and can calculate a reasonable amount of crestal bone loss. The assessment of crestal bone loss radiographically is a routine part of practice and several aspects and techniques should be disseminated to clinicians to aid in their daily practice.
Conclusion and Future Research Directions

This study has yielded several results that confirm reports in available literature and also create new potential areas for study. The concept of splinting adjacent implants with crowns has been addressed and some light has been shed on the effects of implant supported prosthetics. Furthermore, factors effect crestal bone loss yielded key variables to consider. The field of dental implants has reached a point in its evolution that basic concepts of osseointegration, implant design and treatment planning are maturing into evidence based concepts rather than unsupported dogma.

The results of this study should assist in directing future research strategies. Prospective studies that may include a matched or randomized design to examine crestal bone levels in a variety of implant designs should be tested *in vivo*. This would require a large sample size of patients and implant sites in a variety of areas of the mouth and have a sufficient follow up time of at least 5 years. The key to testing this concept is to have matched sites where two or three implants are placed with optimal distance between them and to a standardized relation to the crestal bone level. Then splinted and non-splinted prostheses can be placed and matched according to jaw position, bone type, implant dimensions, surgical protocol and presence of remaining teeth in the jaw and opposing dentition. This stringent protocol is very difficult to achieve in clinical practice and crestal bone loss patterns are multifactorial. The aforementioned design protocol may not be sufficient to incorporate all known factors such as soft tissue biotype, thickness of circumferential bone, parafunctional habits and susceptibility to periodontal disease. Furthermore patient systemic health and habits such as smoking should be included in crestal bone loss investigations.

The current literature demonstrates that implants do indeed survive for long periods of time in both splinted and non-splinted forms. The original dental implants in the Branemark studies were complete mandibular arch splinted prosthesis and these have been tracked for over 30 years with success. Since the general concept is known to work with both options, a more refined and deeper understanding is of value to assist in treatment planning cases to yield optimal long term outcomes.
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Appendix 1 – Sample Radiographic measurement

A = Crown Height
B = Implant Length
C = Crestal Bone loss (Distal)
Appendix 2 – Implant dimensions

<table>
<thead>
<tr>
<th>Labeled Lengths</th>
<th>Actual Implant Lengths With Cover Screw OFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>15mm</td>
<td>14.6mm</td>
</tr>
<tr>
<td>13mm</td>
<td>12.6mm</td>
</tr>
<tr>
<td>11.5mm</td>
<td>11.1mm</td>
</tr>
<tr>
<td>10mm</td>
<td>9.6mm</td>
</tr>
<tr>
<td>8.5mm</td>
<td>8.1mm</td>
</tr>
<tr>
<td>7mm</td>
<td>6.6mm</td>
</tr>
</tbody>
</table>

The actual implant lengths from the top of the implant collar (platform) to the tip of the implant are shorter by 0.4mm than the labeled length.
Decision Tree - Mandible

PA
- No Distortion (87.7%)
- Distortion (12.3%)

vBW
- No Distortion (90.5%)
- Distortion (9.5%)

vBW
- Distortion (28.3%)
- No Distortion (71.7%)

PA
- No Distortion (63.4%)
- Distortion (36.6%)