EVALUATION OF FACIAL ALVEOLAR BONE DIMENSION OF MAXILLARY ANTERIOR AND PREMOLAR TEETH

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ABSTRACT

Carolina Vera-Resendiz: Evaluation of Buccal Alveolar Bone Dimension of Maxillary Anterior and Premolar Teeth. A Cone Beam Computed Tomography Investigation.
(Under the direction of Donald Tyndall, Lyndon Cooper, Glenn Reside, and Ingeborg De Kok)

The thickness of maxillary alveolar facial bone has a significant impact on the outcome of dental treatment. It has been reported that at least 2 mm of facial bone is necessary to prevent soft tissue recession, fenestration, and dehiscence. This research, comprised of two separate studies, uses Cone Beam Computed Tomography (CBCT) to measure horizontal width of the buccal plate in maxillary anterior teeth including first premolars. In the first study, a total of 43 subjects with existing CBCT scans were enrolled. The thickness of the buccal plate was evaluated in five regions along the long axis of each tooth and the average bone thickness was calculated. In the second study, a total of 15 subjects were enrolled to measure and analyze the thickness of the buccal plate before and after implant placement. These measurements will help develop understanding of the mechanism of bone remodeling after tooth extraction and implant placement.

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CHAPTER 1

STUDY ONE: EVALUATION OF FACIAL ALVEOLAR BONE DIMENSION OF MAXILLARY ANTERIOR AND PREMOLAR TEETH. A CONE BEAM COMPUTED TOMOGRAPHY INVESTIGATION

Introduction

Dental implants are frequently used to replace missing anterior teeth, tooth loss due to trauma, or teeth removed due to unfavorable restorative conditions. The process of tooth replacement by means of a dental implant and a crown is diverse and it relies on a complex array of clinical and pragmatic factors. Implants may be placed into extraction sockets immediately[1] or at some period of time following extraction and wound healing[2]. Following implant placement, provisionalization or direct occlusal loading may be generated immediately[3] or after the process of osseointegration has been completed. Both submerged (two-stage) and non-submerged (one-stage) approaches may be utilized. All these methods include tooth extraction followed by implant placement and loading at different times. At present, clinical data indicates implant survival is possible following all of these routes of treatment.

Beyond measurement of implant survival, there is little data concerning the fate of the buccal plate after implant placement in sites where teeth have been recently removed. The concern levied here is for architectural changes in the alveolar bone following extraction and subsequent to implant placement. Unanticipated and excessive tissue changes can result in unacceptable esthetic deficits that range from soft tissue asymmetry to facial tissue discoloration to marked tissue dehiscence and abutment or implant exposure[4]. Loss of osseointegration, pain and peri-implantitis may occur[5]. Clinicians must realize that alveolar resorption is a consequence of tooth extraction or avulsion. Dental implant therapy must include rational consideration of these phenomena.

The recognition of alveolar resorption is longstanding. This process for the edentulous patient has been characterized as an inevitable and progressive process that occurred rapidly following tooth extraction. Remarkable changes in the maxillary alveolar ridges following the removal of teeth have been reported.[6,7]

During the past decade, renewed interest in this phenomenon has surfaced in the context of single missing teeth and the residual alveolar ridge. It has been observed that the maxillary alveolar ridge width diminishes approximately 50% following tooth extraction.[8] It has also been demonstrated that alveolar bone resorption occurs following tooth extraction and implant placement in premolar regions with marked loss of horizontal and vertical buccal architecture.[9]

These clinical studies were confirmed in a series of animal studies that defined buccal and lingual bone changes following tooth extraction and immediate implant placement. It has been established that the buccal and lingual alveolar bone resorbs despite augmentation with different biomaterials, or implant placement in the socket.[10,11] It has been argued that the bone subserved by the collagen fibrils of the periodontium (bundle bone) is preferentially lost with the tooth unable to support bone structure.

Some clinical observations suggest that buccal bone resorption varies in magnitude among individuals and from site to site. Factors implicated in this variation include the presence and absence of existing infection, flap versus flapless extraction and implant placement, the extent of trauma during extraction and the thickness of the buccal plate of bone prior to tooth extraction. The width of the buccal plate of bone may be an important determinant of bone morphologic changes following extraction.[12] Tomasi et al[10] used a refined multivariate analysis of factors affecting architectural bone changes after tooth extraction and implant placement to define significant variables. The study identified the thickness of the buccal plate, the horizontal and vertical position of the implant in the socket as well as age and smoking as influential factors of concern. In this study, and other related work by Huynh-Ba et al [11], the buccal wall thickness has been identified as an important anatomic feature affecting the eventual outcome of immediate implant placement in sockets. If the thickness of the buccal wall is a pre-existing feature of potential tooth extraction sites that affects dental implant outcomes, then it is important to define the buccal wall thickness of human maxillary alveolar bone buccal to existing teeth. The aim of this study was to define the bucco-lingual thickness of the alveolar bone facial to maxillary anterior teeth and premolars using cone beam computed tomography (CBCT).

Materials and Methods

Patient recruitment – The cone beam computed tomography images of forty three (43) patients were evaluated in the anterior maxillary arch from tooth #5 - #12 (Table 1). All subjects included in this investigation were recruited under an institutional review board approved protocol. This protocol included individuals in need of single tooth replacement utilizing dental implants. A total of 1376 sites were analyzed (8 teeth per person, 4 measurements per tooth), of which 1036 sites were measurable. The sites that could not be measured were divided into three different categories: edentulous sites (M), sites with an implant (I), and sites with insufficient bone thickness for measurement (nm).

CBCT evaluation - Participants were scanned using a Galileos Comfort CBCT and Sidexis software was used to format all images. Galaxis/Galileos Implant software was used to complete all the measurements. The regions of interest included the maxillary first premolar teeth and anterior teeth (#5 - #12).

Measurement of buccal bone - Two examiners made four distinct measurements of the buccal bone relative to the tooth in question (Fig. 1). The distance from the radiographic cementoenamel junction (CEJ) to the buccal alveolar bone crest (distance AB) was recorded. The thickness of the buccal bone plate in a buccopalatal direction perpendicular to the long axis of the tooth root was measured in three locations; 1) 1 mm below the buccal alveolar bone crest (C), 2) mid-root (F) and 3) 1 mm above the apex of the tooth root (G). Where bone was not visualized, no value was recorded. Where bone was not measured due to artifact, this finding was recorded.

Statistical analysis

The data was obtained by averaging the measurements from two observers for each tooth and site. Excel was used to obtain descriptive statistics. The remaining analysis and plots were done using the statistical software package *R* (R development Core Team, 2009). We begin with some exploratory analysis. Figures 6-8 show box plots of the measurements at sites AB, C, F, and G. Figure 6 suggests that the AB measurements are similarly distributed across the teeth. Further evidence for this similarity is given below using a sign-test. The overall median (of all teeth) for AB was calculated to be 2.79mm. Similarly the overall 1st and 3rd quartiles are Q1=2.21mm and Q3=3.48mm, respectively. This says that overall, approximately 50% of the AB measurements are between 2.21mm and 3.48mm; these can be thought of as typical measurements. Moreover 122 of the measurements were greater and 172 were smaller than the critical threshold of 3mm (50 sites could not be measured).

We can see from Figures 8 and 9 (and confirmed by a sign-test, see below) that the C and F measurements are not similarly distributed across the teeth, and it is better to summarize the data by providing the five-number-summaries, as well as the number of measurements above and below the critical threshold of 1mm, for all teeth separately (see Table 2 “C measurements” and Table 3 “F measurements”). For the C measurements, the median thickness was 1.04mm for tooth 5, 1.28mm for tooth 12, and smaller than 0.84mm for teeth 6 through 11. The difference between premolars (teeth 5 and 12) and the remaining teeth is statistically significant (Table 4). The range of the middle 50% of the C measurements of tooth 5 was between Q1=0.83mm and Q3=1.38mm. The other ranges for C measurements can be found similarly in Table 2. The measurements at site F are summarized the same way in Table 3. We summarize the G measurements in a similar way as the AB measurements above; note that Figure 8 indicates that the G measurements are distributed similarly across teeth, and an overall five-number-summary seems appropriate. The overall median is 0.88mm, and approximately 50% of the AB measurements are between the 1st and 3rd quartiles, i.e. between Q1=0.65mm and Q3=1.31mm. Moreover 87 of the measurements were greater and 130 were smaller than the critical threshold of 3mm (127 sites could not be measured). The box plots give a concise but incomplete description of the data. In Figures 9-12, the sorted measurements are plotted, which shows further relevant features.

In the plot of sorted C measurements a reference line at the clinically relevant level of 1mm is given. The behavior of the right and left anterior maxillary teeth is similar. We can see how much thicker or thinner the bone is compared to the threshold of 1mm. In particular, for tooth 12 we can see that not only the majority of patients had bone thickness greater than 1mm, but that they were well above the 1mm threshold. On the other hand, we can see that for teeth 9 – 11, the bone thicknesses that are greater 1mm, are typically close to 1mm. The plot for the sorted F measurements shows similar features.

The sorted AB measurements show, similar as the box plots for AB, not much difference between teeth. We can also see that the measurements are not concentrated around the threshold of 3mm, but spread out relatively homogeneously between 1.5mm and about 4 to 5mm. The sorted G measurements do not give such a clear picture. A reason for that is the difficulty of measuring at that site. The measurements were similar across teeth 5 – 8 and relatively concentrated around the threshold of 1mm. Teeth 9 – 12 showed more variability in the larger measurements across teeth.

Dependent-samples sign-tests were performed to test the statistical significance of the differences. That is, for each patient the difference of measurements for a pair of teeth was considered, and it was tested whether the median of these differences was significantly different from 0. The sign-test is non-parametric and based only on the sign of the differences in measurements, and thus more appropriate for the data than for example *t*-tests. Table 4 summarizes the sample median of the differences and the corresponding *p*-values from the sign test. In each cell, the estimate is given with the *p*-value in brackets; NS indicates that the median is not significantly different (at level 0.05) from 0. Note that the *p*-values are not adjusted for multiple testing. The estimates and *p*-values give strong evidence that the median bone thickness at location C is greater for teeth 6 and 12.

For the AB measurements, the plots indicate no significant difference of the median between teeth. The same sign-test as used for the C measurements showed no significant difference in the AB measurements between teeth (at level $\alpha=0.1$). More powerful tests or a greater sample size might show differences, but the plots of the sorted measurements suggest that there is no clinically relevant difference between teeth. The measurements for F showed similar differences among teeth as the C measurements.

The measurements for G did not differ significantly (based on the sign-test at level $\alpha=0.05$) among the teeth; the only *p*-value smaller than 0.05 ($p=0.04$) was for the comparison between teeth 8 and 10. This small *p*-value is likely to be due to sample variation, instead of a real difference between teeth 8 and 10 – evidence for this is the non-significant difference between teeth 8 and 10.

Results

CBCT images revealed alveolar bone buccal to teeth and existing implants. The image quality typically permitted identification of the absence or presence of bone, for the measurement of the buccolingual bone dimension. Figures 2-5 show representative CBCT image examples illustrating this concept.

The distance AB was measured for all maxillary first premolar and incisor teeth present in 43 subjects (Fig. 9). The median distance was 2.79 mm. The distances between the different teeth were not significantly different (at level α=0.1).

The distance C, the thickness of the buccal plate measured 1 mm from the midfacial alveolar crest varied between premolar sites and the anterior maxillary teeth (Fig. 10). The overall median buccolingual thickness for premolars was 1.13 and greater than the 0.8mm measured for anterior maxillary teeth. The middle 50% of the buccolingual thickness for premolars (combined) was between Q1=0.87mm and Q3=1.46mm as compared to the middle 50% of the anterior maxillary teeth that had thickness between Q1=0.69mm to Q3=0.94mm. There were 63 teeth where the distance C could not be measured; per tooth between 4 and 12 sites could not be measured, but there was no indication that a particular tooth type was particularly difficult to measure.

The distance F, the thickness of the buccal plate measured at the mid root location varied between premolar sites and the anterior maxillary teeth (Fig. 11). The overall median buccolingual thickness for premolars was 1.03mm and greater than the 0.70 mm measured for anterior maxillary teeth. The middle 50% of the buccolingual thickness for premolars (combined) was between Q1=0.79mm and Q3=1.51mm as compared to the middle 50% of the anterior maxillary teeth that had thickness between Q1=0.60mm and Q3=0.84mm. There were 100 teeth where the distance F could not be measured, with between 9 and 14 non-measurable thicknesses per teeth.

Regarding distance G, the thickness of the buccal plate measured near the tooth apex was similar for all tooth positions (Fig. 12). The median buccolingual thickness was 0.88mm, with the middle 50% of measurements between Q1=0.65mm and Q3=1.31mm. There were 127 teeth where the distance G could not be measured, and this was most frequently observed at teeth 12 (23 non-measurable), the other sites (teeth 5 -11) were not measurable between 11 and 17 times.

Discussion

The general interest in implant esthetics mandates that a complete understanding of the architecture of the alveolus and enveloping soft tissues be acquired. Included is the clinical definition of alveolar alterations that occur following tooth extraction. The historical observations of Atwood(1962)[6] and Tallgren (1972)[7] and the more recent clinical observations of Schropp (2003)[8] and Botticelli (2006)[9] indicate that alveolar resorption following tooth extraction must be expected.

The magnitude of changes that occurs following tooth extraction must be appreciated if clinical expectations are to be met. Some of the most detailed data comes from a prospective investigation of Ferrus et al (2009)[12]. They observed that the mean horizontal reduction measured from the implant surface to the outer aspect of the crest was 1.0mm (50% of the existing dimension) for anterior teeth and 1.1 (33% of the existing dimension) for posterior teeth.

The buccolingual thickness of the buccal alveolar plate is regarded as a key determinant of implant outcomes following extraction. Most recently, Tomasi et al (2010)[10] determined that the dimension of the buccal plate of bone was a major factor affecting the degree of resorption experienced by the buccal plate following resorption. Additionally, the thickness of the buccal plate was associated with the degree of defect fill following implant placement. Tomasi and co-workers dichotomously ranked the buccal plate wall thickness at greater than 1 mm or less than 1 mm. Following this line of investigation, the measurements obtained here suggest that there are few anterior maxillary teeth with greater than 1 mm of buccal bone thickness (Fig. 6). The recent findings of Huynh-ba et al (2010)[11] which report on the alveolar wall thickness measured clinically following tooth extraction also indicate that more than 80% of sockets presented with buccal wall thickness of less than 1 mm. While the fidelity of the CBCT measurements may be scrutinized because of instrumentation error, motion artifact, scatter artifact and the inherent 0.3 mm voxel size of the system, the present measurements are similar to those obtained by direct measurement. It may be concluded that few maxillary anterior tooth alveolar buccal plates are greater than 1 mm thick.

When considering the previous concerns regarding the outcome of implants placed into extraction sockets and the focus on “biotype” which refer to thick biotypes associated with buccal wall thicknesses greater than 1 mm, the present investigation suggests that there are few anterior maxillary teeth that may be associated with such a “thick biotype”. If the risk for resorption of the alveolus is greater if the buccal plate is less than 1 mm (a “ thin biotype”), then the majority of anterior maxillary tooth sites present an osseous architecture that is of higher risk for resorption. Again, the recent observations that anterior tooth sites experience greater horizontal and vertical bone loss than posterior sites are consistent with such an interpretation.

When considering premolar sites, the buccal alveolar plate width was larger than for anterior maxillary teeth. This may be important in considering existing data regarding outcomes of immediate loading studies. For example, Oh et al (2006) [13] indicated that there was good tissue stability following implant placement in predominantly premolar extraction sockets. This stability could reflect many parameters, but may reflect the influence of a thicker buccal alveolar plate. Findings from the premolar location regarding esthetics might not be inferred to anterior maxillary tooth sites.

Socket classification systems have been proposed to aid in the decision making for dental implant therapy. Both Elian[14] and Caplanis[15] have proposed simple classification systems that enable communication about the extraction site following tooth extraction. The present study did not reconstruct each peri-radicular alveolar structure, but the presentation of mid root buccal bone in the CBCT images suggested that the majority of anterior maxillary teeth have bone present near the cervical portion of the tooth (position C). Few dehiscences were observed prior to extraction. In contrast, far more tooth sites were observed to lack bone at position F, or G or both. The relative impact of dehiscences on esthetics can be debated, but the absence of bone in this region requires additional intervention and risk (Caplanis). The presence of fenestrations, on the other hand, may complicate implant placement and can preclude attainment of sufficient primary stability. The present investigation suggests that pre-extraction evaluation of the anterior maxillary teeth may inform the clinician regarding the presence or absence, abundance and location of buccal alveolar bone.

Conclusion

The present evaluation of CBCT images to determine the presence of and architecture of the buccal alveolar bone residing at maxillary anterior teeth and first premolars indicates that 1) CBCT assessment of socket morphology is possible and informative, 2) the average buccal alveolar bone thickness at all anterior tooth positions is less than 1.0 mm in the majority of individuals, 3) premolar teeth possess greater buccal alveolar bone thickness, and 4) the average vertical distance from the CEJ to the buccal bone crest of 2.79mm is consistent among all sites measured. Clinicians should consider all maxillary anterior teeth to possess a thin buccal plate prior to extraction unless otherwise demonstrated.

Acknowledgements

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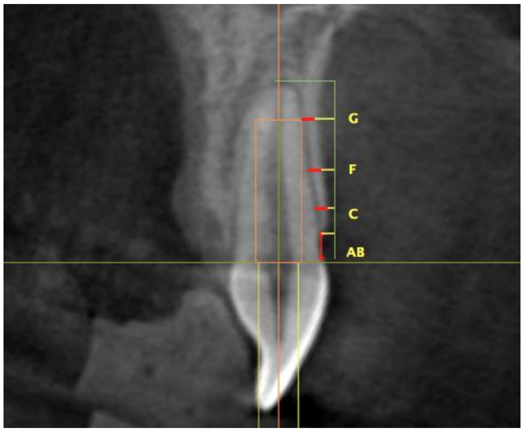


Figure 1 - Measurement locations utilized in this investigation.

- *AB - distance from the radiographic representation of the CEJ to the Buccal alveolar bone crest (mm +/- 0.1 mm);*
- *C - buccal alveolar bone thickness at 1 mm apical to the alveolar bone crest (mm +/- 0.1 mm);*
- *F - mid-root alveolar bone thickness (mm +/- 0.1mm);*
- *G - apical alveolar bone thickness at 1 mm coronal to the root apex (mm +/- 0.1mm).*

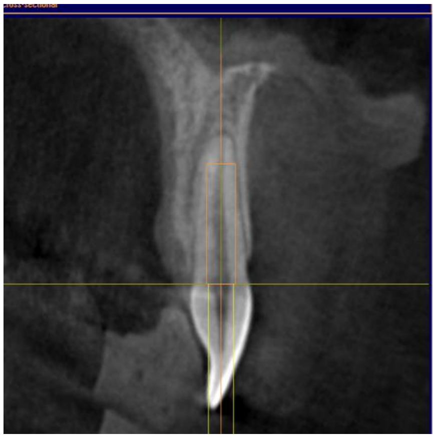


Figure 2. Representative CBCT image of a central incisor tooth with an intact buccal plate.

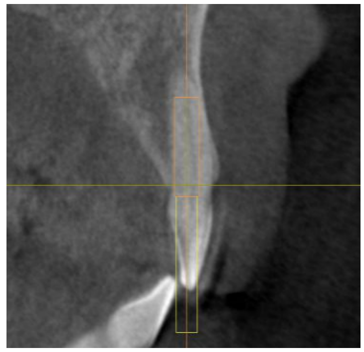


Figure 3 Representative CBCT image of a central incisor tooth missing buccal alveolar bone at the mid-root region (F).

Figure 4. Representative CBCT image of a canine tooth missing buccal alveolar bone in both the mid-root and the apical regions (F and G).

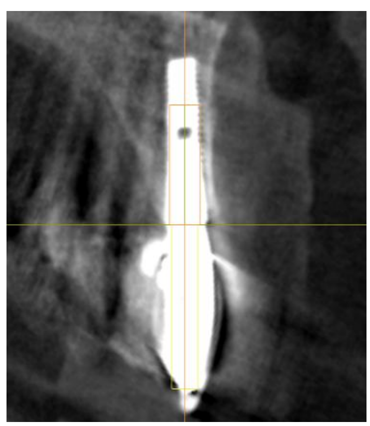


Figure 5. Representative CBCT image of an existing implant in the central incisor position. Note that the buccal bone is visible and intact.

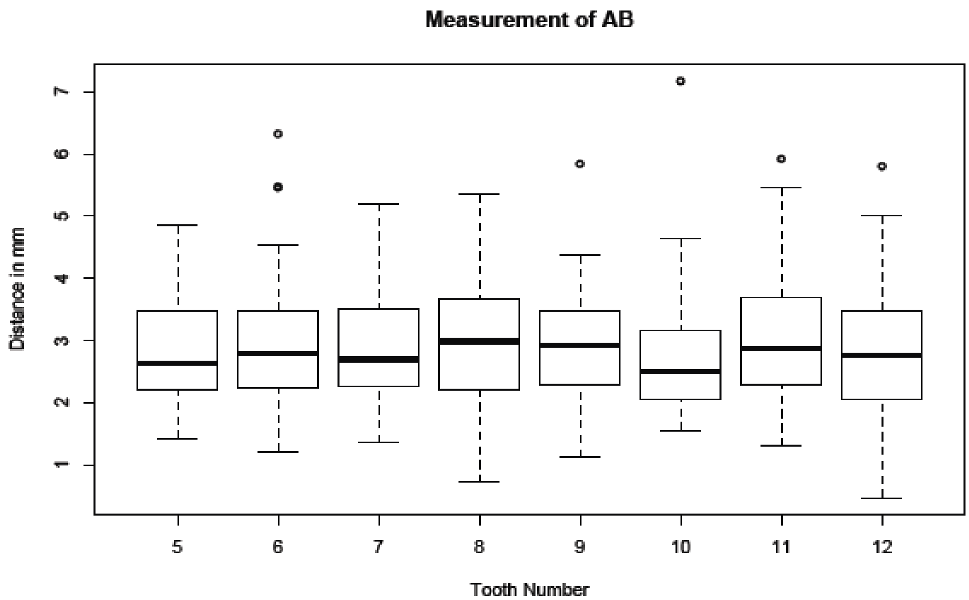


Figure 6. Box plot of the distances from the radiographic representation of the CEJ to the buccal alveolar crest (AB) at teeth #5 - #12.

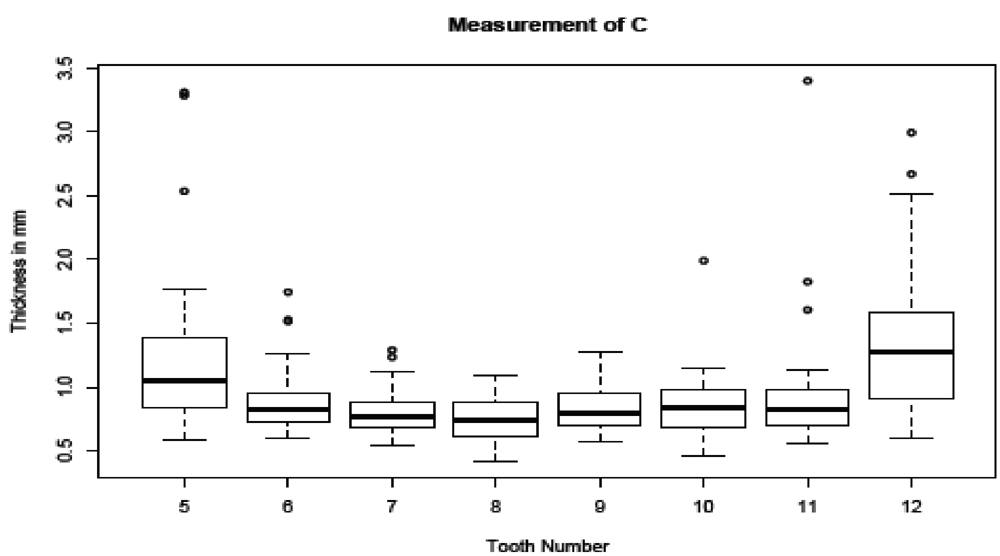


Figure 7. Box plot of C, the thickness of buccal alveolar bone at 1 mm apical to the alveolar bone crest at teeth #5 - #12.

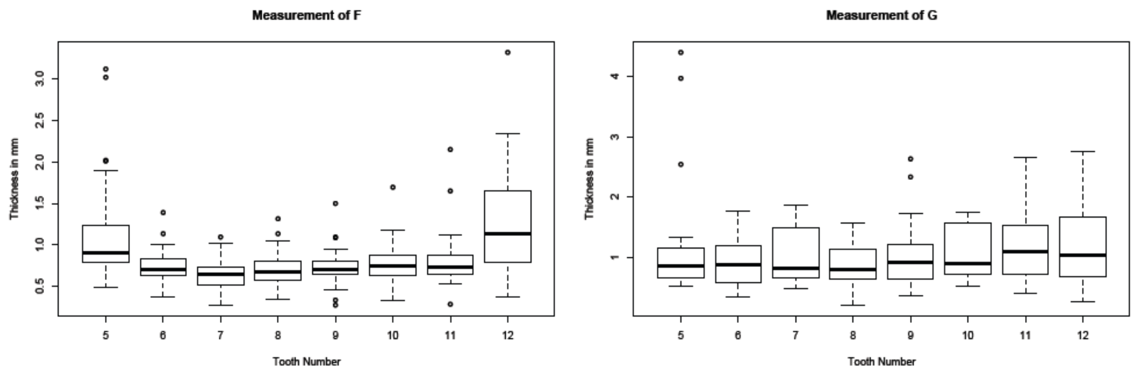


Figure 8. Box plots of the measurements F and G, for teeth #5 - #12.

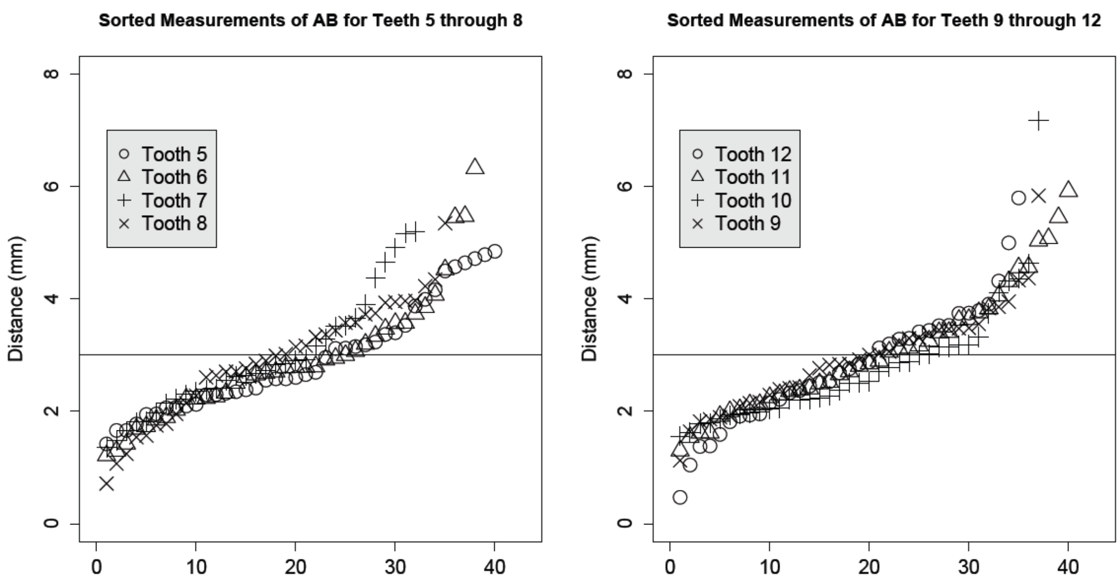


Figure 9. Sorted AB measurements for all teeth (#5 - #12).

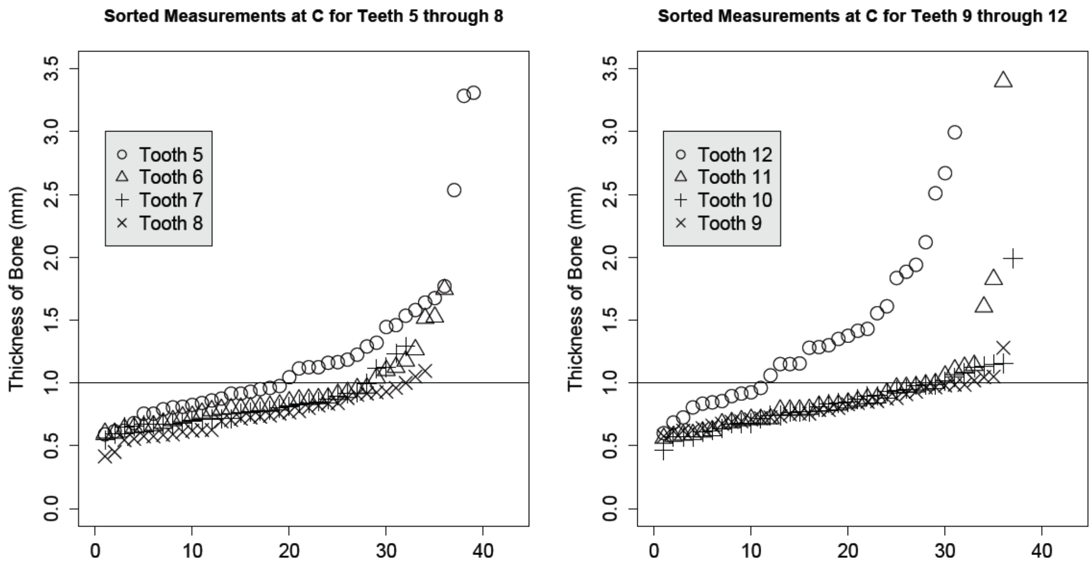


Figure 10. Sorted measurements of buccal alveolar bone thickness 1 mm apical from the alveolar crest (position C) for all teeth (#5 - #12).

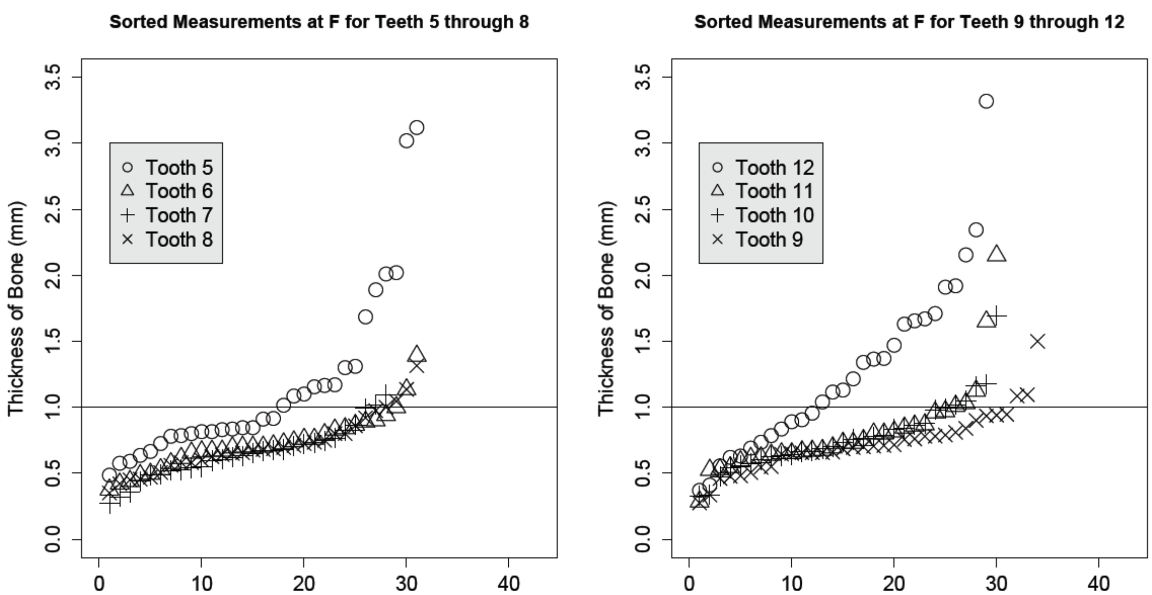


Figure 11. Sorted measurements of buccal alveolar bone thickness at the mid root location (position F) for all teeth (#5 - #12).

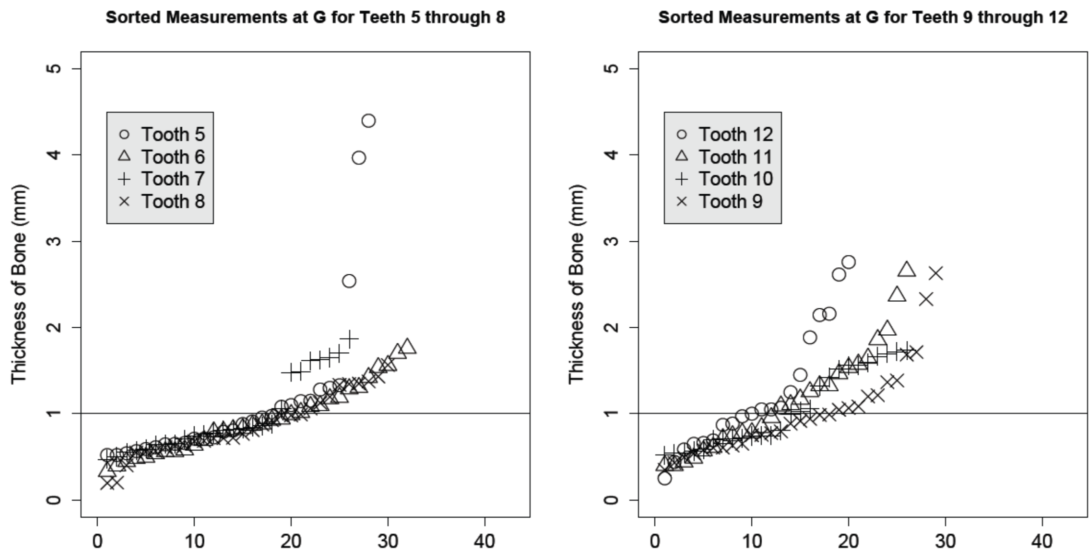


Figure 12. Sorted measurements of buccal alveolar bone thickness at the apical root location (position G) for all teeth (#5 - #12).

Table 1. Study Demographic

Total # Patients	**Teeth analyzed in 4 different segments**	**Total # sites analyzed**	**Total # measurable sites**	**Total # sites that could not be measured**			
				Missing (M)	Implants (I)	Due to very small bone thickness	Due to scatter and lack of clarity in images
43	#5 - #12	1376	1036	108	36	111	85

Note:
* Every site was measured by 2 observers.
**When a particular site was deemed measurable by one observer and not measurable by the other observer that site was re evaluated and then a final assessment was made.

Table 2. Five number summaries for the measurements at site C and the number of measurements at each site that had a thickness above and below 1mm.

	5	6	7	8	9	10	11	12
Minimum	0.59	0.6	0.54	0.41	0.57	0.46	0.56	0.6
1st quartile (Q1)	0.83	0.73	0.68	0.61	0.70	0.68	0.70	0.90
Median	1.04	0.82	0.77	0.73	0.81	0.84	0.82	1.28
3rd quartile (Q3)	1.38	0.95	0.87	0.87	0.93	0.98	0.97	1.58
Maximum	3.31	1.74	1.29	1.09	1.28	1.99	3.4	2.99
Number of Measurements>=1	20	8	4	3	4	8	7	20
Number of Measurements <1	19	28	28	31	32	29	29	11

Table 3. Five number summaries for the measurements at site F and the number of measurements at each site that had a thickness above and below 1mm.

	5	6	7	8	9	10	11	12
Minimum	0.485	0.375	0.27	0.35	0.275	0.33	0.285	0.37
1st quartile (Q1)	0.7925	0.635	0.52375	0.58	0.64625	0.62625	0.6425	0.785
Median	0.91	0.7	0.64	0.68	0.7025	0.745	0.73	1.13
3rd quartile (Q3)	1.235	0.835	0.73375	0.8	0.805	0.8725	0.8675	1.655
Maximum	3.12	1.39	1.095	1.315	1.5	1.695	2.15	3.32
Number of Measurements>=1	14	3	2	4	3	5	5	17
Number of Measurements <1	17	28	26	27	1	25	25	12

Table 4. The sample median of the differences in the C measurements between teeth are given. The corresponding p-values from testing the hypothesis that the median of the differences is 0 (based on the dependent-samples sign-test) are given in brackets. NS indicates that the median is not significantly different (at level 0.05) from 0. Note that the p-values are not adjusted for multiple testing. Greater buccal bone thickness is observed for premolar teeth compared to anterior maxillary teeth. Recommendations for therapy based upon studies utilizing a pre-molar model should not be extended to anterior maxillary teeth without further experimental evaluation.

	6	7	8	9	10	11	12
5	**0.28 (0.007)**	**0.45 (<0.001)**	**0.18 (0.003)**	**0.2 (0.002)**	**0.3(0.017)**	**NS**	**NS**
6	**---**	**NS**	**0.15 (0.036)**	**NS**	**NS**	**NS**	**-0.44 (<0.001)**
7		**---**	**NS**	**NS**	**NS**	**NS**	**-0.44 (<0.001)**
8			**---**	**0.1 (0.005)**	**NS**	**-0.1 (0.0192)**	**-0.5 (0.0002)**
9				**---**	**NS**		**-0.39 (0.002)**
10					**---**	**NS**	**-0.44 (<0.001)**
11						**---**	**-0.44 (0.009)**

CHAPTER 2

STUDY TWO: EVALUATION OF POST-IMPLANT FACIAL BONE RESORPTION USING THE SIRONA GALILEOS SYSTEM FOR RADIOLOGIC ASSESSMENT

Introduction

A contemporary problem in implant dentistry is the maintenance of tissue levels following the immediate placement of implants in either extraction sockets or healed alveolar ridges. There are significant data to suggest that buccal bone and the soft tissue levels are reduced within a year following implant placement. No fewer than ten different studies demonstrate that this occurs. While more recent studies suggest that this can be reduced by proper implant placement, there still remains the question of what is the fate of bone and soft tissue at dental implant following their placement. The aim of this study is to evaluate whether cone beam computed tomography could be used to measure such changes following implant placement. The following questions will be explored: What is the accuracy of cone beam tomographic imaging for detecting facial bone before and after implant surgery? What is the accuracy of cone beam tomographic imaging system to measure the thickness and length of facial bone? Is there a difference in the amount of facial bone before and after implant placement?

Marked volumetric alteration in the alveolar ridge occurs following tooth extraction (Atwood, 1961)[6]. Shropp et al (2003)[8] revealed that there was a marked reduction in the buccolingual dimension (approximately 50%) of the extraction site over the first 3 – 6 months following tooth removal. Following tooth extraction, the alveolar ridge is remodeled. Boticelli et al (2004)[9] evaluated the situation of healing of the gap that exists between the dental implant surface and the internal aspects of the socket wall comprised of buccal and lingual alveolar bone. In a study involving 18 subjects, implants were placed into sockets by a one stage procedure without additional materials in the gap. After four months, the alveolus including the socket and implant was markedly changed. The horizontal dimension of the socket was reduced by greater than 50% on the buccal aspect, while the corresponding lingual resorption was approximately 30%. Vertically approximately 0.5 mm of buccal and lingual resorption was measured at the time of re-entry. The authors concluded that the gap between a newly installed implant and the alveolar wall was resolved by a process of bone formation and "substantial" bone resorption of the alveolus.

This process of alveolar resorption has been modeled in dogs and has been characterized over the initial 8 week healing period to be of magnitudes that may induce clinically significant alveolar deficiencies (Araujo et al 2005)[16]. The resorption of buccal alveolar walls occurs in this initial healing period by a process of osteoclast-mediated resorption (Trombelli 2008) and results in vertical reductions of approximately 2.5 mm in the mongrel dog model. Following this phase of crestal reduction, a second phase of buccal and lingual cortical bone resorption was observed.

While Botticelli et al (2005) concluded by virtue of histological evidence that the placement of an implant in the alveolus with a circumferential marginal defect resulted in new bone formation and the establishment of an osseointegrated interface along the entire implant, they noted marked changes did occur in the alveolar bone surrounding the implant.

In fact, Araujo et al (2005) [16] demonstrated that the placement of an implant in a socket did little to alter the process of remodeling of the buccal and lingual alveolar walls.

When Botticelli et al (2006) [9] next considered the impact of healing of marginal defects at implants placed in healed ridges or extraction sockets they observed that bone modeling and remodeling at the implant in an extraction socket differed from that of an implant placed in a healed ridge. This investigation using ‘modeled’ socket defects revealed that the vertical reduction in socket wall height was again approximately 2.5 mm after 8 weeks of healing. In a similar study conducted for 12 weeks, Araujo et al (2006) observed that the osseointegration that occurred along the implant placed into the alveolar bone and separated by a gap during the first four weeks of healing was in part lost due to the process of continued remodeling that occurred. The authors state that the height of the buccal bone wall was reduced about 1 mm during this period. They further suggest that this bone loss was the result of surgical trauma that included flap elevation and detachment of the periosteum, while the initial bone resorption was a result of hard tissue changes related to bone trauma of implant placement.

This series of studies conducted in a single laboratory setting using the mongrel dog model demonstrated that 1) following tooth extraction the horizontal dimension of the alveolar ridge is reduced by approximately 50%, 2) that vertical reductions of the buccal alveolar wall are pronounced and approximate 2.5 mm, 3) vertical reductions of the lingual alveolar wall are less pronounced, 4) placement of a dental implant into the socket does not alter the process and 5) placement of a xenograft bone grafting material in the socket does not alter the resorptive process either.

Accepting that resorption of the buccal plate occurred following extraction of teeth and implant placement the dog model is relevant to the human situation, several questions become relevant. First, is the process of flap elevation significant to the process and is flapless surgery a means of preventing buccal alveolar bone reductions? Second, is the situation for implant placement in healed ridges significantly different than for implant placement in extraction sockets?

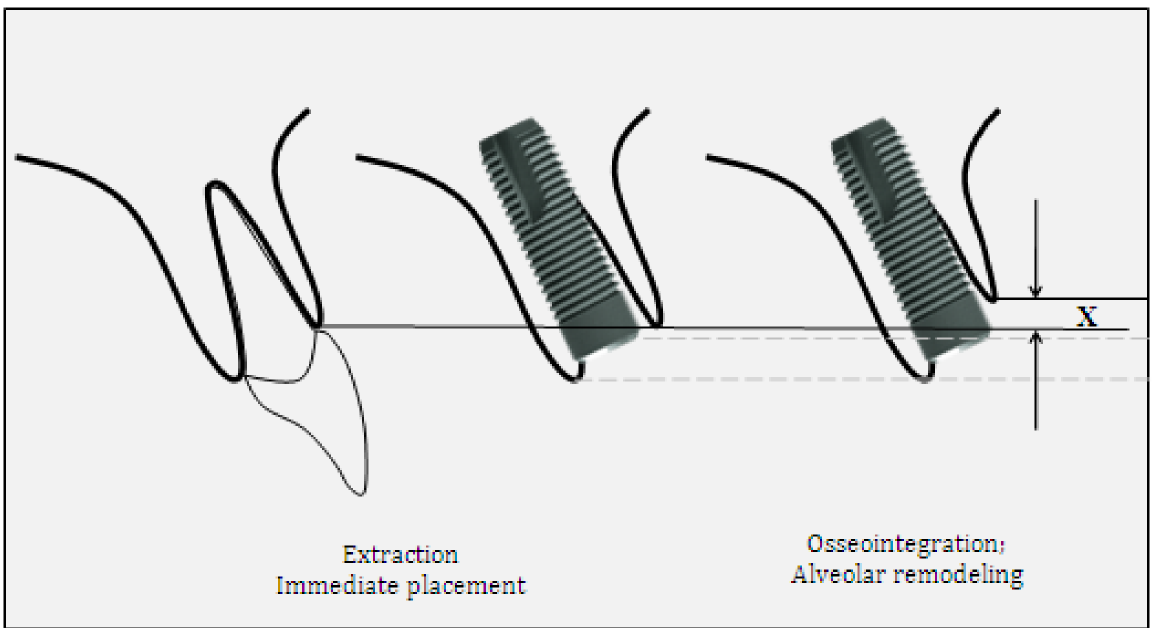


Figure 13. Existing data indicates that following extraction and implant placement, alveolar remodeling will occur over a period of approximately 8 – 24 weeks. During this period, the buccal alveolar bone wall will experience rapid vertical reduction (bundle bone resorption) and additional horizontal reduction of the buccal cortex. The result is an observed 'shortening' of the buccal alveolar bone housing the endosseous implant and exposure of the implant to the superficial mucosa or the oral environment.

The process of alveolar remodeling following tooth extraction and dental implant placement has been evaluated in man. During the period of this investigation, Sanz and co-workers performed a direct evaluation of the healing of gaps facial to dental implants placed into extraction sockets. This was performed by re-entry surgery and direct measurement. The aim of this investigation was to determine if the putative changes that occur in the buccal alveolar bone wall following tooth extraction and implant placement could be measured using conventional cone-beam computed tomography (CBCT). It was a second aim of this investigation to compare both qualitatively and quantitatively the vertical bone reduction that occurred in association with implants placed in healed ridges or into extraction sockets.

This study incorporated fifteen patients from the UNC School of Dentistry in need of a single implant replacing missing or extracted teeth in the maxillary anterior ridge. Each patient was studied over the course of one year and had three different CBCT images taken at the following intervals: two weeks prior to, immediately after, and one year post-implant placement.

A qualitative assessment of the Sirona Galileos' ability to accurately detect the facial bone using the technique used and described by Nair et al[37]. The literature clearly shows that cone beam computed tomography (CBCT) technology, which provides 3D and cross-sectional views of the jaws, is being used with increasing frequency in the dental practice as a substitute from a traditional two dimensional conventional panoramic and cephalometric images. CBCT scanners are easy to use and produce a 3-D image volume that can be reformatted using software for customized visualization of the anatomy. CBCT hardware is not in the same class as the original CT machines in cost, size, weight, complexity, and radiation dose. It is thus considered to be the examination of choice when making a risk–benefit assessment [18]. Also the availability of real 3-D planning software which allows a reliable transfer to the surgical field through drilling templates helps the surgeon to achieve an adequate oral implant placement [19]. The CBCT machines were employed previously in radiotherapy using fluoroscopic systems or modified simulators to obtain cross-sections of the patient in the same geometric conditions as the treatment. It was also used in vascular imaging and in micro-tomography of small specimens for biomedical and industrial applications. [20]

With CBCT technology, the data acquisition and parameters such as slice thickness and interval of the reconstruction can determine the imaging resolution which has enabled this technology to excel at capturing high-contrast structures[21]. In addition, several authors[22.23.24] revealed excellent image acquisition for different structures. The 3D data greatly expand our diagnostic capabilities and have been incredibly useful in the evaluation of the axial inclination of teeth to supplement the information obtained from patient models. The exact position of impacted teeth and their relationship to adjacent roots or other anatomical structures can be comprehended so surgical exposure and subsequent movement can be planned. Common CBCT usage ranges from diagnostics and treatment planning of congenital malformations, to localization of impacted teeth to positioning of dental implants. Regarding pre-surgical implant planning, only an exhaustive and comprehensive radiological assessment can provide the necessary information to select such optimal sites and the number and size of implants to be placed. CBCT enables correct identification of anatomic structures to avoid damage and other perioperative complications during the implant surgery.

The selection of the radiological technique should be based on weighing the required image quality against the radiation risks and costs involved[17]. As with all diagnostic imaging, it is critical that the patient-benefit of a procedure outweighs the risk of exposure to ionizing radiation. One clear advantage of CBCT over conventional CT scanners is its lower radiation dose. Each CBCT scan will deliver the equivalent dosage of 3 Panoramics or 1/3 of a full mouth series. This is roughly equivalent to about 1-2 days of natural background radiation.

A study by Gijbels found that the skin dose was almost the same as with rotational panoramic radiography. This means an effective dose of approximately 20 μSv (microsievert)[26]. Published effective doses from digital panoramic radiography range from 4.7 to 14.9 μSv per scan. Other published data on nondigital panoramic radiographs puts the effective dose as high as 26 μSv. Arai et al[27] found that the effective dose in one projection by the 3DX MultiImage Micro-CT was 7.4 μSv. Mishima et al[28] reported an advantage on the exposure values of the 3D Panoramic X-ray CT scanner PSR 9000N. The integral absorbed dose of radiation was less than 1/15 that of spiral CT, at least when the exposure condition of the latter was optimized, to obtain a thinner slice width and a more accurate data. The CT machines can perform a full scan of the head in a few seconds and give the patient an effective dose of only micro Sv (1) compared with about 2000 m Sv from a typical conventional CT scan of the whole head in a few seconds.

Considering the increased interest in cone beam CT, further adaptations, optimizations, and new developments will soon follow. The future may offer fully adaptable systems regarding exposure parameters and scanning volumes and image quality improvements. The evolution in hardware will be followed by a refinement of the software including dedicated surgical tools such as preoperative implant planning software. With the combination of application-specific software tools, cone beam computed tomography can provide practitioners with a complete solution for performing specific diagnostic and dental implant planning[32].

Surgical guidance for implant placement relieves the clinician from multiple perioperative decisions. Precise implant placement is under investigation using sophisticated guidance methods, including CAD/CAM templates.

Protocols have been developed that optimize the visualization of images for implant site assessment[31]. The conditions surrounding dental implants installed in the bone can be observed three-dimensionally. Moreover, three dimensional CBCT imaging systems are suitable for clinical assessment of alveolar bone grafting before and after installation of dental implants or orthodontic treatment of the cleft-adjacent teeth[30].

Implants placed immediately after tooth extraction offer several advantages, but many authors have reported problems in filling the residual gap between the implant and the socket walls. Barrier and grafting techniques have been tested and yield varying results, so it has been suggested that the timing of implant placement may be important for success. Histologically, peri-implant defects of over 1.5 mm heal by connective tissue apposition, rather than by direct bone-to-implant contact, but clinically this healing may be very successful. The different rate of bone remodeling around immediate or delayed implants could have implications for the preferred timing of implant placement in sites of high esthetic concern[35]. However, little is documented in the literature about the rate and amount of actual facial bone loss following implant placement in the maxillary anterior area. This study attempts to quantify this unknown.

The literature also shows that lesions causing intraosseous defects in the head and neck region are difficult to diagnose using two-dimensional radiography, and three-dimensional (3D) data provided by CT is useful but often difficult to obtain. The recent introduction of CBCT technology has shown great promise to overcome this limitation; however, there is limited evidence to prove that defect volume can be determined accurately. Therefore, one *in vitro* validation study aimed at establishing whether linear and 3D CBCT, using volumetric measurements, is accurate for determining osseous defect sizes. CBCT has the potential to be an accurate, non-invasive, practical method to reliably determine osseous lesion size and volume. Further clinical validation will lead to a vast array of applications in oral and maxillofacial diagnosis[36]. Similarly, this study attempts to establish whether 3D CBCT is accurate for determining facial bone loss after implant surgery, a technological challenge which has up to now been difficult to ascertain. If proven accurate in this endeavor, future research can incorporate CBCT analysis to determine optimal techniques for preserving facial bone before, during, and after implant surgery.

Materials and Methods

Patient recruitment – Twenty patients between the ages of 18-75 were recruited into this study under an approved institutional review board protocol. Patients were in need of a single tooth replacement for a missing or extracted tooth in the maxillary anterior ridge. Patients were excluded from consideration if they had periodontal disease present or were in need of a bone graft. During the study, five of the original twenty patients were dismissed for various reasons including systemic health problems, having a fenestration requiring bone grafting, failure to make their appointments, etc. The fifteen remaining patients were divided into two groups: those missing a tooth with a healed alveolar ridge, and those needing an extraction. Eight patients had healed alveolar ridges, and seven were in need of an extraction.

CBCT evaluation – Subjects had three CBCT scans during the study: an initial scan two weeks prior to surgery, a scan immediately after the implant placement, and a follow-up scan one year after the surgery. Subjects were scanned using a Galileos Comfort CBCT and Sidexis software was used to format all images. Galaxis/Galileos Implant software was used to complete all the measurements. The regions of interest included the maxilla including the first premolar teeth and all anterior teeth (#5 - #12).

Measurement of buccal bone – One examiner made four distinct measurements relative to the implant in question. The distance from the radiographic abutment/implant interface to the buccal alveolar bone crest (distance AB) was recorded. The thickness of the buccal bone plate in a buccal-palatal direction perpendicular to the long axis of the implant was measured in three locations; 1) 1 mm apical to the implant / abutment interface (C), 2) mid-implant (F) and 3) at the apical portion of the implant (G). These measurements were repeated three separate times from which the median could be obtained.

Statistical Analysis

Each implant had four measurements taken, as previously described. The observer took these four measurements per implant three separate times. The data was obtained by averaging the three separate rounds of measurements taken for each of the four sites per implant. Excel was used to obtain descriptive statistics. The remaining analysis and plots were done using the statistical software package *R* (R development Core Team, 2009). We begin with some exploratory analysis. Figure 14 shows an overall analysis of box plots of the measurements at sites AB, C, F, and G taken at the time of surgery and one year later at the follow-up appointment. This figure includes data from all fifteen study-patients. Looking at the midlines in box plots, which equates to the average for the dataset, it is clear that over time there was bone loss as measured in each of the four sites on a tooth. At point AB, the average measurement at the time of surgery was 0mm. This intuitively makes sense as this means that on average the implant abutment interface was at the same height as the crest of the buccal bone at the time of surgery. However, as the figure illustrates, the buccal bone resorbed between 1 and 1.5mm apically at measurement point AB. The boxplot of AB at the one year follow-up is significantly different from the time of surgery. This point is further corroborated in Table 5 which shows that there is actually 1.123mm median difference in AB over time across all patients. Most importantly, the p-value of 0.018 is statistically significant as it is less than 0.05.

Looking at the remainder of the sites in Figure 14, it is clear that there is also a sizable difference in bone levels at points C and at point F over time. There is little overlap in the box plots for these sites, and there is no overlap between the median value one year later, and the whole range of measurements taken at the time of surgery. As we would expect, Table 5 corroborates this finding by illustrating that the median difference in measurement after one year for C is 0.623mm and for F is 0.567mm. This corresponds to a p-value of 0.004 for both C and F. As this is less than 0.05 it is a statistically significant amount of missing bone. Note that the measurement at G has a median difference in measurement of 0.187mm and a p-value of 0.059 which is close, but not statistically significant over time.   It is possible that with a larger sample size that this figure would turn out to be significant, as it had a p-value just slightly higher than 0.05.

Breaking the analysis up into subgroups, Figure 15 shows the box plots for all four measurements AB, C, F, and G over time in the “Healed Ridge” patient population (n=8). Once again a cursory review of the four box plots shows that there was bone loss over time as measured right after surgery and one year later.   However this time it appears that the amount of bone loss is not as much as indicated in the overall study. Most of the box plots over time in this figure have significant overlap indicating that the amount of bone loss is less significant over time in this group as compared to the group at large. The one difference to this is measurement C. You can see that the median measurement for this group at the one year follow up is close to 0.5mm. Table 6 confirms for us that C is the only site that had a difference of statistical significance (p= 0.035) in the amount of bone loss over time for the healed ridge group.

For the group of patients requiring extraction and immediate implant placement, Figure 16 shows the box plots for all four measurements.   A quick scan of this table highlights the fact that there are sizable differences between measurements AB, C, and F, as there is not even any overlap in the box plots from before surgery and one year later. Table 7 presents a slight surprise in that only AB and F have statistically significant differences (p-value .008 for both), showing a median amount of bone loss of 1.71mm and 0.79mm, respectively. The surprise is that the p-value = 0.063 for C which is close, but not quite, statistically significant (<0.05). Once again, if our sample size were larger, there is a higher possibility that C could be statistically significant.

Figure 19 examines the relationship for potential correlations between measurements AB and C at the one year follow-up appointment. For both the extraction and the healed ridge groups, there is in fact a fairly strong correlation between these two measurements. There are limited data points as the sample sizes for these two groups are 7 and 8 and if the sample sizes were larger it would likely present an even stronger pattern of correlation. As it is, the data points are generally from lower left to upper right.

Results

CBCT images revealed alveolar bone buccal to implants both immediately after surgery and one year post-surgery. The image quality typically permitted identification of the presence or absence of bone, however results indicated there was more accuracy to do so immediately after implant placement rather than one year later. Moreover, as illustrated in Table 8, there was slightly more accuracy in determining presence or absence of bone at the one year follow up with patients who initially presented with a healed ridge (75%) versus those with extraction and immediate implant placement (57%). This difference is likely due to the sample size (n=8 and 7, respectively) and might be eliminated with a larger study population.

The overall analysis is based on data from all fifteen study patients. Figure 14 shows the exploratory analysis including all 15 patients, as the box plots in four measurements: AB, C, F, and G. The two longitudinal data sets (taken immediately after surgery and at the one year follow up) are compared. From the mid-line, median, we can see clearly there is a reduction after one year in AB, C and F, which are the major measurements of bone shape. It indicates that the bone has resorbed after one year from the surgery (Confirmed by a sign test in the Table 5).

The data is composed of two sub-groups: those patients presenting with a healed ridge (eight patients) and those patients having need for extraction (seven patients). Comparing the box plots of the measurements from the two groups shows several things: The extraction group has much larger difference in measurement AB. The difference in G is not very significant (confirmed by a sign test). There are reductions in measurements C and F in both groups. (By a sign test, we can see there's more significant reduction in the extraction group.)

In additional to quantitative analysis of the data, Table 8 illustrates a qualitative assessment of the study. For each of the measurement locations C, F, and G this information is tracked by whether or not the examiner could determine if there was buccal bone. This was studied for both groups (Healed Ridge, and Extraction) at the time of the surgery and also at the year follow-up.

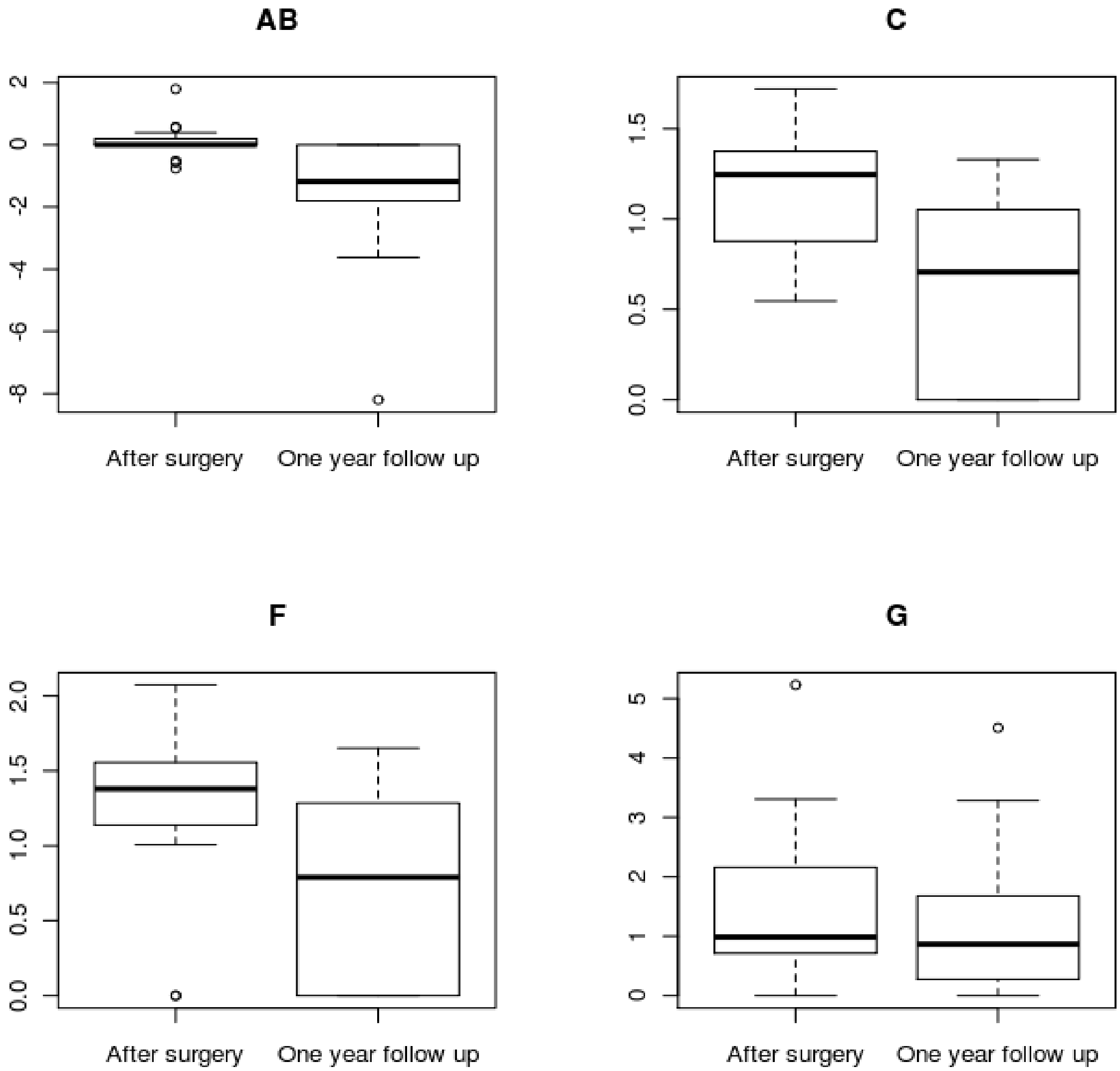


Figure 14. CBCT average values over time for all measurements (15 patients).

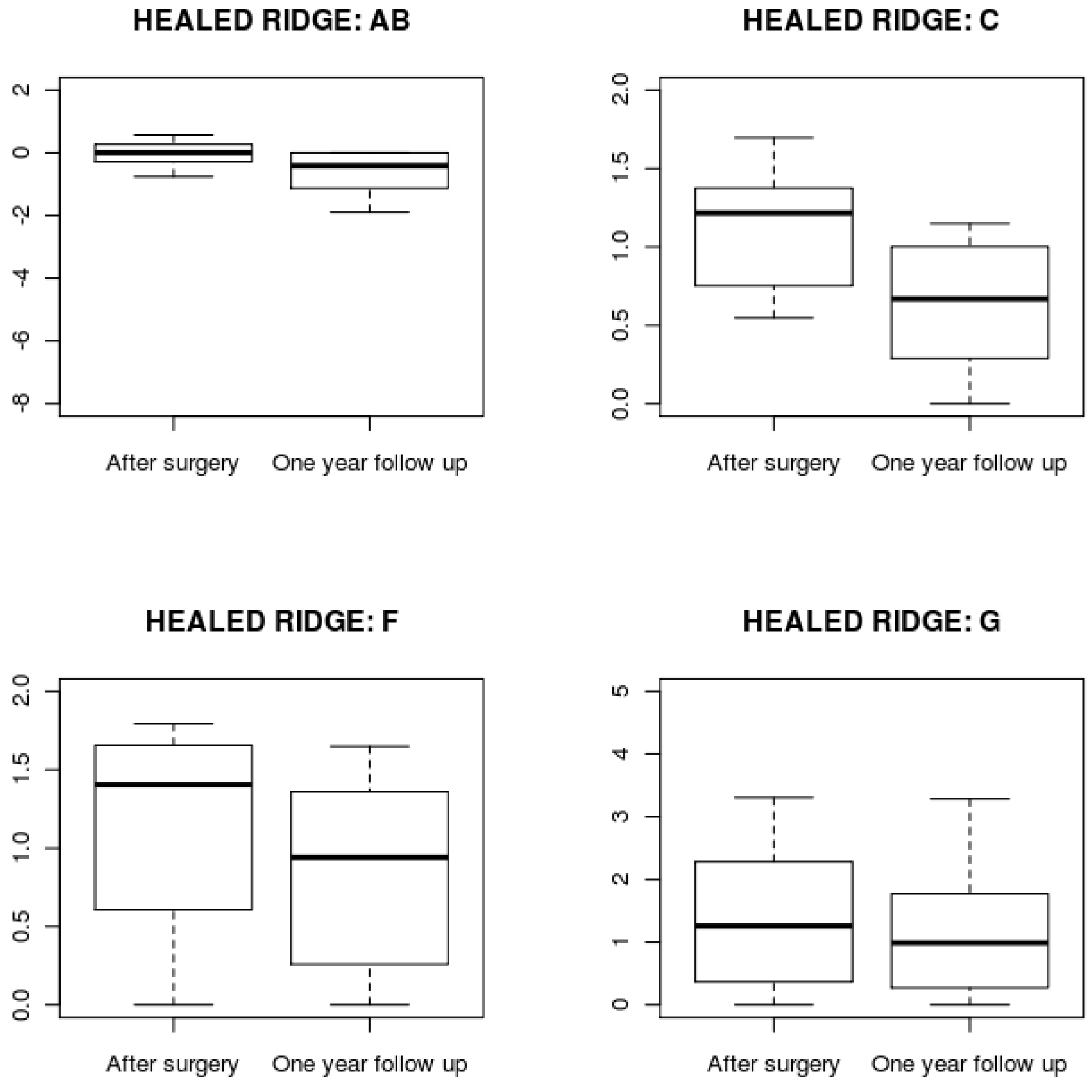


Figure 15. Average CBCT values over time for all measurements – Healed ridge group.

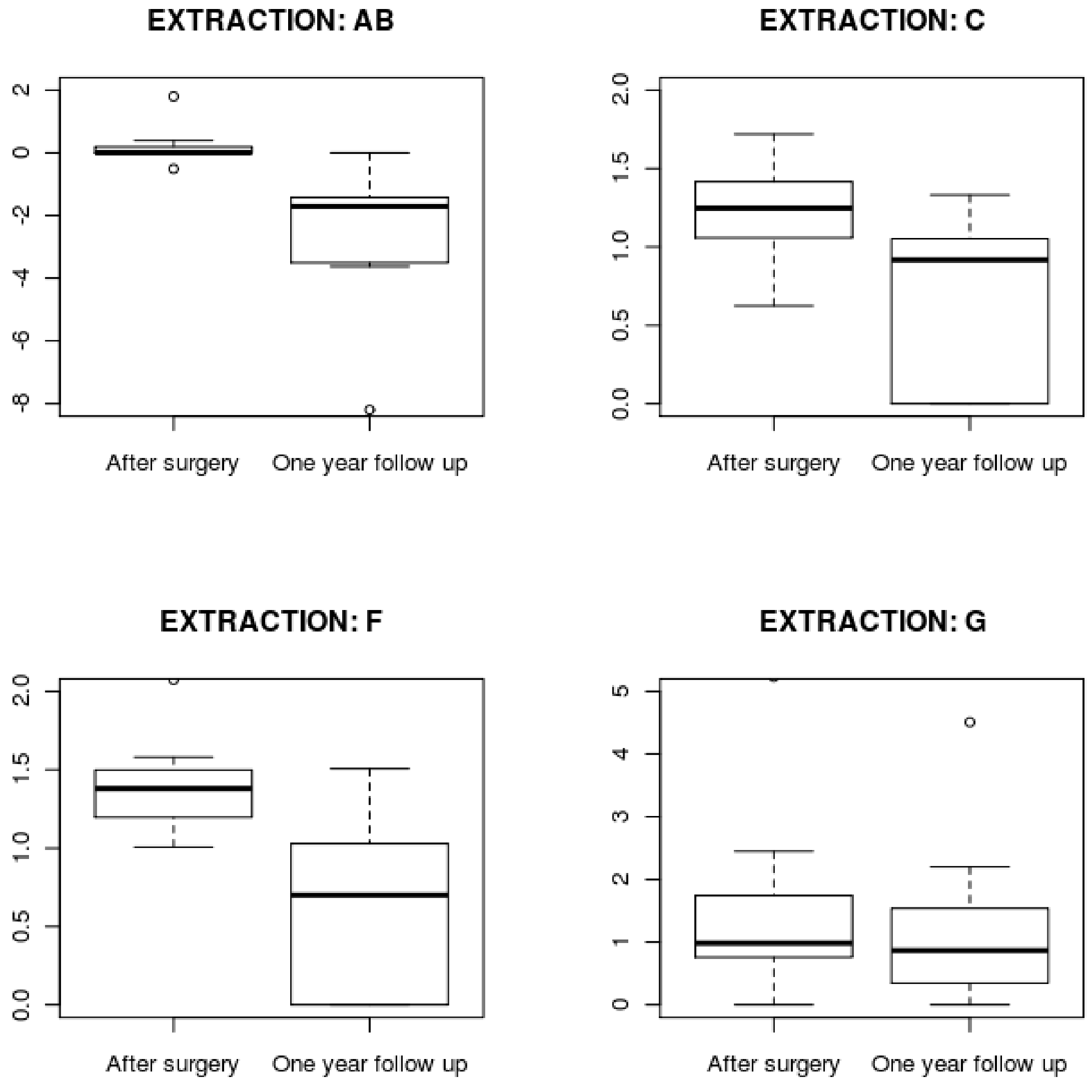


Figure 16. Average CBCT values over time for all measurements – Extraction group.

Table 5. Sample median differences in the measurements after one year (all 15 patients)

Measurements	**AB**	**C**	**F**	**G**
Median (p-value)	1.123 (0.018)	0.623 (0.004)	0.567 (0.004)	0.187 (0.059)

Table 6. Sample median differences in the measurements after one year in the healed ridge group (8 patients).

Measurements	**AB**	**C**	**F**	**G**
Median (p-value)	0.492 (0.363)	0.535 (0.035)	0.215 (0.145)	0.160 (0.145)

Table 7. Sample median differences in the measurements after one year in the extraction group (7 patients)

Measurements	**AB**	**C**	**F**	**G**
Median (p-value)	1.710 (0.008)	0.623 (0.063)	0.790 (0.008)	0.250 (0.227)

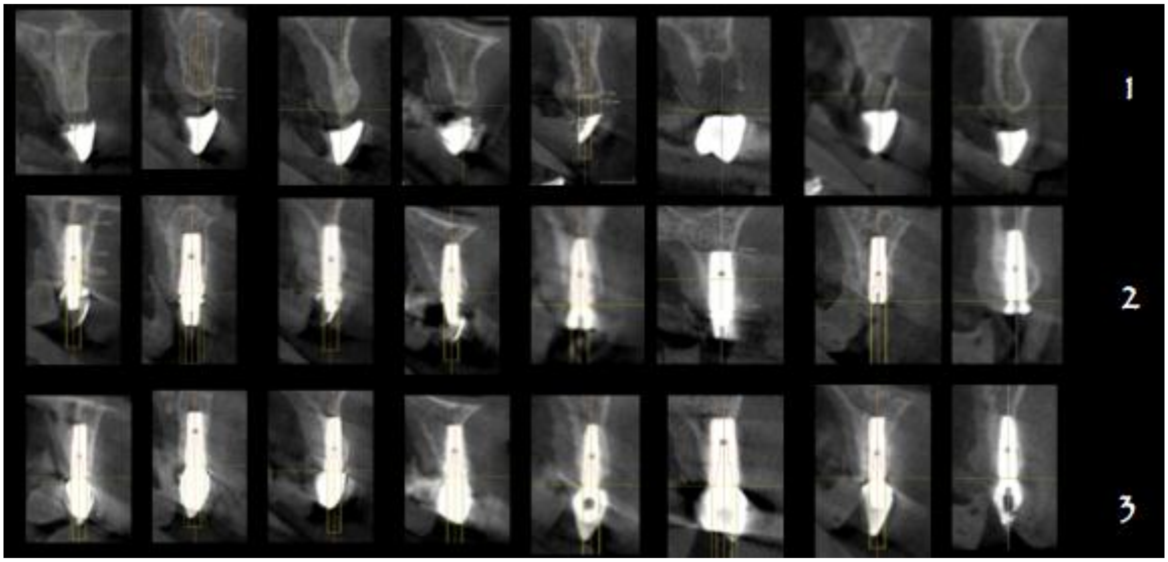


Figure 17. Healed Ridge group – 8 patients. CBCT images in row 1 are pre-operative, row 2 are immediately after implant placement, and row 3 are one year follow-up.

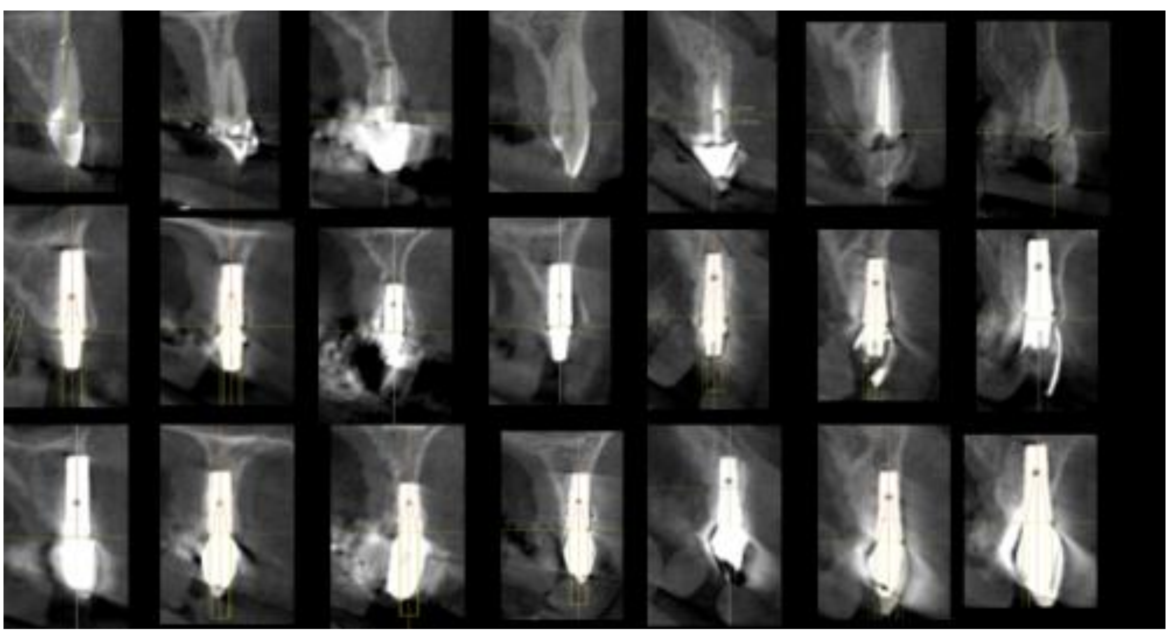
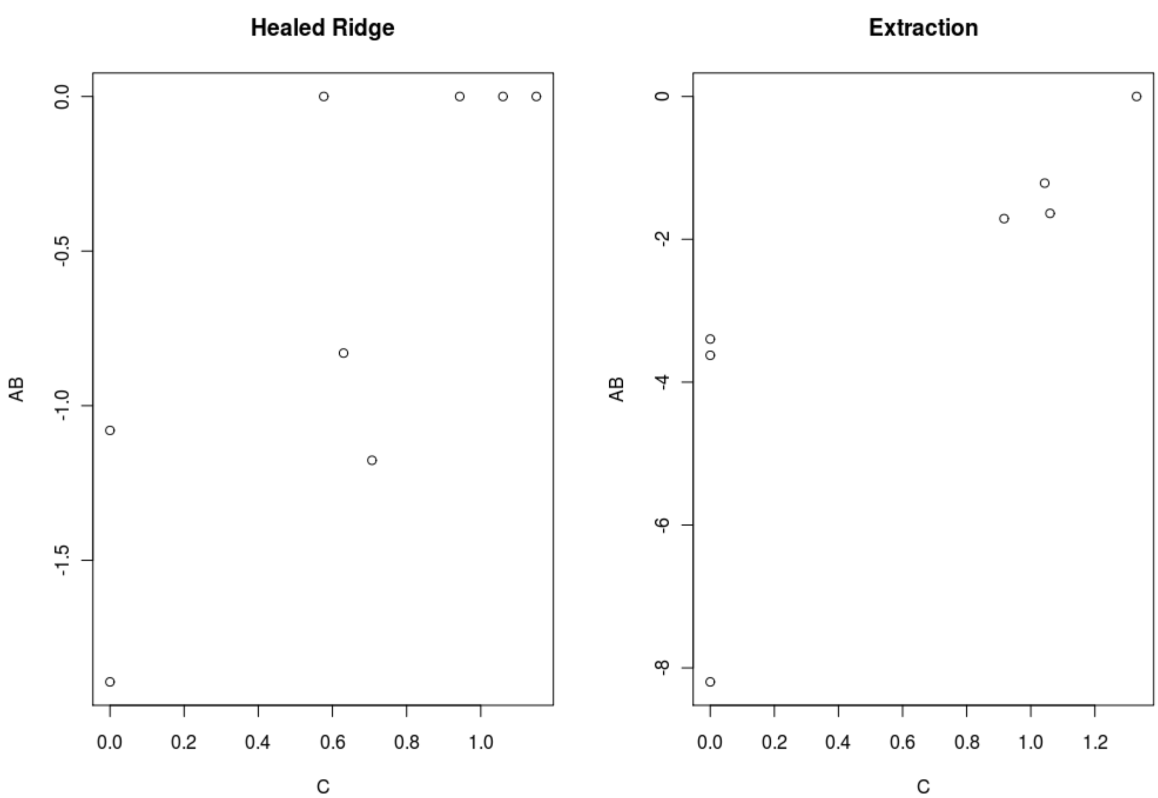


Figure 18. Extraction group – 7 patients. CBCT images in row 1 are pre-extraction, row 2 are immediately after extraction & implant placement, and row 3 are one year follow-up.

Table 8. Qualitative assessment of the ability to see facial bone in the CBCT image both after surgery and one year later, for each of the three measurement locations: C, F, and G.

		Number of patients	C	F	G
AFTER SURGERY	**HEALED RIDGE**	**8**	**8/8**	**6/8**	**6/8**
	EXTRACTION SITE	**7**	**7/7**	**7/7**	**6/7**
ONE YEAR AFTER IMPLANT PLACEMENT	**HEALED RIDGE**	**8**	**6/8**	**6/8**	**6/8**
	EXTRACTION SITE	**7**	**4/7**	**4/7**	**5/7**



R = 0.7604225. R = 0.7604225

Figure 19. Correlation between AB and C measurements at one year follow-up.

Discussion

Prognostic information is essential to managing esthetic expectations of the dental implant patient, especially when contemplating higher risk therapy such as immediate tooth replacement using a dental implant. Cone beam computed tomography should be the examination of choice when making a risk-benefit assessment. The availability of 3D planning software allows creation of surgical templates to further control implant placement. CBCT data acquisition and parameters such as slice thickness and interval of the reconstruction can enhance imaging resolution to resolve high-contrast structures and produce excellent image acquisition. It may be possible to fully investigate the structure of the alveolus prior to tooth extraction. Such information might better prepare clinicians and patients for post-extraction decisions regarding implant placement and/or its outcome. As a supplemental assessment concerning the result of implant placement on the residual alveolar socket buccal bone response, this study used CBCT technology to find quantitative and qualitative changes in buccal bone height and thickness in the anterior maxillary area in single immediate loaded implant restorations in missing or extracted sites.

All the extractions of the non-restorable teeth were performed without flap elevation. Afterward, the extraction sockets were cleaned and evaluated for the presence of an intact buccal plate with no fenestration or dehiscence defects. A flapless technique was also selected for the second group of patients – those with an intact, healed alveolar ridge. Several investigators Becker (2005)[38] and Schwartz (1998)[39], recommended placing implants into extraction sockets with minimal flap elevation or without elevation of surgical flaps in attempt to minimize marginal mucosal recession and enhance aesthetic outcomes. However it has been reported that flapless surgery does not prevent resorption of the facial crestal bone and did not affect the dimensional changes of the alveolar process when compared with the usual placement of implants raising mucoperiosteal flaps (Chen et al 2009)[40]. In this study, a surgical guide was used to establish the ideal implant placement. The goal of this study was to evaluate the buccal plate immediate after surgery and one year after placement. After the second CBCT we noticed that some of the implants were placed slightly buccal. This was an expected factor. Because in some cases were the virtual planning for the surgical guide fabrication was made around the amount of bone present in each case without bone graft added to the procedure. Caneva et al (2010)[41] reported that implant procedures without flap elevation were documented to be associated with faulty positioning and wrong inclination of implants compared with meticulously planned implant position (Van de Velde et. al 2008)[42]. Implants placed without flap elevation are associated with a significant recession of the buccal marginal mucosa, especially at those implants placed in a more buccal position (Evans & Chen 2008 [43], Chen 2009 [40]).

Chen and Buser (2009)[4] indicated that risk factors for recession of the facial mucosal margin included a thin biotype, malposition of the implant, and a thin or damaged facial bone wall.

Current beliefs regarding esthetic outcomes for immediate implant placement include the notions that a) buccal tissue recession is largely inevitable following dental implant placement and b) this recession is negatively impacted by the absence or limited thickness of buccal bone preceding tooth extraction. Although it has been reported, Mayfield et al

(1999)[44], Chen et al (2004)[45], that placing implants into tooth sockets immediate following extraction is as predictable as healed sites several factors seems to influence the frequency and extent of the marginal mucosa recession including tissue biotype. Kois (2001)[46] and Kan et al (2009)[47] identified extrinsic factors (3-D implant position, provisional crown contours, and surgical approach) and intrinsic (patient factors (bone level, hard and soft tissue relationships, and soft tissue biotype and bone thickness). Unfortunately, there is no defined relationship of biotype and bone thickness with dental implant esthetic outcomes.

The thickness of maxillary alveolar facial bone is believed to have a significant impact on the outcome of dental treatment. It has been reported, Qahash (2008)[48] and Spray (2000)[49] that a minimal width of 2mm is necessary order to maintain the crest around the implant. In some cases of immediate placement maybe a greater width is needed to counteract the dimensional changes following tooth extraction, to avoid resorption of the buccal bone and obtained an ideal tissue support. Belser (2007)[50]. However, clinical observations that anterior buccal wall thickness following extraction was 0.8 +/- 0.4 mm; n=39 and that posterior thickness was 1.1 +/- 0.5 mm; n=54; (Ferrus et al 2009)[12]. The authors concluded that buccal wall thickness influences hard tissue alterations following immediate implant placement.

Clinical studies (Spray 2000)[49] show that changes in the facial bone are more evident in sites with a mean thickness of 1.3mm in comparison with sites that have a mean thickness of 1.8-1.1-0 mm and that the buccal bony wall is thinner than the palate wall.

Previous studies (Denissen & Kalk 1991[51], Denissen et al. 1993[52]) suggested that the bone in the alveolus can be preserved with implant placement. However, animal studies have shown that the bony architecture after extraction is clearly modified. (Araujo & Linde 2005[16], Cardaropoli et al. 2005 [53]). Previous studies showed that the outer bony structure in the alveolus develops some vertical and horizontal changes, showing more resorption in the thin buccal wall. Botteceli (2004 a,b)[54] observed that the healing pattern of the extraction of the extraction socket is different and is less favorable when the implants are placed immediate after the extraction procedure.

Araujo (2005[)55] and Tomassi (2009)[56] suggested that dimensional changes can be predicted based on the defect size be predicted based on the defect size and configuration resulting from the tooth extraction. However it has been shown that in terms of immediate placement there is another important factor to consider. The gap distance between the implant and the bone wall socket specially because may exist a difference between the dimensions of the teeth and the dimension of the implant. Wilson (1998)[57] showed that small gaps with no more than 1.5mm at the immediate placement site cold heal without additional procedures

The stability of tissues surrounding the implant are related to many factors. Chen (2007)[58] suggested that the extent of the vertical crest bone resorption is related to the initial thickness of the buccal crestal bone.

In this study the gap distance between the implants and bone wall was not evaluated.

Conclusions

Bone may be visualized by CBCT following placement in both extraction sockets and healed ridges. Bone changes could be qualitatively evaluated 1 year following placement by

CBCT. Bone was maintained qualitatively at the buccal aspects of most implants in both groups. Quantitative changes in bone architecture remaining at the buccal aspects of dental implants one year following placement can be measured at (a) 1 mm from the implant/ abutment interface, (b) mid-implant and (c) apical levels

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CHAPTER 3

CONCLUSIONS

These investigations suggest that clinicians may be guided in clinical therapy by understanding that the general architecture of buccal bone following anterior tooth extraction is “thin” by conventional terminology. Premolar sites possess greater buccal bone thickness following extraction. CBCT assessment of socket morphology is possible and informative, and in most cases is sensitive enough to ascertain the presence or absence of the thin alveolar facial bone in the anterior maxilla.

The research found that minor changes in the buccal bone of approximately 1mm occurred after one year in both healed ridges and extraction sockets.

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