A 3D Approach in Quantification of the Alveolar Bone Changes After Dental Implant Placement Based On CBCT Images

XIAOLI CHENG

xiaoli.cheng@qmul.ac.uk

Submitted to
Bart's and The London School of Medicine and Dentistry,
Queen Mary, University of London
for the Degree of Doctor of Philosophy

2016

Statement of Originality

I, Xiaoli Cheng, confirm that the research included within this thesis is my own work or that where it has been carried out in collaboration with, or supported by others, that this is duly acknowledged below and my contribution indicated. Previously published material is also acknowledged below.

I attest that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge break any UK law, infringe any third party's copyright or other Intellectual Property Right, or contain any confidential material.

I accept that the College has the right to use plagiarism detection software to check the electronic version of the thesis.

I confirm that this thesis has not been previously submitted for the award of a degree by this or any other university.

The copyright of this thesis rests with the author and no quotation from it or information derived from it may be published without the prior written consent of the author.

Signature:

程晓莉

Date: 31-10-2016

Acknowledgement

It is a great pleasure to thank many people who made this thesis possible.

I would like to express my deepest gratitude to my two supervisors, Dr.Lifong Zou and Prof. Farida Fortune. I feel so lucky that I have two the best supervisors during my Phd. Lifong always provides invaluable suggestions during this work. She taught me how to think about a problem, how to make everything clear, how to make complex simple, how to ask and answer questions and how to express my ideas. Her patience, love and encouragement always put me in the correct way to my research. Prof. Fortune is a pure researcher with high enthusiasm and inspiration. She showed me how to be a true academia person. Her great efforts to explain things clearly and sharing of her wisdom and knowledge with students always boost my confidence. I believe I will benefit from her for my future career life.

Besides my supervisors, I offer my grateful thanks to all the persons who involved in this research. Dr. Zhang Ying and Dr. Chen Guang are dentists and researchers in Oral Surgery Department in Shanghai 9th People’s Hospital, Shanghai China. They gave their valuable suggestions and shared the CBCT data sets and clinic information. This research only could be carried out with their cooperation. Dr. Shakeel Shahdad gave the financial support for using the software OnDemand3D which is essential for this research. He also shared many useful ideas about how to do the research more related with clinical application. Alessia D'Onofrio, she assisted me a lots at the early stage of establishing measurement strategy. The helpdesk staffs in Cybermed Inc. provided good supports on the usage of OnDemand3D.

I would also express my thanks to Dr Graham Davis and Prof. Ferranti Wong who are the examiners for my PhD progress on 9 month and 18 month stages. Both of them are nice and gave me valuable suggestions on my research, encouraging me to keep going forward in this research.

Last but not least, I would like to express my deepest gratitude to my family. I would like to thank my lovely my parents for laying a good foundation for my life that lead me to greater achievement and emotional support, understanding. And thank my encouraging brother who managed my absence and supported my parents all the time. Without their encouragement and support, I cannot achieve this PhD.

Abstract

This retrospective clinical study aimed: (1) to establish and validate a reproducible geometrical measurement strategy in quantifying peri-implant alveolar bone changes based on CBCT images taken before and one year after implantation; (2) to quantify and compare the bone changes of Type 1 and Type 4 implant placement in the patient cohort that requested implant placement at premolar and molar sites; (3) to analyse the bone changes in relation to the two implant protocols in aspects of buccal and lingual, maxilla and mandible, within the cohort and combined cohorts.

3D imaging analysis in this study had used a software package - OnDemand3D. The evaluation of the measurement strategy was based on a simulation model which was made of human dry skull with and without a standard implant (Straumann Standard Plus, Ø3.3 mm diameter, L12 mm) to simulate before and after the implant placement. The recruited cases were 69 (44 Type 1 cases and 25 Type 4 cases); all data sets were provided by Shanghai 9th people's hospital, China. Each case had two CBCT data sets at before and one year after implant placement. With 69 cases, bone grafting was applied to all Type 1 cases, and the flap surgery was applied to Type 1 cases when buccal bone recession greater than 3 mm. The measurements were made in bone height (H_L) and bone thickness (L_0O_0, L_1O_1, L_2O_2, L_3O) at lingual side, while the same at buccal side ($H_{B,}$ B_0O_0, B_1O_1, B_2O_2, B_3O_3). The four sections of bone thickness were at 0, 1 mm, 4 mm and 7 mm from the top of the implant. Additionally, six special cases were reported, as they provided extra information. They were two spilt-mouth control cases, three 2-year follow-up cases and one 3-year follow-up case.

The evaluation of the measurement strategy showed the error of the measurement strategy was –0.06 mm and the measurement uncertainty was

±0.05 mm. The main measurement outcomes from the clinical cases were as follows: (1) at buccal side, the mean value of bone changes in height was a positive value of +0.18±1.64 mm for Type 1, which was significantly more than +0.01±0.86 mm for Type 4 ($p<0.05$). However the standard deviation over the 44 and 25 patient cohorts were as large as 1.64 mm and 0.86 mm; (2) at buccal side, the bone changes in thickness showed significantly more loss at B_0O_0 ($p<0.01$) and B_1O_1 ($p<0.05$) sections in Type 1 (-0.38±1.49 mm and -0.25±1.15 mm) compared with Type 4 (-0.19±0.34 mm and -0.16±0.76 mm); (3) in Type 1 cases, the bone thickness at buccal side showed significantly more absorption at $L_1O_1B_1$ ($p<0.05$), $L_2O_2B_2$ ($p<0.01$), $L_3O_3B_3$ ($p<0.01$) section (-0.25±1.15 mm, -0.19±0.99 mm, -0.12±0.57 mm) compared to lingual side (-0.13±0.85 mm, -0.16±0.28 mm, -0.05±0.28 mm); and the bone height (+0.18±1.64 mm) increased significantly more at buccal side than lingual side (-0.25±0.79 mm) with bone augmentation procedure ($p<0.01$). However, within Type 4 cases, no significant difference in bone changes between buccal and lingual sides could be found.

In conclusion, the measurement strategy established in this study was reproducible and provided valid quantifiable data of bone changes in relation to implant placement based on 3D CBCT images. The data analysis from these two patient cohorts suggested that Type 1 implant placement protocol could re-build the bone height at buccal side better than Type 4.

Table of Contents

2. Establish and Evaluate the Measurement Strategy of Alveolar Bone Changes in Relation to Implant Placement 59

3. An Investigation of Bone Changes in 44 Type 1 and 25 Type 4 Cases 108

List of Figures

List of Tables

1. Literature Review

1.1 Introduction

Modern dental implant, as one of the routine treatments modality, has been applied world-wide to facilitate dental rehabilitation since 1970s (Brånemark et al. 1977). Many publications suggest that it is a reliable long-term solution for replacing the function as well as esthetic (Adell et al. 1981, Albrektsson et al. 1986, van Steenberghe 1989, Lindquist et al. 1996, Buser et al. 1997, Arvidson et al. 1998, Lekholm et al. 1999, Weber et al. 2000, Leonhardt et al. 2002, Becktor et al. 2004, Esposito et al. 2010). According to business report provider GBI (Goble Business Intelligence) Research, the global dental implants market is expected to grow almost double in value from $3.4 billion in 2011 to $6.6 billion in 2018 (GBI Research 2013). Extensive academic investigations and scientific testing have been carried out nearly all countries around the world in materials; geometrical designs; mechanical and biological characteristics of implants and different types of implant treatment.

These have made implant dentistry experienced far more innovation and development in recent years in comparison to all the other dental disciplines. That includes development of new implant systems, new and improved diagnostic procedures, introduction of novel surgical techniques and technical procedures. Clinically, teeth could have been lost through dental disease or trauma or be congenitally absent, and a treatment plan or prognoses are limited by the existing condition of the dentition. In many clinical situations compromised teeth or roots may still exist with patients. This provides the opportunity that dentists could decide on the timing of implant placement after tooth extraction (Schropp & Isidor 2008, Chen & Buser 2009).

Success rate, complications, esthetics and patients satisfaction are normally used to evaluate the performance of each time point for implant placement following tooth extraction. However, there is insufficient evidence to conclude the possible advantage or disadvantage of immediate implant placement and delayed implant placement (Chen et al. 2009).

Additionally, in implant dentistry, a contemporary problem is the esthetic maintenance of the gingival margin level following dental implant placements (Hämmerle et al. 2004). It is well acknowledged that preservation of peri-implant soft tissue is related to many clinical parameters, e.g., peri-implant biotype, alveolar bone crest level, implant fixture angle, the interproximal bone crest level, the depth of implant platform (Cooper 2008, Nisapakultorn et al. 2010). Especially, bone preservation is a key factor for enhance the eventual peri-implant soft tissue and esthetic outcome (Buser et al. 2007, Nisapakultorn et al. 2010).

Many methods have been used to assess the alveolar bone surrounding implant such as periodontal probe, manual caliper and digital caliper, intraoral peri-apical radiography, conventional CT and Cone-beam computerized tomography (CBCT) etc. Among these methods, CBCT provides satisfying 3D radiographic images with less exposure time and less X-ray radiation. It allows clinicians to measure peri-implant bone dimensions at multiple levels over time. However, CBCT is still prone to the appearance of artifacts generated by dental implants (Draenert et al. 2007, Razavi et al. 2010, Schulze et al. 2010), which is any distortion or error on the image and is unrelated to the subject being examined. It is problematic for image interpretation. Therefore, a good understanding of the influence and distribution model of the metal artifacts
on CBCT image is important when interpreting the CBCT images particularly of the regions adjacent to the surface of dental implants.

The present study reviews the literature in five aspects:

(1) The history of dental implant and the classification system based on the timing of implant placement after extraction;

(2) The evaluation of the performance for each type of implant placement protocol;

(3) The methods for measuring bone changes after implant placement;

(4) The development and advantage of CBCT in dentistry;

(5) The influence of metallic artifacts on CBCT image.

1.2 History of dental implant

An endosteal implant is an alloplastic material surgically inserted into a residual bony ridge as a prosthodontic foundation primarily. The prefix endo means “within,” and osteal means “bone” (Soblonsky 1982). The major subcategory of endosteal implants covered in this literature is dental implant. Dental implant is the design most regularly used in restoration of the partial or completely edentulous patient. Nowadays, social recognition and acceptance of the replacement of lost teeth with dental implant has shown a dramatic increase in recent years. However, the history of the evolution of dental implants is a rich and fascinating travelogue through time.

1.2.1 Dental implant in ancient civilization and early days

The desire that has always been to replace missing teeth with something similar to a tooth dates back thousands of years. Evidences have shown dental implants have been tried almost since humans have been using technology in various civilizations such as the ancient Chinese, Egyptian, Etruscans, Honduran and Incas (Bobbio 1972, Anjard 1981, Ring 1985, Tapia et al. 2002). Archaeological findings demonstrated that materials used to replace missing human teeth include ox teeth, human teeth from corpses, sea shells, coral, wood, stones, ivory, jade, and metals (gold or silver) (Hobkirk et al. 2003, Anusavice 2006).

The earliest attempts at dental implant tooth replacements on record were discovered in the Mayan civilization dating back to 600 A.D. (Bobbio 1973, Anjard 1981). The first documented dental implant placement was from Albucasis de Condue (936-1013 A.D) who was an Arabian surgeon and used ox bone to replace missing teeth. From the 1500's to about the 1800's, the attempt of transplanting allogenic teeth had high failure rate and leaded to other serious complications such as infection, disease transmission and strong rejection, because the level of the development of science and medicine was so limited at that time (Anusavice 2006).

It is possible that the first description of the technique of modern dental implant was published by Maggiolo, a French Dentist. In his book, Le Manuel de I'Art du Dentiste (1809), Maggiolo illustrated a methods that an 18-carat gold alloy with three branches was implanted into the jawbone and a porcelain crown was installed as a superstructure. Although implants failed after a period of time, this made the researchers to experiment using various metals and alloplastic materials to replace the missing teeth, such as gold, silver, platinum, iridium, vitallium, porcelain etc. (Ring 1995). However, the implant technique still couldn't be widely used in clinic due to high failure rate and the lack of fundamental knowledge and basic theoretical research in this period.

In 1913, E.J. Greenfield placed a "24-gauge hollow latticed cylinder of iridio-platinum soldered with 24-carat gold" as an artificial root to "fit exactly the circular incision made for it in the jaw-bone of the patient" in Boston, Massachusetts (Greenfield 1991). He was regarded as the scientist who documented the foundation of modern implantology in 1915. First, he referred to the health standards of cleanliness and sterility. Then, he introduced innovative concepts such as the current relevance of the intimate association between implant and bone. He also described the concept of submerged implant, the healing tissue and dental implant immobility. Furthermore, he developed and improved surgical tools such as the drilling systems used in present practice. He not only introduced trephine bur and dental implants with a hollow cylindrical design, but also reported the failure of implant treatment due to infection firstly.

In the 1930s, more emphasis was placed on the tissue biocompatibility as well as interaction between bone and material. In 1937, Drs. Alvin and Moses Strock, two brothers, at Harvard University experimented with orthopedic screw fixtures made of Vitallium which was considered to be inert, compatible with living tissues, and resistance corrosion in the body fluids (Hobkirk et al. 2003, Anusavice 2006). They observed how physicians successfully placed implants in the hip bone, then they implanted them in both humans and dogs to restore missing teeth (Strock 1939). The vitallium screw provided anchorage and support for replacement of the missing tooth. The Strock brothers were acknowledged for achieving a long term endosteal implant survival for the first time (Dahle 1990, Linkow & Dorfman 1991, Block et al. 1997).

However, the success rate and service life of these implants were highly variable and unpredictable (Hobkirk et al. 2003). From 1950s to 1960s, although a large number of sound scientific researches and clinical applications have verified and validated their usefulness in replacing missing teeth, the clinical application was far ahead of fundamantal resaerch and the high failure rate of dental implant came out due to over using of these immature dental implant technique driven by economic profits behind it.

1.2.2 Development of modern dental implant technique

At the present time dental implant treatment is much advanced and most of clinical success is related to the improvements in surgical management, combined with greater understanding of biological responses and engineering of dental implants (Clark M. Stanford 2006). The outcome and the success rate of dental implants are mainly based on the principles of creating and maintaining a stable interface between the implant and surrounding bone. This was called 'osseointegration'. It was occasionally discovered by Brånemark, who is now known as the father of modern dental implantology. He defined it as 'a direct structural and functional connection between ordered, living bone, and the surface of a load carrying implant' (Hobkirk et al. 2003).

The fusion of titanium to bone was first reported by Bothe et al in 1940 (Bothe et al. 1940). In the 1950s a research was being carried out at Cambridge University in England to study blood flow *in vivo*. They devised a method of constructing a chamber of titanium which was then embedded into the soft tissue of the ears of rabbits. In 1952, the Swedish orthopaedic surgeon, Per-Ingvar Brånemark was interested in studying bone healing and regeneration. He adopted the Cambridge designed 'rabbit ear chamber' for use in the rabbit femur. After several months, he attempted to retrieve these expensive chambers from the rabbits and found that they were unable to be removed. The bone had grown into such close proximity with the titanium and effectively adhered to the metal. Brånemark carried out several further researches confirming this unique property of titanium and its unique potential for dental implants. If a fracture occurred, it always occurred between bone and bone, never between bone and implant. The bone actually bonded to the titanium surface (Brånemark et al. 1977).

In 1965, Brånemark placed the first titanium dental implant into a human volunteer. This was the first well-documented and the most well-maintained dental implants so far. These implants integrated within a period of six months and remained in place for the next 40 years (Brånemark et al. 1985). The original Brånemark implant was created as a cylindrical shape, and later in a cone shape that has tapered with a small angle. Many other types of implants were introduced after the Brånemark implant, such as ITI-sprayed implant, Stryker implant, IMZ implant and Core-Vent implant with different surface treatments to increase the biocompatibility. All these increased the popularity of implants to a new level.

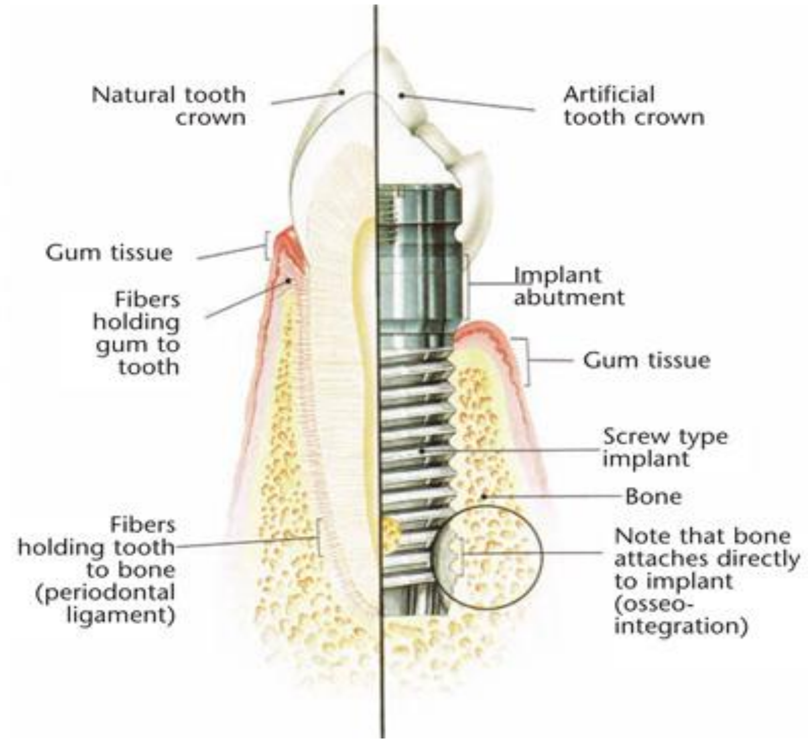


Figure 1–1. The difference in bone attachment between a natural tooth and dental implant (Taylor & Laney 1993).

While Brånemark was researching osseointegration, André Schröeder was working on dental implant for clinical application in the University of Berne. He collaborated with Institute Straumann which was a pioneer in the integration and application of metal in orthopedic surgery at that time. He demonstrated the in-growth of bone into titanium plasma-sprayed hollow endosseous implants in histological level in 1976 (Laney 1993).

Furthermore, along with the breakthrough discovery by Brånemark, there were many other researchers working conscientiously and contributing uncountably to develop and establish modern implant in both theoretical and clinical aspect (Cherchieve 1959, Linkow 1964, Linkow 1966, Weiss & Judy 1974, Small & Misiek 1986, Cranin 1988, Linkow & Dorfman 1991). However, outcome of implant treatment were still erratic at that time. The success rate of subperiosteal implants ranged from 39% to 66% at 10 years (Boucher 1978). Smithloff and Fritz also reported similarly poor outcomes for blade-vent implants with a cumulative success rate of 55% at 5 years (Smithloff & Fritz 1976).

In 1978, the first Dental Implant Consensus Conference, the Harvard Consensus Conference sponsored jointly by the National Institutes of Health and Harvard University, was held to establish consensus on the application of implants at Harvard University. The benefits and risks of implants were identified and a panel made specific recommendations for patient informed consent. The standard for a successful implant was also settled on whether the implant remained embedded and functional for five years. Although this standard may seem extremely short, it was a landmark and illustrated what the expectations of implant treatments were at the time.

In 1982, then, the Toronto Conference on Osseointegration in Clinical Dentistry came up with the first guidelines on what is to be considered as successful dental implantology and which introduced the concept of osseointegration. On this conference Brånemark presented all the results of his research over 30 years and his clinical practice for nearly 20 years. In 1985, Nobelpharma AB Sweden (today Nobel Biocare, Switzerland) filed the first application for commercial use of dental implants in the United States. In the following year, their application was approved which leaded in a new era of dental implantology.

Since then, dental implant design has continued to evolve driven by a combination of commercial and scientific concerns. Modern endosseous root-form implants come in a variety of shapes and sizes to suit the different type of prosthetic teeth they will replace. Their surfaces have been modified to enhance the osseointegration process. Some incorporated the use of hydroxyapatite, composites, carbon, glass and ceramic as well as titanium oxide. Instead of being smooth or machined, they are generally roughened by sandblasting and acid etching, which dramatically increases the surface area to which bone can attach (Alla et al. 2011). The major factors that determines which endosseous implant system will be chosen over another include the design, the surface roughness, prosthetic considerations, ease of insertion into the bone, costs and how successful they were over a period of time.

In conclusion, the history of the development and advancement of dental implants is a marvellous and fascinating journey through time. Implantology, an entirely new scientific discipline in dentistry which requires the integration of surgical, prosthetic and biomechanical concepts, gradually emerged over the last 30 years. The application of dental implants was supported scientifically and dental schools began to slowly inculcate the teaching of Implantology in their regular syllabus.

1.3 Classification of dental implant placement based on timing after tooth extraction

Several classifications have been proposed to quantify timing of implant placement. Wilson and Weber proposed the terms immediate, recent, delayed and mature as guidelines to place implants in relation to soft tissue healing and predictability of guided bone regeneration procedures (Wilson & Weber 1993). However, no time frames were assigned to these terms. Gomez-Roman and Coworkers defined immediate implants as occurring between 0 and 7 days after tooth extraction (Gomez-Roman et al. 1997), while Zitzmann et al. considered implant placement as delayed when it occurred between 6 weeks and 6 months after extraction (Zitzmann et al. 1997). In a more recent suggestion by Mayfield (Mayfield 1999), the terms immediate, delayed and late are used to describe implant placement time intervals of 0 week, 6–10 weeks, and 6 months or more after extraction. Hämmerle and Lang defined delayed implant placement as those placed between 8 and 14 weeks in a report (Hämmerle & Lang 2001). And Schropp et al. stated immediate implant placement between 3 and 15 days (mean 10 days) following extraction (Schropp et al. 2003a). It can be seen that the description terms for the time points for implant placement after tooth extraction encountered in the dental literature were imprecise and open to interpretation.

Therefore, at the 3rd ITI Consensus Conference in 2003, a classification system for timing of implant placement after tooth extraction was proposed, which is based on desired clinical outcomes during healing rather than on descriptive terms or rigid time frames following extraction (Hämmerle et al. 2004). There are four types in this classification system:

(1) Type 1 refers to the placement of an implant into a tooth socket synchronously with the tooth extraction;

(2) Type 2 refers to the placement of an implant after substantial soft tissue healing has taken place, but before any clinically significant bone fill occurs within the socket;

(3) Type 3 is placement of an implant following significant clinical and/or radiographic bone fill of the socket;
(4) Type 4 is placement of an implant into a fully healed ridge.

Another two additional terms were also defined. Type 1, type 2, and type 3 implant placements are collectively described as post-extraction implant. Early implant is used to collectively describe type 2 and type 3 implant placements (Chen et al. 2009).

1.4 Evaluation criteria of dental implant

On account of the proliferation of dental implant, a set of criteria for implant success based on scientific investigations is essential. Implant failure may be easier to describe, including any pain, vertical mobility, and uncontrolled progressive bone loss warrant implant removal. However, implant survive is difficult to describe as the success criteria required for a tooth, which ranged from health to disease exists in both conditions.

1.4.1 Basic criteria for implant success

The success criteria for dental implant most commonly reported in clinical reports is the survival rate. It was first settled in 1978, on the Harvard Consensus Conference, that the standard for a successful implant was on whether the implant remained embedded and functional for five years. Since then, success criteria have been proposed and modified by several researchers, which revolved around the mobility, peri-implant radiolucency, marginal bone loss and absence of infection or discomfort to the patient (Schnitman & Shulman 1979, Cranin et al. 1982, McKinney et al. 1984, Albrektsson et al. 1986, Smith & Zarb 1989, Albrektsson & Zarb 1998). In 1986, Albrektsson and colleagues codified success criteria including: (1) Individual unattached implant that is immobile when tested clinically; (2) Radiography that does not demonstrate evidence of peri-implant radiolucency; (3) Bone loss that is less than 0.2 mm annually after the implant's first year of service; (4) No persistent pain, discomfort or infection; (5) By these criteria, a success rate of 85% at the end of a 5 year observation period and 80% at the end of a 10 year period are minimum levels for success (Albrektsson et al. 1986). However, the amount of crestal bone lost during the first year hadn't been taken into account. Afterward, an emphasis was placed on some topics, such as the health of the soft tissues, inflammation around the implant, the pattern of peri-implant bone loss, effect on adjacent teeth, function, esthetics, patient's emotional and psychological attitude and satisfaction (Smith & Zarb 1989).

1.4.2 Evaluation of peri-implant soft tissue

Better understanding of the osseointegration process makes implant rehabilitation no longer a treatment to regain lost masticatory and phonetic function. But, to achieve esthetic restoration, which is a matter of concern for quality of life, is becoming an essential expectation both among patients and dentists. Although the esthetic result is rarely included among the success criteria for implant therapy, there is an increasing tendency to do so in the most recent studies (Henriksson & Jemt 2004, Ryser et al. 2005, Schropp et al. 2005, Cordaro et al. 2006, Hall et al. 2006, Oh et al. 2006, Noelken et al. 2007). In most studies the esthetic appraisal concerned the maxillary frontal implant-supported prosthetic elements, which is considered to be a key factor of the final result.

However, esthetic can be rated in a subjective and an objective manner. A subjective method is the use of questionnaires, which must be completed by the patients (Moberg et al. 1999). An objective method, with a rating score, has to been carried out by professional observer. Jemt developed a Papilla Index to estimate the degree of filling of the interproximal space by the tooth implant pseudopapilla in order to judge the esthetic result of 25 implant-supported single crowns with a mean follow-up of 18 months (Jemt 1997). This index was perhaps the first attempt to apply a scientific feature for the esthetic judgment regarding the presence and the height of the interproximal papilla. It was used most frequently and often in combination with other indices or integrated with further measurements (Annibali et al. 2012).

1.4.3 Relationship of bone preservation and peri-implant soft tissue

Marginal gingiva recession is another key element regarding the quality of implant restorations. A mean facial marginal recession of 0.5-1 mm around single-tooth implants has been reported in many studies (Chang et al. 1999, Grunder 2000, Kan et al. 2003, Cardaropoli et al. 2006, Jemt et al. 2006, De Rouck et al. 2008, Evans & Chen 2008), while 1 mm or more facial recession was observed in 17–40% of the study sites (Jemt et al. 2006; Evans & Chen 2008). And it has been well acknowledged that preservation of peri-implant soft tissue is related to many clinical parameters, e.g., peri-implant biotype, implant fixture angle, the depth of implant platform, contact point, bucco-lingual position of the dental implant, alveolar bone crest level, the interproximal bone crest level (Choquet et al. 2001, Kois 2001, Ryser et al. 2005, Zetu & Wang 2005, Palmer et al. 2007, Cooper 2008, Lops et al. 2008, Nisapakultorn et al. 2010). Although each factor is intimately related to the others, bone preservation is a key factor for enhance the eventual peri-implant soft tissue and esthetic outcome (Buser et al. 2007, Nisapakultorn et al. 2010).

Firstly, the osseous crest is a critical foundation for gingival levels. The concept of biologic width (Figure 1–2) is ‘the distance between the most extent of the gingival sulcus and the crest of the alveolar bone in nature teeth’. This space is occupied by gingival fibres, hemidesmosomes, and connective tissue directly contacting with the tooth structure and building a natural seal around teeth. Average biologic width values constant 2.04 mm, which consists of the epithelial attachment (0.97 mm) plus connective tissue attachment (1.07 mm). It is a principle predictor for gingival levels after any intervention (Gargiulo et al. 1961).

Kois developed quantitative data for three different biologic variations on clinical data from 100 healthy patients (Kois 1994), which was based on, vertical distance of the dentogingival complex from the alveolar crest to the free gingival margin (FGM), and categorized as normal crest, high crest, and low crest. With a lower crest, more gingival recession tends to occur after extraction. In other word, the greater the distance of the osseous crest to the FGM, the greater the risk of gingival recession after an invasive procedure. Kois stated that a slight apical loss of gingiva (up to 1 mm) was anticipated after extraction, if the vertical distance of the dentogingival complex on the midfacial aspect was 3 mm. Less or great than 3 mm of vertical distance implied that the change would range from negligible change to potentially >1 mm apical.

The interproximal relationship followed the same logic, but the measurement was varied. In the interproximal area, a vertical distance up to 4 mm measured from the FGM to the alveolar crest has less risk. The interproximal numbers are based on the most coronal portion on the interproximal alveolar crest of adjacent teeth instead of that of the tooth being removed (Jemt 1997, Choquet et al. 2001, Kan et al. 2003, Henriksson & Jemt 2004, Cardaropoli et al. 2006). Therefore, if the interdental papilla measures >4 mm (low crest) on the adjacent teeth, there will predictably be some interproximal tissue loss after extraction to the 3 mm to 4 mm vertical distance. Therefore, it is an important and valuable diagnostic procedure to measure the distance from the FGM to the alveolar crest before extraction (Kois 1994).

Secondly, subsequent to teeth extraction, the alveolar bone undergoes significant dimensional changes (Atwood 1957, Hedega°rd 1962, Atwood 1971, Tallgren 1972, Cardaropoli et al. 2003, Farmer & Darby 2014). This complicates implant placement in the ideal prosthetic position. Concurrent with bone growth into the socket, there is also well-documented resorption of the alveolar ridges and the bundle bone at the extraction site noticeably will lose its function and disappear (Botticelli et al. 2004b, Araujo & Lindhe 2005, Araujo et al. 2005, Araujo et al. 2008). The greatest amount of bone loss is in the bucco-lingual (horizontal) dimension and occurs mainly on the facial aspect of the ridge. An obvious vertical reduction also goes along with these changes (Atwood 1957, Lekovic et al. 1997, 1998, Schropp et al. 2003b, Araujo & Lindhe 2005, Hammerle et al. 2012, Tan et al. 2012). Moreover, the horizontal bone resorption of the socket is generally more pronounced at the buccal plate, and the vertical loss is more distinct on the buccal contour of the ridge as well (Pietrokovski & Massler 1967, Araujo & Lindhe 2005). Van der Weijden carried out a review included 12 qualified publications and demonstrated that after 3 months of healing (1) the reduction in width of the alveolar ridges was -3.87±0.82 mm, (2) the mean clinical mid-buccal height loss was -1.67±1.11 mm, and (3) the mean crestal height change as assessed on the radiographs was -1.53±0.88mm, (Van der Weijden et al. 2009). And other studies confirmed that a 63% and 22% dimensional loss in a horizontal and vertical plane took place at the first 6 months after the extraction (Hammerle et al. 2012, Tan et al. 2012). This kind of resorption process results in a narrower and shorter ridge and relocates the ridge to a more palatal/lingual position (Pinho et al. 2006). Furthermore, Schropp et al. reported the width of the alveolar ridge reduced up to 50% during the 12 month after tooth extraction and proximately two thirds of this reduction occurred within the first 3 months (Schropp et al. 2003b). And bone resorption activity in the residual ridge continues throughout life at a slower rate (Jahangiri et al. 1998).

Thirdly, peri-implant marginal recession was partly a result of bone remodelling following implant surgery. The concept of biological width has been applied to dental implants as well, with an epithelial attachment of approximately 2 mm (Cochran 1997). Biologic width forms within the first 6 weeks after the implant/abutment junction has been exposed to the oral cavity, which is protective mechanism against bacterial invasion and food ingress at the implant-tissue interface. The ultimate location of epithelial attachment following second-stage surgery partly determines early post-surgical bone loss (Figure 1–2). Cardaropoli et al. assessed dimensional remodelling of the peri-implant tissue of single tooth implants in the anterior maxillary region from 11 patients over one year. The radiographic measurement showed a mean loss of -0.9±0.4mm between abutment connection and crown placement and a further -0.7±0.7mm loss at one year. This was accompanied by a mean recession of the facial gingival margin of -0.6±0.7 mm (Cardaropoli et al. 2006).

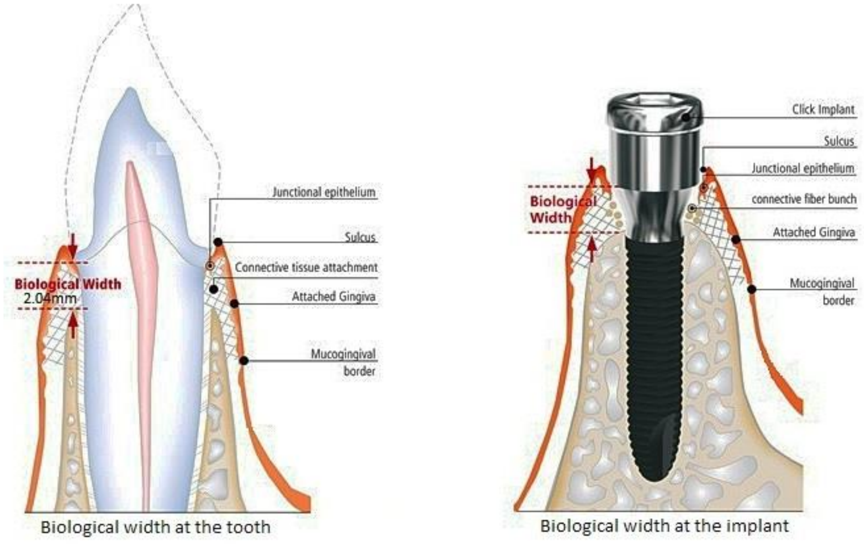


Figure 1–2. Biological width at the tooth and the implant (Taylor & Laney 1993).

So implant bone loss is partially a process of re-establishing the biologic seal (Oh et al. 2002). Histological studies about the incorporation of implants placed into extraction sockets or into healed ridges have documented that similar patterns of osseointegration occur in both humans (Wilson et al. 1998, Paolantonio et al. 2001) and animals (Anneroth et al. 1985, Barzilay et al. 1996, Karabuda et al. 1999).

Additionally, it was stated that early crestal bone loss is often evaluated after the first year of function, followed by minimal bone loss of ≤0.2 mm annually thereafter (Oh et al. 2002, Wennstrom et al. 2004, 2005, Horwitz et al. 2007, Botticelli et al. 2008, Cochran et al. 2009, Eliasson et al. 2009, Nemli et al. 2016, Voss et al. 2016). On the other hand, facial crest thickness was confirmed to critically prevent future bone dehiscence and marginal recession. Spray et al. (2000) measured the change of facial crestal bone height in 3000 dental implants between implant insertion and uncovering. They found that the facial crest resorption was more pronounced when the facial bone thickness was decreased. Based on their finding, it was proposed that at least 2 mm of facial bone thickness should be left after implant placement to avoid future recession (Spray et al. 2000). Furthermore, some studies states that the level of the interproximal papilla of the implant is predominantly related to the bone level at the adjacent tooth (Jemt 1997, Choquet et al. 2001, Kan et al. 2003, Henriksson & Jemt 2004, Cardaropoli et al. 2006).

In conclusion, the vertical distance from the FGM to the alveolar crest determines the level of gingival recession after extraction, while the width and height of alveolar ridge reduce obviously 3 month after teeth extraction. Then, following implant placement, the crestal bone remodels and enough facial bone thickness is important for avoiding facial crest resorption. All these changes of the bone are accompanied by the remodelling of gingival margin which makes out the esthetic appearance of implant.

1.5 Comparison of Type 1 with Type 2, Type 3, and Type 4 implant placement protocols

1.5.1 Advantage and disadvantage

Success rate, patients' satisfaction, complications and esthetics are normally used to evaluate the performance of each time point for implant placement following tooth extraction.

The Success rates of post-extraction (Type 1, Type2, Type3) implants are high and comparable to those of implants placed in healed alveolar bone (Type 4) (Schwartz-Arad & Chaushu 1997, Chen et al. 2004, Penarrocha et al. 2004, Fugazzotto 2005, Quirynen et al. 2007, Esposito et al. 2010, Annibali et al. 2011, Muddugangadhar et al. 2015). According to these previous reviews, over an observation period of 5 years, approximately 5% of implants could be expected to be lost regardless the protocol being used in general. And, these 4 types implant placements have various particular clinical conditions which can be advantage to the treatment outcome, but may also constitute risk factors (Chen et al. 2009).

However, the significant treatment outcomes from the patient's viewpoints may differ from those of the dentist. High comfort, improved esthetic, better chewing function, better phonetics are parameters typically considered being important to the patient, while probing pocket depths, degree of osseointegration, crestal bone levels, etc. are of minor significance. Many studies have demonstrated that high patient satisfaction with the esthetic outcome of implant-supported single-tooth restorations can be achieved (Chang et al. 1999, Gibbard & Zarb 2002, Vermylen et al. 2003, Schropp et al. 2004). Furthermore, it should be noted majority of patients are interested in shortening the treatment time between tooth extraction and implant placement, especially Type 1 which combines extraction and implant placement in the same surgical procedure. Therefore, this protocol might be expected to increase patient satisfaction. Ferrara showed overall patient satisfaction was good in the study combining immediate placement and immediate loading of 33 single-implants (Ferrara et al. 2006). Schroop et al. compared early and delayed implant placement and illustrated that overall satisfaction of the treatment was highest with the early placed implants, while there was no significant differences between the groups in patient assessment of shape, colour, chewing function, and ease of cleaning were found (Schropp et al. 2004). So, it seemed that patients treated with Type 1 protocol are highly satisfied.

Additionally, in Type 1 protocol, peri-implant defects usually present as two- or three-walled defects which are favorable for simultaneous bone augmentation procedures. And Type 1 provides an opportunity to attach a provisional restoration to the implant soon after placement so that the patient avoids the need for a temporary removable prosthesis. Another potential advantage is the amount of bone loss which physiologically occurs after tooth extraction might be reduced if the implant is placed early during the healing process (Denissen et al. 1993, Watzek et al. 1995, Wheeler et al. 2000, Esposito et al. 2010).

On the other hand, there are also some potential disadvantages with Type 1 protocol, such as: (1) an enhanced risk of infections and the associated failures if the socket becomes infected (Rosenquist & Grenthe 1996, Takeshita et al. 1997); (2) the mismatch between the implant surface and the socket wall, which increases surgical difficulty in preparing the osteotomy to allow the implant to be placed with initial stability and in a good prosthetic position; (3) increased risk of mucosal recession which may compromise soft tissue esthetic outcomes (Martin et al. 2007); (4) the necessity of additional hard and soft tissue augmentation procedures, if a two-stage implantation procedure is preferred (Rosenquist 1997, Evans & Chen 2008).

Despite of Type 1, other three types implant placement protocols all require at least two surgical procedures (extraction and implant placement), and especially Type 3 and Type 4 need more extended treatment time, but they allows for resolution of pathology associated with the extracted tooth prior to implant placement. With Type 2 implant placement, healing of the soft tissues increases the volume of mucosa at the surgical site which allows the primary closure in implant site. Although there is minimal bone regeneration within the socket at this time point, peri-implant defects are usually still present and initial stability of the implant is relatively difficultly obtained, which performs as same as that with Type 1 implant placement (Chen et al. 2009).

For Type 3 and Type 4 protocols, partially or full bone healing in the socket usually allows implant stability to be more readily attained, compared to Type 1 and Type 2 placement. The soft tissues are also usually fully healed, which may enhance soft tissue esthetic outcomes. However, the socket walls exhibit varying degrees of resorption that could lead to limited or insufficient bone volume for implant placement. Peri-implant defects may still be present. In Type 3, two- and three-walled defects are amenable to simultaneous bone augmentation procedures (Hämmerle et al. 2004, Chen et al. 2009).

1.5.2 Advanced researches on potential problems of Type 1 implant placement protocol

Although the Type 1 has the shortest treatment period, which may favourable for some of patients, many studies have been carried out to research four potential problems mentioned above.

First, it was said that pathology of the tooth or the periodontal tissues may have an influence on the treatment success of Type 1. However, Lindeboom et al demonstrated that there was no statistically differences in success rates between Type 1 and Type 4 implant placements according to the results comparing 25 single implants placed immediately after tooth extraction in sites with periapical infection and 25 implants placed after 3 months of healing (Lindeboom et al. 2006). Furthermore, two animal studies illustrated that implants placed in infected sites were not at risk (Novaes et al. 2003, Novaes et al. 2004). But it was found the success of immediate implants replacing teeth with a history of periodontitis was slightly lower in humans (Rosenquist & Grenthe 1996, Polizzi et al. 2000). Therefore, it is not valid to recommend or caution not to do Type 1 in an extraction site with infection.

Secondly, manufacturers have designed specific implant systems having various conical shapes and different diameters in order to be used as immediate implants in sockets of varying dimensions (Gomez-Roman et al. 1997, McAllister et al. 2012).

Thirdly, it was stated that some portion of the implants could remain exposed and there might remain a residual gap between the implant surface and the bone walls of the extraction socket. It depends on the damage level of socket, the shape and the diameter of the extracted root. In addition, the degree of bone resorption after tooth extraction is difficult to predict. This could leave some portion of the implants exposed and lead to a poor esthetic outcome. In order to solve this problem, augment the socket has been suggested to carried out just after implant placement using various bone augmentation techniques such as autogenous bone grafts (Ross et al. 1989, Becker et al. 1994b) , bone substitutes (Block & Widner 1991, Yukna 1991), guided bone regeneration (GBR) with resorbable or non-resorbable barriers (Lazzara 1989, Becker et al. 1994a, Rosenquist & Ahmed 2000), and various bone promoting molecules such as enamel matrix derivative (Cangini & Cornelini 2005), platelet rich plasma (PRP), growth factors and bone morphogenetic proteins (BMPs) in order to accelerate and increment bone formation.

However, it has been a matter of debate whether bone augmentation procedures are of any benefit for immediate implants or whether such gaps or dehiscence defects could be left for spontaneous healing (Covani et al. 2004). Several researches have demonstrated that infrabony defects were fully or partly resolved without intervention of augmentation treatments. Schropp et al carried out a study comparing Type 1 and Type 4 in 46 patients and illustrated a high potential for spontaneous bone healing in three wall infrabony defects for both protocols (Schropp et al. 2003a). Rosenquist & Grenthe also stated total bone formation occurred in the sockets without the use of membranes or bone grafting in 46 patients treated with Type 1 (Rosenquist & Grenthe 1996). Additionally, Botticelli et al claimed that a circumferential gap of 1-1.25 mm lateral to an implant may heal with new bone and that placement of a membrane did not improve the healing in an animal study (Botticelli et al. 2003). Chen et al. compared Type 1 on maxilla in patients treated with particulate autogenous bone with patients not subjected to any augmentation procedure. They concluded that substantial bone gain was obtained in both groups and no statistically significant differences were found (Chen et al. 2005). On the other hand, several studies have demonstrated that the potential for spontaneous bone formation was poor in Type 1, which resulted in a fenestrated implant or a dehiscence defect (Dahlin et al. 1991, Schropp et al. 2003a). It has been suggested that predictable augmentation of dehisced sites associated with immediate implants is possible using membranes alone or in combination with bone grafts (Schwartz-Arad & Chaushu 1997, Chen et al. 2004, Polyzois et al. 2007).

Therefore, it can be concluded that a gap around the implant in Type 1 has good potential to heal. But the healing potential is poor with the presence of a dehiscence of alveolar bone, and various bone augmentation techniques are recommended to be used in different cases.

1.5.3 Esthetic results in Type 1 implant placement protocol

It has been pointed out improvement of esthetic outcome may be one advantage of Type 1 implant placement protocol. The rationale is that soft and hard tissue may be preserved by this protocol (Chen et al. 2009, Cooper et al. 2010, Kinaia et al. 2014).

1.5.3.1 Bone preservation

It is widely accepted that the crest bone alteration around implants is multifactorial. The remodelling may be influenced by occlusal forces, trauma during the surgical procedure, inflammation, implant bulk device design, and timing of implant placement after extraction, load timing, and implant placement in grafted socket (Hagiwara 2010) etc. And, if the implant is placed early during the socket healing process, one of potential advantages is that the amount of alveolar bone loss which occurs physiologically during the remodelling stage of the extraction socket might be reduced (Denissen et al. 1993, Watzek et al. 1995, Zitzmann et al. 1999, Wheeler et al. 2000, Block et al. 2009, 2009, Esposito et al. 2010). A long-term study carried out by Denissen et al. showed that immediately placed submerged hydroxyapatite implants contributed to the maintenance of alveolar ridge volume (Denissen et al. 1993). And in a clinical report, Wheeler et al. demonstrated preservation of hard and soft tissue with enhancement of the esthetic result after immediate placement of tapered root-analog implants combined with custom healing abutments (Wheeler et al. 2000). Furthermore, Botticelli and colleagues carried out a clinical study, in which 21 implants were installed into extraction sockets in 18 patients (Botticelli et al. 2004a). After 4 months of healing, through surgical re-entry, the gap between a newly placed implant were found to have been filled with newly formed hard tissue, but the buccal–lingual dimensions of the ridge were still markedly reduced (buccal 45%, lingual about 30%). It was described as a process of new bone formation from the inside of the defects and substantial bone resorption from the outside of the ridge (Botticelli et al. 2004a).

However, on contrary, through experiments in dogs, Araujo and Lindhe found that placing implant immediately in the socket after tooth extraction was associated with marked osteoclastic activity that resulted in reduction of the buccal and lingual walls (Araujo & Lindhe 2005, 2006a, 2006b). Vignoletti et al. also illustrated that the buccal socket wall underwent bone resorption appeared to be more pronounced at the implant sites than the site left to heal spontaneously (Vignoletti et al. 2012). Besides, by clinical studied, Covani et al. indicated that morphologic changes of the alveolar ridge cannot be prevented by Type 1 and the pattern of coronal bone remodeling showed a narrowing of the bucco-lingual width which was clinically similar for Type 1 and Type 4 groups (Covani et al. 2003, Covani et al. 2004).

On other hand, Chen et al. concluded in a review that no significant differences were found in radiographic crestal bone level or in probing depth at implants placed immediately, late, or delayed relative to tooth extraction (Chen et al. 2004). And peri-implant defects had a high potential for healing by regeneration of bone, irrespective of healing protocol and bone augmentation method. Grandi et al. compared the clinical and esthetic outcome of single post-extractive implants with implants placed in a preserved socket after 4 months of healing on the anterior maxilla in 50 patients. The results showed peri-implant bone resorption was similar in both groups 12 month after implantation, 0.71 mm (rang 0.45-0.97 mm) in Type 1 group and 0.60 mm (range 0.38-0.82 mm) in Type 4 group (Grandi et al. 2013). Additionally, through a 5-year prospective single-cohort study in which implants were placed in fresh extraction sockets with the use of a flapless technique and a xenograft to treat the peri-implant bone defect, Covani et al. evaluated the marginal bone level and soft tissue stability in 47 patients. The mean values of changes in the marginal bone level were -0.68±0.39 mm, -0.94±0.44 mm, and -1.08±0.43 mm at the 1, 3, and 5-year follow-up, which demonstrated the changes in the bone level were minimal at the 5-year point of the survey and a positive final esthetic outcomes (Covani et al. 2014).

Overall, although it has often been stated that one of the advantage of Type 1 protocol is to prevent or at least minimize the loss hard tissue at the extraction socket, there are controversies exist on this issue whether the different timings of implant placement after extraction may lead to various bone remodelling results.

1.5.3.2 Gingival stability

There is no conclusive result on whether soft tissue can be better preserved by post-extraction implant protocol compared with delayed protocol. Contradictory conclusions have been demonstrated in a direct comparison of the esthetic outcome following the early and delayed placement techniques (Gotfredsen 2004, Schropp et al. 2005).

Gotfredsen using a submerged technique found that, from dentist judgment, delayed implant placement performed better than early implant placement after tooth extraction, but no difference in the patients' satisfaction with esthetic appearance. Schropp et al. concluded that early placement (on average 10 days after extraction) of single-tooth implants may be preferable to delayed implant placement technique (12 weeks) in terms of early generation of interproximal papillae and the achievement of an appropriate clinical crown height. On the other hand, no difference in papilla dimensions was observed at 1.5 years after seating of the implant crown on the implant (Schropp et al. 2005). Furthermore, in the trial carried out by Palattella et al., 9 single immediate implants were compared with 9 immediate-delayed implants (8 weeks after extraction) at maxillary anterior and premolar teeth. The marginal bone resorption, Papilla index (Jemt 1997), and position of the mucosal margin (the distance from the most apical point of the gingival margin to the implant shoulder) were evaluated. They illustrated that there were no statistically significant differences in the level of the perimplant marginal gingiva and perimplant marginal bone level changes two years after implant placement (Palattella et al. 2008). In the study carried out by Grandi et al, although an ideal gingival marginal level was reached most frequently in the delayed implant, the rates of full closure of the papilla were similar between the two groups (Grandi et al. 2013).

Conversely, Block et al. compared Type 1 with Type 4 in 76 patients and stated that support of the gingival margin with a provisional at the time of tooth extraction and implant placement preserved 1 mm more facial gingival margin position compared with the delayed group (Block et al. 2009). Additionally, Raes et al. observed midfacial soft tissue dynamics following 16 patients with single Type 1 and 23 patients with Type 4 in the anterior maxilla. They stated that Type 1 demonstrated fairly stable midfacial soft tissue levels with only a minority of cases showing advanced recession compared with delayed implants (Raes et al. 2011).

Therefore, Type 1 may improve the short-term aesthetic results. Other than the timing, some factors may also influence the optimal esthetic results: such as position and angulation of the implant, bone and soft tissue grafting, gingival biotype, implant design, submerged versus non-submerged implants, and immediate or early restorations (Schropp & Isidor 2008). However, to the performance, the studies cited in this section were protocols across Type 1, Type 2, Type 3, and Type 4, that along has brought a large variation in the confounding factors. So the results from these researches were lack conformability and comparability.

In conclusion, the clinician has the option of choosing Type 1, Type2, Type 3 and Type 4 implant placement protocols. The advantages and disadvantages of each protocol need to be carefully considered in order to reduce the risk of complications. However, there is insufficient evidence to determine possible advantages or disadvantages of each protocol according to the findings of published studies (Quirynen et al. 2007). It is only suggested the esthetic outcome might be better when placing implants just after teeth extraction. So Type 1 implant placement may be considered in patients and sites with a low esthetic risk profile (Martin et al. 2007, Schropp & Isidor 2008).

1.6 Methods of bone remodelling measurement

1.6.1 Non-radiographic measurements

Various methods and instruments have been used to assess the alveolar bone surrounding implant. Some used periodontal probe which provides a simple way for direct bone measurement, but it lacks the required precision of other methods (Schropp et al. 2003; Sanz et al. 2010; Spray et al. 2000). Some used manual caliper and digital caliper which are limited to measuring bone thickness in the extraction socket only and are not practical after implant placement (Katranji et al.2007; Huynh-Ba et al. 2010). Some are invasive and perhaps not ethical, such as surgical re-entry approach (Botticelli et al. 2004; Ferrus et al. 2010; Tomasi et al. 2010; Matarasso et al. 2009). Others used histomorphometric analysis which allows observation of remodelling patterns adjacent to the implant and quantification of bone dimensions, but it requires en bloc resection and is not sequentially reproducible for longitudinal studies (Botticelli et al. 2004; Araújo et al. 2005; Botticelli et al. 2006; Araújo et al. 2006a; Araújo et al. 2006b).

1.6.2 Radiographic measurements

1.6.2.1 Intraoral Peri-apical Radiography

Radiographic image of bone is widely used as diagnostic and evaluation tool in implant dentistry. Radiography in comparison with several images and standard measurement of some specific sites on implant can provide valuable information (Benkow 1957; Rosling 1975; Harris et al. 2012; Palattella et al. 2008). Therefore, intraoral peri-apical radiography is universally used for the follow-up checkup of dental implant placement. The marginal alveolar bone level and identifying signs of failing osseointegration could be assessed (Albrektsson et al. 1986). However, due to its two-dimensional nature, the diagnostic value is limited by geometric distortions and anatomical superimpositions (Tyndall & Brooks 2000; Patel 2009; Patel et al. 2009). In addition, since intraoral radiography does not allow assessing those parts of the alveolar process which are directly in front or behind the implant, these methods could evaluate mesiodistal bone changes around dental implants, but could not detect the buccolingual bone remodelling. There is very little scientific evidence that provides the timely amount of bone remodelling at buccolingual aspects of dental implants in humans (Chiapasco & Zaniboni 2009; Teughels et al. 2009).

1.6.2.2 Cone-Beam Computerized Tomography

Computerized Tomography (CT) has successfully been used to represent the true 3-dimensional (3D) morphology of the skeletal structures of the cranium. There are two x-ray beam geometry for acquisition: fan beam and cone beam (Scarfe et al. 2006).

With “conventional” fan-beam CT systems, an x-ray source and solid-state detector are mounted on a rotating gantry. Projection data are obtained using a narrow fan-shaped x-ray beam transmitted through a specified part of a patient.

The patient is imaged slice-by-slice, usually in the body axial plane. And interpretation of the images is achieved by stacking the slices to acquire multiple 2D representations. The linear array of detector elements is a multi-detector array in conventional fan-beam CT scanners, which allows multi-detector CT (MDCT) scanners to acquire up to 64 slices simultaneously, and considerably reducing the scanning time and dose of radiation compared with single-slice systems (Hu et al. 2000). Conventional CT was introduced into medical practice in 1971 (Hounsfield 1973). It is used selectively for imaging of the craniofacial region to evaluate the temporomandibular joint (Honda et al. 2004), osseous pathology (Fuhrmann et al. 1995), deformities and asymmetries (Hamada et al. 2005), etc.. However, its application in dentistry is limited to special patients because of scanning cost, equipment size, and risks associated with relatively high radiation doses.

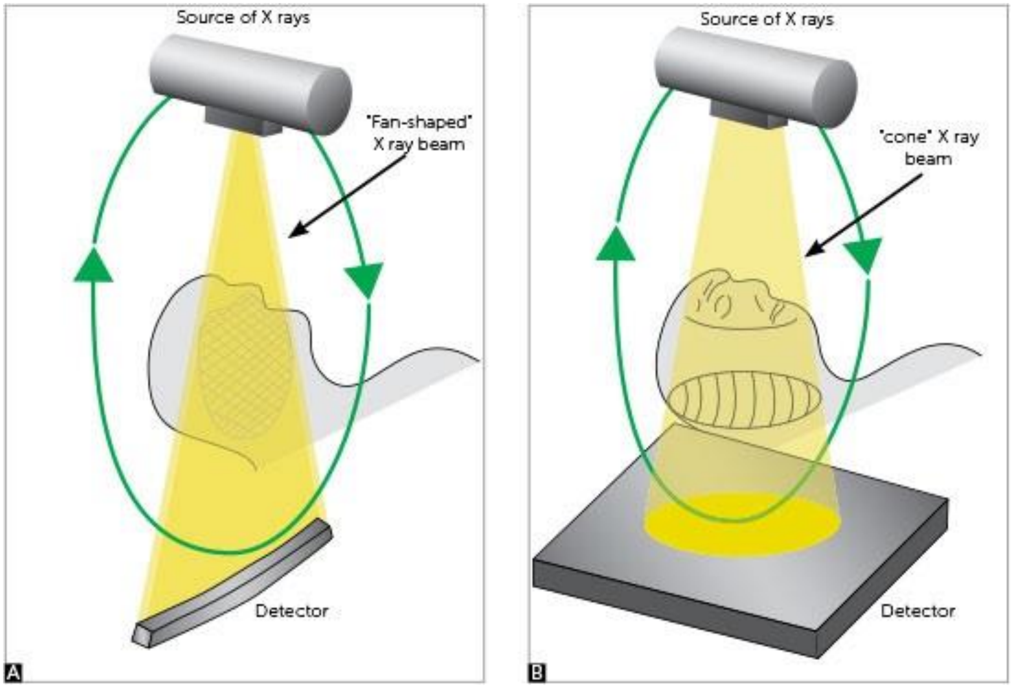


Figure 1–3. X-ray beam projection scheme comparing a single detector array fan-beam CT (A) and cone-beam CT (B) geometry (Sukovic 2003).

Cone-Beam CT (CBCT) scanners are based on volumetric tomography, using a 3D cone-shaped x-ray beam and a 2D extended digital array providing an area detector. The cone-beam technique involves a single 360° scan in which the x-ray source and a reciprocating area detector synchronously move around the patient's head stabilized with a head holder (Figure 1–3). At certain degree intervals, single projection images are acquired as “basis” images. This series of basis projection images is referred to as the projection data. The images are reconstructed in a three-dimensional (3D) data set using a modification of the original cone-beam algorithm developed by Feldkamp et al. in 1984, which can be used to provide primary reconstruction images in 3 orthogonal planes (axial, sagittal and coronal) (Feldkamp et al. 1984). In oral and maxillofacial (OMF) field, CBCT scanners were pioneered in the late 1990s by Arai et al. in Japan (Arai et al. 1999) and Mozzo et al. in Italy (Mozzo et al. 1998). Because of the development of inexpensive x-ray tubes, high-quality detector systems and powerful personal computers, affordable systems were developed and CBCT become commercially available, such as NewTom QR DVT 9000 (Quantitative Radiology s.r.l., Verona, Italy)(Mozzo et al. 1998), CB MercuRay (Hitachi Medical Corp., Kashiwa-shi, Chiba-ken, Japan), 3D Accuitomo– XYZ Slice View Tomograph (J. Morita Mfg Corp., Kyoto, Japan) and i-CAT (Xoran Technologies, Ann Arbor,Mich., and Imaging Sciences International, Hatfield, PA).

1.6.2.3 Advantages of CBCT

CBCT has been well suited for imaging the craniofacial area which provides clear 3D images of highly contrasted structures and is particularly useful for evaluating bone (Ziegler et al. 2002, Sukovic 2003, Schulze et al. 2010). In addition, compared with conventional CT, it offers a series of potential advantages for maxillofacial imaging in clinical practice.

Firstly, most CBCT units can be adjusted to scan small regions for specific diagnostic tasks. So collimation of the primary x-ray beam to the interest area reduces the size of the irradiated area, which minimizes the radiation dose (Hu et al. 2000, Ludlow et al. 2006, Ludlow & Ivanovic 2008). And CBCT acquires all basis images in a single rotation, so scan time is rapid (10-70 seconds) which can reduce effective dose of radiation and motion artifacts as well. The effective dose of radiation (average range 36.9-50.3 microsievert [µSv]) (Cohnen et al. 2002, Ludlow et al. 2003, Mah et al. 2003, Heiland et al. 2004, Schulze et al. 2004) is significantly reduced by up to 98% compared with conventional CT systems (Dula et al. 1996, Scaf et al. 1997, Ngan et al. 2003). This reduces the effective patient radiation dose to approximately that of a film-based periapical survey of the dentition (13–100 µSv) or 4-15 times that of a single panoramic radiograph (White 1992, Danforth & Clark 2000, Gibbs 2000).

Secondly, CBCT achieves high image accuracy. The volumetric data set comprises 3D block of smaller cuboid structures, known as voxels, each representing a specific degree of x-ray attenuation. The size of these voxels determines the resolution of the image. In conventional CT, the voxels are anisotropic, where the longest dimension of the voxel is the axial slice thickness and is determined by the parameter of slice pitch, which is controlled by the operator at the stage of setup a scan. Although CT voxel surfaces could be as small as 0.625 mm^2, the depth is usually in the order of 1-2 mm. While with CBCT, the voxel of image are mostly isotropic that are equal in all 3 dimension, which produces sub-millimetre resolution ranging from 0.4 mm to as low as 0.125 mm (Scarfe et al. 2006).

Additionally, many researches were carried out to make clinicians have confidence in the accuracy of measuring anatomic structures from CBCT images (Kobayashi et al. 2004, Lascala et al. 2004, Marmulla et al. 2005, Loubele et al. 2008, Stratemann et al. 2008, Suomalainen et al. 2008, Veyre-Goulet et al. 2008, Berco et al. 2009, Brown et al. 2009, Kamburoğlu et al. 2009, Fatemitabar &

Nikgoo 2010, Al-Ekrish & Ekram 2011, Kamburoğlu et al. 2011, Timock et al. 2011, Benninger et al. 2012, Moshfeghi et al. 2012, Kamburoğlu et al. 2014).

Some studies compared the measurement accuracy between CBCT and multi-slice CT (MSCT). Kobayashi et al. compared the accuracy of distance measurement using CBCT (3D Accuitomo) and MSCT. The vertical distance from a reference point to the alveolar ridge was measured in five cadaver mandibles. A significantly smaller measurement error was observed for CBCT (1.4%) than for MSCT (2.2%) (Kobayashi et al. 2004). And Suomalainen et al. evaluate the accuracy of linear measurements obtained with CBCT and MSCT, using pre-operative planning of the placement of oral implants as a model, which showed significant differences between two methods. The measurement error was 4.7% for CBCT and 8.8% for MSCT (Suomalainen et al. 2008). Al-Ekrish & Ekram also carried out a similar study to investigate the accuracy and reliability of linear measurements of edentulous ridges of human dry skulls recorded from 16-row MDCT images and CBCT images acquired using a flat panel detector with a large field of view. The mean of the CBCT errors (0.48±0.44 mm) was smaller than that of the MDCT absolute errors (0.65±0.57 mm) for the overall data and they concluded CBCT measurements were significantly more accurate than those of MDCT (Al-Ekrish & Ekram 2011).

Other studies assessed the difference of the measurement results between CBCT and direct linear measurement. In the study carried out by Beroc et al., they used 17 landmarks on a skull, obtaining 29 interlandmark linear measurements, and compared those measurements to the measurements made on the CBCT scans. The method errors were 0.19, 0.21, and 0.19 mm in the x-, y- and z-axes, and mean measurement error was -0.01±0.129 mm, which were all below the known voxel size and clinically insignificant (Berco et al. 2009). This was agreed by Loubele et al. They also claimed that both CBCT and MSCT yielded submillimeter accuracy for linear measurements of alveolar bone of maxilla (Loubele et al. 2008). Moreover, Timock et al. measured buccal alveolar bone height and thickness measurements of 65 teeth on CBCT (i-CAT, 0.3 mm voxel size) scanning of twelve embalmed cadaver heads and compared with direct measurements made by dissection (Timock et al. 2011). They demonstrated that the mean differences were 0.30 mm (range -0.77 to 0.81 mm) in buccal bone height and 0.13 mm (range -0.32 to 0.38 mm) in buccal bone thickness. And agreement between the two methods was higher for the measurements of buccal bone height than buccal bone thickness and there was no significant difference between the results of two methods. They concluded that CBCT can be used to quantitatively assess buccal bone height and buccal bone thickness with good precision and accuracy. Furthermore, Benninger et al also concluded in their study that measurements on teeth from CBCT imaging could reflect the actual tooth length (Benninger et al. 2012). The results showed the average value of differences between measurements of the CBCT imaged teeth and those of the extracted teeth were 0.098±0.060 mm in vertical dimension, 0.009±0.006mm in the facial to lingual dimension and 0.009±0.006mm in the mesial to distal dimension, resulting in no statistically significant difference in each dimension. Moshfeghi et al. measured 22 anatomic landmarks in four dry human skulls using a digital caliper and CBCT (Newtom VG, 0.3 mm voxel size) (Moshfeghi et al. 2012). The mean differences of real and radiographic measurements were -0.10±0.99 mm in the axial sections and -0.27±1.07 mm in the coronal sections of the images of 0.3 mm resolution; +0.14±1.44 mm in the axial sections and 0.02±1.4 mm in the coronal sections of images of 0.15 mm resolution. No statistically significant difference was found between the radiographic measurements and real measurements. They concluded CBCT (Newtom VG) was highly accurate and reproducible in linear measurements in the axial and coronal image planes and in different areas of the maxillofacial region. And the conclusion is consistent with a similar research done by

Kamburoğlu et al. in 2011 (Kamburoğlu et al. 2011). Kamburoğlu et al. made a further effort to investigate the reliability and accuracy of CBCT images in detecting and quantifying simulated buccal marginal alveolar peri-implant defects prepared in 69 implants inserted into cadaver mandibles. They said that depth, width and volume measurements of the defects from various CBCT images correlated highly with physical measurements (Kamburoğlu et al. 2014).

Thirdly, reconstruction of CBCT data could be performed natively by a personal computer, while access and interaction with conventional CT data are not possible because workstations are required. Software can be made available to the dentists and researchers, not just the radiologist. This provides the opportunity for clinicians to use chair-side 3D image display, real-time analysis and multi-planer reconstruction (MPR) modes that are task specific (Scarfe et al. 2006). In addition, the CBCT volumetric data set is isotropic which means the entire volume can be reoriented. So the patient’s anatomic features are realigned. And, the availability of cursor-driven measurement algorithms allow the practitioner to do real-time dimensional assessment, annotation, and measurement (White & Pharoah 2013).

In conclusion, CBCT, providing satisfying 3D radiographic images with less exposure time and less X-ray radiation, allows clinicians to measure peri-implant bone dimensions at multiple levels over time. Therefore, CBCT has the potential to assess buccolingual bone adjacent to implants and to provide valuable long-term data on biological bone remodelling processes that occur after implant placement.

1.6.2.4 Aspects of CBCT image quality and metal artifact of CBCT

As stated above, many studies illustrated that CBCT provides accurate linear measurements of maxillofacial bone structures. However, there are no established image quality criteria for dental CBCT, which is important for providing consistent image quality for medical professionals (Farman 2009). Fundamentally, like other CT modalities, the image quality of CBCT includes six basic factors: low contrast resolution, high contrast resolution (spatial resolution), image uniformity, linearity, noise ratio, and artifacts (Kamath et al. 2011). The overall image quality is dependent on balancing these factors to produce the best possible image for the anatomical region being scanned. Some work has been performed in this area and provided valuable information about dose-to-image-quality tradeoffs. It was stated that CBCT scanning protocols should be adjusted and optimized according to the specific clinical applications (Kamath et al. 2011, Lofthag-Hansen et al. 2011, Horner et al. 2013).

CBCT is also prone to the appearance of artifacts generated by dental implant (Figure 1–4) (Draenert et al. 2007, Razavi et al. 2010, Schulze et al. 2010, 2011), which might influence the precise of bone measurement around implant. An artifact is any distortion or error on the image that is unrelated to the subject being examined, which could be problematic for image interpretation. Many factors can cause image artifacts in CBCT, such as motion, metal implants, partial volume effect, and inadequate calibrations. Noise, scatter, extinction artifacts, beam-hardening artifacts, aliasing artifacts, ring artifacts, and motion artifacts are predominant artifacts in CBCT images (Schulze et al. 2011). Among them, there are two main X-ray metal artifacts affecting image quality seriously (Scarfe & Farman 2010). One is beam hardening, which appears as a series of streaks or dark bands as a result of the increasing absorption of incident radiation by radiodense objects (e.g., dental implants, metal crowns and amalgam restoration), and causes the loss of information for reconstruction. The other effect is scatter radiation, appearing as white bands at edges and “star” artifacts, which are the results from the absorption and re-emission of radiation. While these effects are predominantly observed at the level of the occlusal plane in axial images, they may be prominent within the alveolar bone adjacent to teeth restored with amalgam and, in particularly, are associated with titanium implant (De Man et al. 1999, Scarfe & Farman 2010).

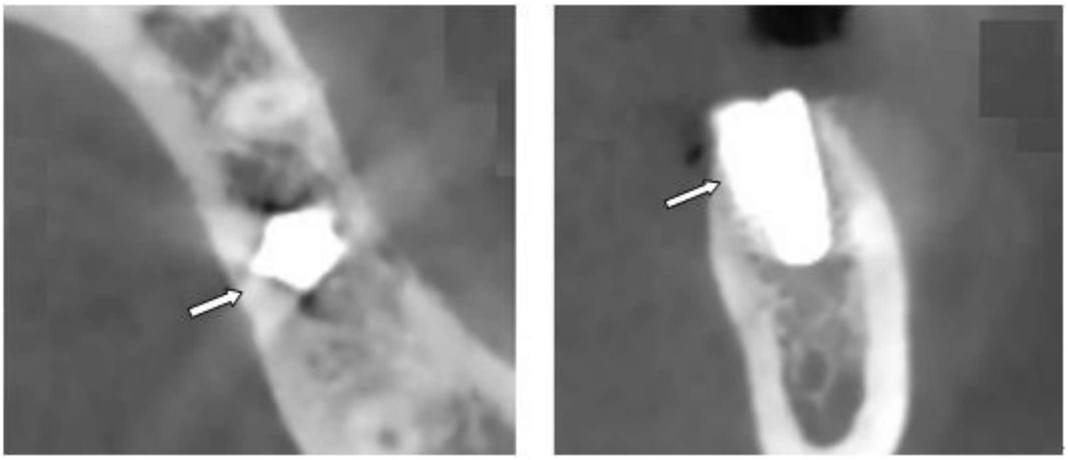


Figure 1–4. Metal artifacts around dental titanium implant.

It is suggested, compared with conventional CT, clinical experiences have shown CBCT images could result in a low level of metallic artifacts with manufacturers' artifact suppression algorithms and increasing number of projections (Cohnen et al. 2002, Holberg et al. 2005). Measurements from CBCT images displayed only slight deviations in the extent of the peri-implant defects and CBCT showed high imaging quality (Mengel et al. 2006, Corpas Ldos et al. 2011). However, other researchers said that CBCT has more artifacts around implants than conventional CT does and these artifacts could seriously affect image quality and lead to inaccurate evaluation (Draenert et al. 2007, Zhang et al. 2007, Kovacs et al. 2008). Draenert et al. examined beam hardening artifacts of the NewTom 9000 CBCT device compared with the Philips MX 8000 (4-row MDCT). The quality of the MDCT was rated to be better than the CBCT. None or less than 10% of implant depictions on MDCT images were disturbed by artifact, while CBCT scans showed minimum artifacts in more than 25% of the implant images and most of the images were rated to be more than 50% disturbed by the beam hardening effect (Draenert et al. 2007).

Moreover, a model for the distribution of artifacts around titanium implants in CBCT showed that increased grey values were observed at the buccolingual aspects, while the regions with reduced grey values were located along the long axis of mandibular body (Benic et al. 2013). And the closer one observes the region of the implant bone interface, the less reliable the reconstruction is (Schulze et al. 2010, Benic et al. 2013). In the interproximal regions adjacent to the implants, a reduction of grey values of approximately 50% was found (Schulze et al. 2010). However, Razavi et al. said that the CBCT scanner with a spatial resolution of 0.125 mm provided accurate measurements in samples with a bone thickness >0.8 mm (Razavi et al. 2010). Nonetheless, no correlation between the artifact intensity and the inaccuracy of CBCT-based bone measurement around implant so far can be inferred (Benic et al. 2013).

Furthermore, various methods for metal artefact reduction (MAR) on CBCT have been proposed (Kalender et al. 1987, Mahnken et al. 2003, Kovacs et al. 2008, Prell et al. 2010, Boas & Fleischmann 2011, Wang et al. 2013, Takrouri et al. 2015, Wuest et al. 2015). Some studies proposed new algorithms to improve image quality through enhancing the reconstruction of the image or developed post-processing techniques for MAR. Other studies examined the effect of increasing the radiation dose by increasing either the milliampere second factor or the peak kilovoltage. Most studies concluded the reduction of metal artifacts could be achieved to obtain better image quality in patients with metallic implants (Mahnken et al. 2003, Meilinger et al. 2011, Bechara et al. 2012, Wang et al. 2013). But Sononda et al. compared the quality of the images acquired with single energy MAR on CT scans of hip prosthesis, iliac artery aneurysm embolization, and dental prosthesis in human body (Sonoda et al. 2015). They said MAR setting did not performed better on scans of dental prostheses, especially in the area 1 cm from the edge of the implant.

In conclusion, well understanding the metal artifacts on CBCT image is essential when measuring the bone volume at the regions adjacent to the surface of dental implants on CBCT images.

1.7 Objectives

This study was a clinic based retrospective *in vivo* study. Based on CBCT data sets, through the measurement of dimensional changes of alveolar bone, it assessed whether the bone reformation process was at the same rate when using Type 1 and Type 4 implant placement protocols; as well as the difference between buccal and lingual sides, maxilla and mandible. The objectives of this thesis can be further detailed as follows:

(1) To establish a reproducible 3D measurement strategy to quantify dimensional changes of alveolar bone related to dental implant based on consecutive CBCT images;
(2) To evaluate the reproducibility and precision of the measurement strategy;
(3) To measure alveolar bone dimensional changes from 44 Type 1 cases and 25 Type 4 cases;
(4) To find the differences of bone dimensional changes between lingual and buccal sides separately in two groups of Type 1 and Type 4;
(5) To find the differences of bone dimensional changes between maxilla and mandible separately in two groups of Type 1 and Type 4;
(6) To find the total differences of bone dimensional changes between two groups of Type 1 and Type 4, in terms of thickness and height at lingual and buccal aspects;
(7) To find the differences of bone dimensional changes between two groups

of Type 1 and Type 4 separately in maxilla and mandible.

1.8 Layout of thesis

The layout of the material in this thesis reflects the work undertaken encompasses several stages, each of which is distinct but dependent on those preceding it. Therefore a modular structure was adopted with each topic presented within its own separate Chapter, for this reason an introduction, materials and methods, results and discussions relevant to each module are presented in each Chapter.

This Chapter has given a general introduction to the subject. It will then be developed into establishment and application of measurement strategy for quantification of bone changes around dental implant in Chapters 2, 3, 4, 5 and 6.

Chapter 2 established and evaluated the measurement strategy for quantification of bone changes related to dental implant. Chapter 3 assessed the bone changes in 44 paired CBCT data sets of Type 1 cases and 25 paired CBCT data sets of Type 4 cases. It was aimed at discovering the difference of bone changes between Type 1 and Type 4 groups, lingual and buccal sides, maxilla and mandible. Chapter 4 was a report of 2 spilt-mouth design cases, which provided more valuable information of the difference in bone changes between Type 1 and Type 4 protocols. Chapters 5 explored 3 cases which followed up 2 years and Chapter 6 analysed a 3-year follow-up case from a patient suffered with auto-immunes disease ‘lupus erythematosus’.

Finally, the Conclusion and Future Work relevant to the thesis are presented in Chapters 7 and 8.

2. Establish and Evaluate the Measurement Strategy of Alveolar Bone Changes in Relation to Implant Placement

2.1 Introduction

Few studies had used CBCT data sets to evaluate horizontal or vertical bone remodelling after implant placement (Cho et al. 2011, Miyamoto & Obama 2011, Benic et al. 2012, Degidi et al. 2012, Roe et al. 2012, Vera et al. 2012, Coomes et al. 2013, Spin-Neto et al. 2013b, Kuchler et al. 2016, Mazzocco et al. 2016). However, the measurement strategies utilized in these researches were not good enough to provide accurate results.

Three publications reported the bone dimensional measurements, based only on one CBCT data set that was taken at months or years after implant placement (Cho et al. 2011, Miyamoto & Obama 2011, Benic et al. 2012). Miyamoto & Obama estimated postoperative labial bone thickness in maxillary anterior implants. No baseline was set and no bone changes were calculated. Then Cho et al. evaluated the amount of resorption and thickness of labial bone in anterior maxillary implant. Implant platform was positioned vertically at the same level of bony scallop of adjacent teeth, which determined the base line (original height) of labial bone in CBCT. But after crown rehabilitation, it is difficult to locate the position of implant platform on the CBCT image due to the metallic artifact. The same problem was in the research carried out by Benic et al. Additionally, in these three studies, the determination of the existence of labial bone on CBCT image depended on the image grey shade and examiner's judgment, which could be influenced by metallic artifact and be judged subjectively. Furthermore, no specific points were determined to define the thickness of labial bone, which could lead to poor measurement reproducibility. Hence, the reliability of the results was poor, which also didn’t mention any uncertainty of the measurement methods.

Other studies utilized two CBCT data sets taken at different time points to evaluate the bone changes around implants. Roe et al. evaluated horizontal and vertical dimensional changes of the facial bone following maxillary anterior single immediate implant placement (Roe et al. 2012). Immediate post-treatment and one year post-treatment CBCT data sets were used to make the measurement. In this study, specific points were determined to define the horizontal and vertical level of bone. However, in order to get two comparable images from two CBCT data sets, the coronal, sagittal and axial axes were rotated to specific position according to the implant image which was inevitably influenced and seriously distorted. It was difficult to locate the exact position of central axis of implant. So the paired images of immediate post-treatment and one year post-treatment CBCT data sets couldn’t be in the exact same position of the alveolar bone. This led to worse comparability between paired images. Furthermore the horizontal bone thicknesses were measured from the bone margin to the outer contour of implant image which also lacked sharpness due to artifacts. Although the author provided inter- and intra- examiner reliability, the result of this study was still questionable. The study carried out by Spin-Neto et al. utilized a similar approach to achieve the same spatial orientation of paired CBCT data sets (Spin-Neto et al. 2013b), which was not precise as well. Vera et al.(Vera et al. 2012) didn’t describe the procedure about how to obtain the target paired images which should be on the same position of alveolar bone in their research. And they also utilized the outer counter of implant image to measure the bone thickness. Moreover, Kuchler et al. used implant shoulder and surface of implant as reference structure to define the measurement positions on CBCT images, while Mazzocco et al. utilized the shape of extraction socket (Kuchler et al. 2016, Mazzocco et al. 2016). Both of them had the same weakness mentioned above. Degidi et al used a software program for removing scattering defects and obtaining maximal quality of CBCT image (Degidi et al. 2012). It could minimize the measurement deviation caused by artifacts. But no procedure about how to make the measurement on the same position of two data sets was illustrated.

Only the researches carried out by Coomes et al. described that the medical imaging software, which is capable of loading two sets of CBCT DICOM files and aligning the images, was used to obtain the exactly same slice for comparisons (Coomes et al. 2013). Since the study evaluated the buccal bone formation after flapless extraction, no implant and metallic artifacts were involved. So how to minimize the measurement deviation caused by artifact wasn’t discussed in this study.

Furthermore, most sample size in these studies was less than 20 participants and no more than 30. It is difficult to get any conclusive results according to these researches.

It should be noted there are three key points for evaluating bone changes after implantation on CBCT image: (1) How to superimpose images of two CBCT data sets and obtain the slices for measurement on same position. (2) How to determine the specific points to define the bone thickness and height and minimize the influence of metal artifact. (3) How to avoid the subjective judgment of image grey shade which could be deviated by image contrast and different examiners.

In this chapter, it focused on (1) exploring the influence of artifact on the measurement of implant images under four different CBCT settings; (2) establishing a reproducible and precise approach in quantification of the alveolar bone changes after dental implant placement based on CBCT images, which minimized the influence of artifact and provide an acceptable precision level.

2.2 Materials and methods

2.2.1 3D image analysis software package

The 3D measurement of alveolar bone changes used a software package called OnDemand3D™ App (version 1.0.10.6388, OnDemand3D Technology Inc, USA). It is a highly-advanced 3D imaging software developed for dentists, clinicians and research experts for use in the planning and simulation of patient treatment, accurate diagnosis, and advanced research, which provides specialized layouts, reconstructed images and tools for accurate and precise diagnoses. Image analysis procedure included the following stages: image reconstruction from CBCT DICOM data; registration of two consecutive CBCT images; bone density analysis at the interface of bone and soft tissue; selection of the window width and window level for the identification of boundary of the cortical bone for the measurements of bone dimensional changes.

This software provides ‘measuring’ functions module. Such as ‘ruler’ can retrieve information of a distance between two points. And ‘profile’ can show the pixel values on a line on the image with a histogram graph, according to the intensity of the tissue on that line. Each endpoint of the line can be moved on the graph or on the image. The distance between two points will be displayed automatically and the pixel value on each point also revealed on the graph. Furthermore, the software has registration function in ‘fusion’ module. By loading up two series of Primary and Secondary images in one window and put only the interesting region of CBCT image into the window, the software registers two 3D structures to the same position. This makes it possible to compare the changes between pre- and post-implantation in the images from same patients.

2.2.2 Methods of quantifying bone changes related to dental implant

One of the clinical cases was used here as an example for explain the measurement strategy of quantifying the alveolar bone changes from before and one year after implantation. The CBCT images were taken by NewTom VG with the resolution of 0.125 mm, from a 19-year-old female patient who received a single immediate implant placement (Nobel Replace Tapered Groovy, 5.0 mm diameter, 13 mm length) on site of mandibular left second premolar. One CBCT scan (as primary images) was taken before implantation on 08-12-2013; and another CBCT scan (as secondary images) was taken one year after implantation on 03-12-2014 (Figure 2–1).

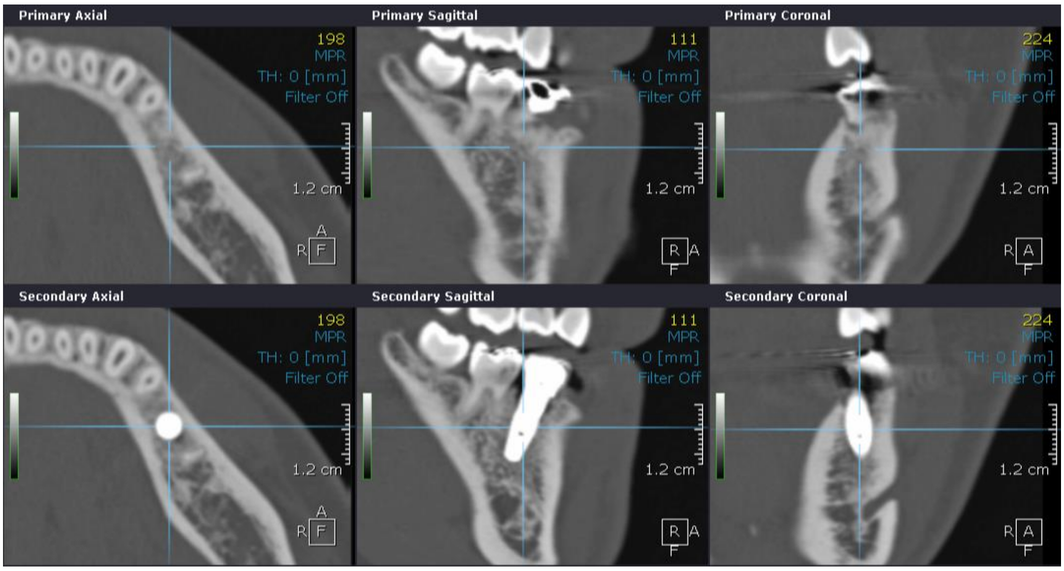


Figure 2–1. Primary CBCT images and secondary CBCT images were loaded up in one window.

2.2.2.1 Registration of two CBCT data sets and definition of measurement sections

It is almost impossible to reproduce the position and orientation when taking CBCT scans of a patient at consecutive occasions without mechanical gauging device. However, it is essential to reproduce the same position and orientation when taking the measurements for comparisons. Therefore, the first key point is to make the target primary image and secondary image for bone measurement exactly in the same position of the patient's alveolar bone. It was determined as follows:

Firstly, opening paired CBCT data sets by 'fusion' module of OnDemand3D, primary images, secondary images, and fused images could be displayed together. The primary planes were from the data set before implant placement and the secondary planes were from the data set one year after implant placement. In the fused windows, the images from the paired CBCT data sets were not properly superimposed which were pointed out on axial, sagittal and coronal planes by the white arrows. The axes of primary and secondary planes were also mismatched which were indicated by the yellow circles (Figure 2–2).

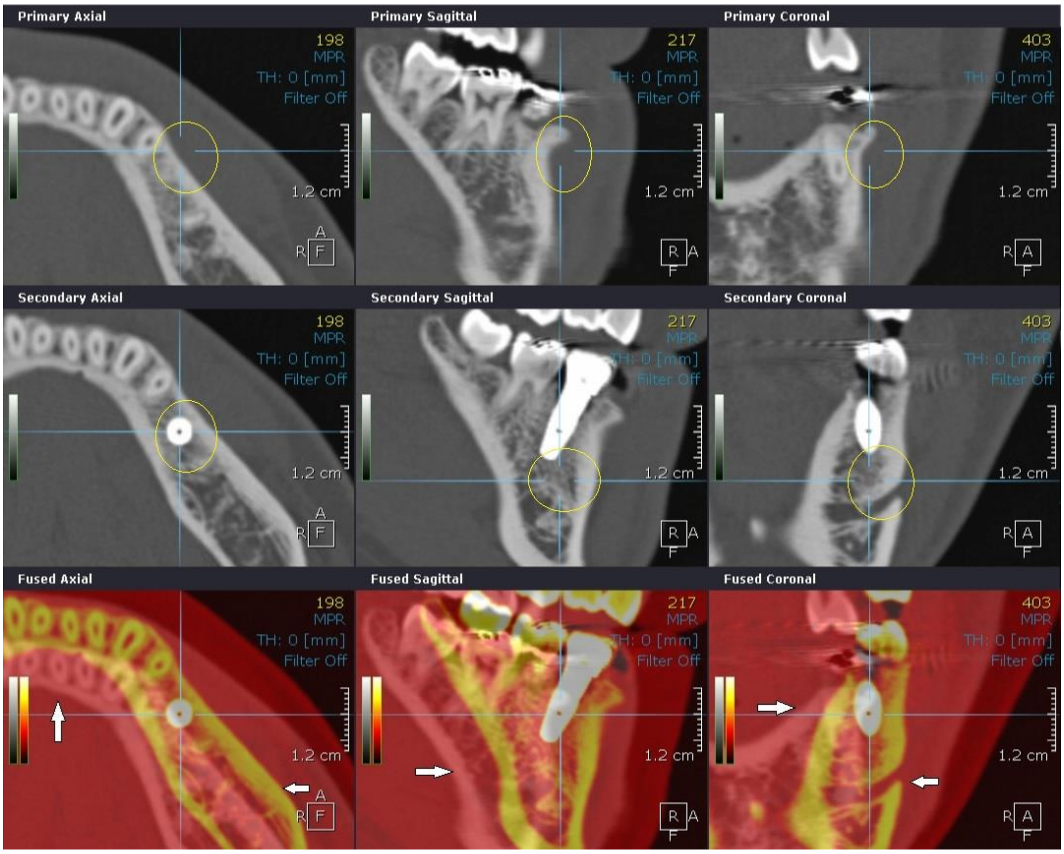


Figure 2–2. Opening paired CBCT data sets together by module 'fusion', the first and second rows were three aspects CBCT images taken before and after implant placement; and the third row was composited images of primary and secondary where arrows indicates a poor registration.

Secondly, using tool 'auto-registration', primary images, secondary images, and fused images could be displayed in the same position on axial, sagittal and coronal planes. On the fused planes, primary and secondary images were superimposed perfectly (Figure 2-3).

But the axes of primary and secondary planes were still in different positions. This was caused by the patient's head position which could be slightly difference in two CBCT scanning. Additionally, due to the same reason, the relative positions of maxilla and mandible in paired CBCT data sets were also not identical sometimes. This makes it impossible to superimpose both maxilla and mandible of consecutive CBCT data sets at same time. Therefore, it is important to choose a region of interest where the structures were outside of the surgery site and remained the same was selected to be the reference for registration. This example was a right mandibular premolar immediate implant. So only the mandible and the mandibular teeth were included in the region of 'auto-registration'. The voxel information of the reference in two registration windows were used to bring the two images as close as possible based on the algorithm of Mutual Information (MI). This procedure need to be repeated several times to achieve a best possible superposition.

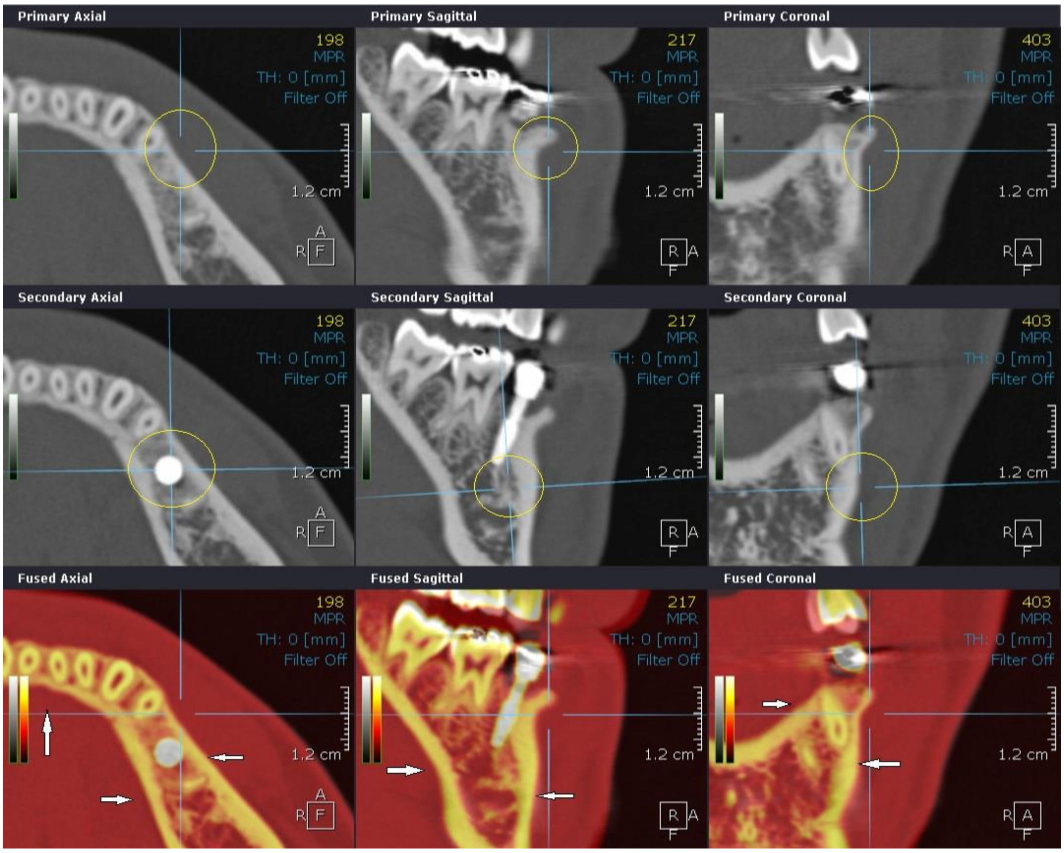


Figure 2–3. Superimpos interest region of primary and secondary CBCT images, arrows in the third row indicated an excellent registration, but the yellow circles showed the axes of primary and secondary images were still not in the same position and direction.

Thirdly, using tool 'reslice' to get a new CBCT data set of secondary CBCT data set, which could adjust the axes of secondary CBCT image to the same position of the axes on primary CBCT image. After 'reslice', the new secondary data set and the primary data set were then loaded together. The windows showed the axes of primary and new secondary data sets were on the same position and direction, while images taken before and one year after implant placement were superimposed satisfyingly as well (Figure 2–4).

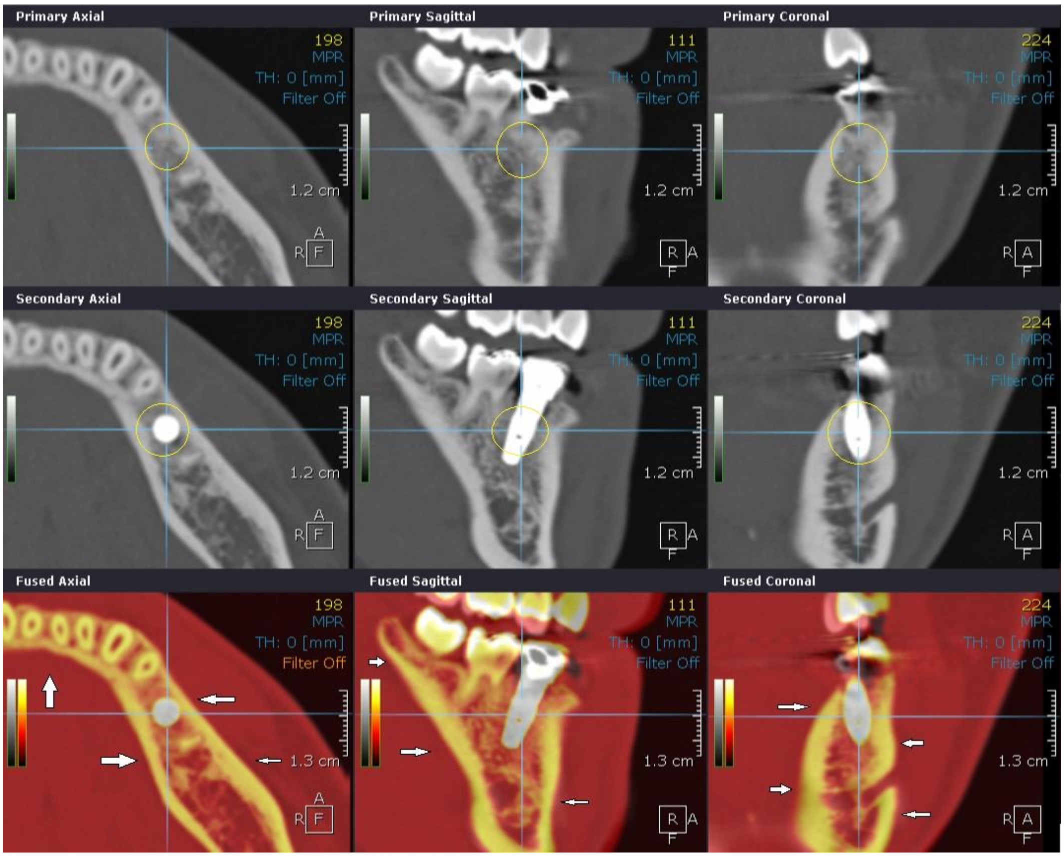


Figure 2–4. Superimposing primary and 'resliced' secondary CBCT images, white arrows and yellow circle showed good registration of interest area of primary and secondary images and axes on primary and secondary images were also at same position and direction.

Afterwards, the direction of axial plane was adjusted perpendicular to the centre axis of implant. The direction of coronal plane was adjusted parallel to the distal edge of mesial adjacent tooth. The direction of sagittal plane was perpendicular to coronal plane automatically. Then the axial axis was moved parallel to the bottom of implant image and the sagittal axis was moved to overlap with the central axis of implant. All of the adjustments in position and orientation were changed simultaneously in primary and secondary images, after they were registered. The slice numbers of axial (216), sagittal (126) and coronal (225) planes were indicated in red boxes, while the rotation degrees of axial (20.79), sagittal (150.58) and coronal (36.02) axes were marked in yellow boxes (Figure 2–5).

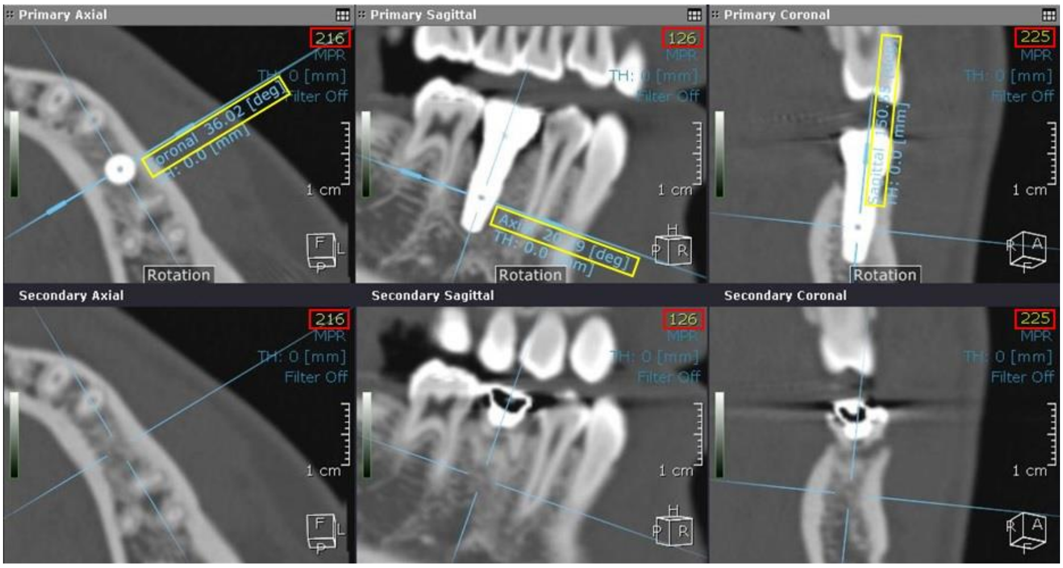


Figure 2–5. Slice number and the rotation degree of sagittal, coronal and axial planes, which were adjusted simultaneously in all windows after primary and secondary images were registered.

All these slice numbers and rotation degrees were recorded which would be used to repeat measurement procedure three times on the same target images from each pair CBCT data sets, in order to evaluate inter-examiner reproducibility of the measurement methods.

The primary and secondary coronal planes across the implant centre were the target images for measurement, which were exact on the same position of this patient's alveolar. And the sagittal and axial axes on these two coronal planes were also on the same position and direction. So these two axes were chosen as the datum for the measurement, instead of any anatomic structure.

Parallel line to axis could be obtained automatically by changing the thickness of axis line. The intersection points for measurement were determined as the following steps:

First, draw three parallels which were 12, 8, and 4 mm coronal to the axial axis. All the lines were across the sagittal axis and bone edge of lingual and buccal boundaries. The intersection points at buccal side were marked as B_1, B_2, B_3 (12, 8, 4 mm coronal to the axial axis), while those at lingual side were L_1, L_2, L_3 and those on sagittal axis were O_1, O_2, O_3. The distances (B_1O_1, B_2O_2, B_3O_3) between $B_{1\text{-}3}$ and $O_{1\text{-}3}$ were defined as the bone thicknesses at buccal side, while those (L_1O_1, L_2O_2, L_3O_3) between $L_{1\text{-}3}$ and $O_{1\text{-}3}$ were bone thicknesses at lingual side (Figure 2–6). This step avoided the metal artifacts. The measurement datum was shifted from the interface of bone and implant to sagittal axis. The bone thickness measurements were taken between two intersection points of sagittal axis and the boundary of cortical bone on each measurement section.

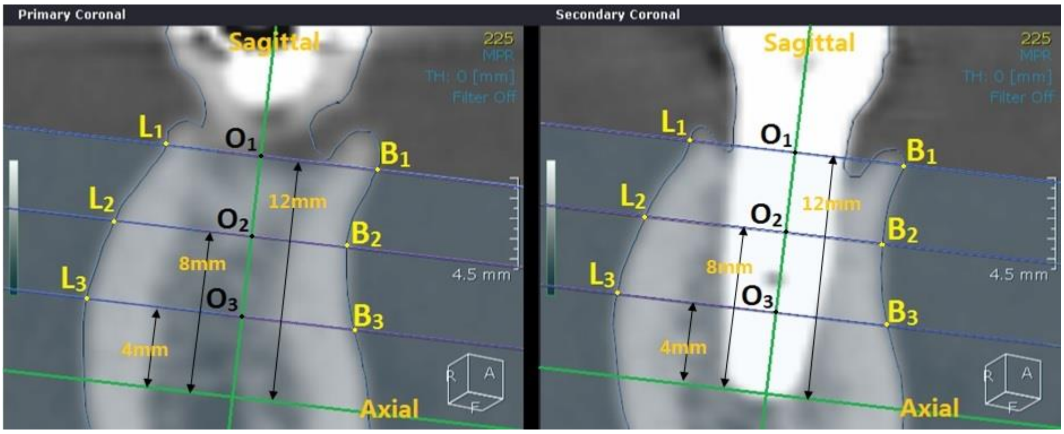


Figure 2–6. The measurement sections of bone thickness at buccal (B_1O_1, B_2O_2, and B_3O_3) and lingual (L_1O_1, L_2O_2, and L_3O_3) sides.

Second, draw two parallels to the sagittal axis, which were across the highest points on the bone edge of lingual and buccal boundaries on the secondary coronal image (one year after implant placement). The intersection points at lingual and buccal sides were marked as H_L and H_B, while those on axial axis were O_L and O_B. The distance (H_BO_B) between H_B and O_B was defined as the bone height at buccal side, while that (H_LO_L) between H_L and O_L was the bone height at lingual side (Figure 2–7).

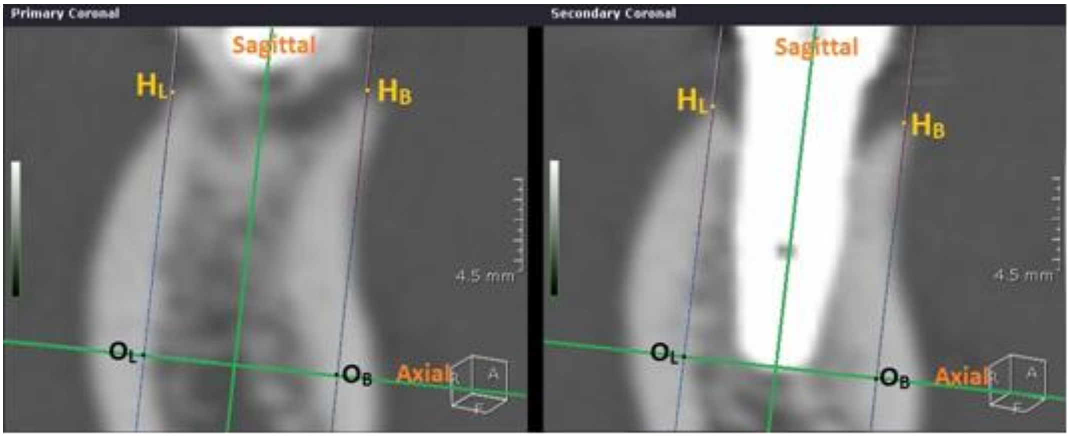


Figure 2–7. The measurement sections of bone height at buccal (H_BO_B) and lingual (H_LO_L) sides.

All the corresponding intersection points on the primary coronal image (before implant placement) could be obtained synchronously and marked in the same way to define the bone thickness and height.

Finally, the subtraction values of ΔB_1O_1, ΔB_2O_2, ΔB_3O_3 were defined as the changes of buccal bone thickness on each target position (12, 8, and 4 mm coronal to the axial axis). They were the value of B_1O_1, B_2O_2, B_3O_3 on the image one year after implantation minus those on the image before implantation. The subtraction value of lingual bone thickness and bone height were calculated in the same miner. ΔL_1O_1, ΔL_2O_2, ΔL_3O_3, as the changes of lingual bone thickness, were the subtraction values from L_1O_1, L_2O_2, L_3O_3 on the image one year after implantation minus those on the image before implantation. And, H_LO_L and H_BO_B on the image one year after implantation minus those on the image before implantation gave out the subtraction values of ΔH_L and ΔH_B, which were the changes of bone height at lingual and buccal side.

The values of the bone thickness and height were not the real value of bone quantity around the implant. But the subtraction value of bone thickness and height were the exactly actual value illustrating the value of bone changes.

2.2.2.2 Three methods of identifying the boundary of alveolar bone

Besides the influence from metal artifact, one of the major factors that affect the measurement accuracy is the identification of the boundary of alveolar bone from the surrounding soft tissues when measuring the bone changes related to dental implant. Therefore, three methods were developed and compared to achieve an acceptable precision in identification of the bone boundary.

2.2.2.2.1 Method based on image grey shade

In order to make the measurement more precise, the margin of the bone image was identified and marked by line, using the measurement tool ‘area’ which can automatically recognize the margin of bone according to the grey level of the pixels (Figure 2–8). However, the line alone the margin was not sleek enough to represent the shape of bone. According to the grey shade, a further fine adjustment was done manually to mark the margin more accurately (Figure 2–9). After that, the parallels were automatically generated and all the target intersection points were obtained. Use tool ‘Ruler’ to get the value of each distance between target intersection points which were the values of thicknesses and heights of lingual and buccal bone. In the Figure 2–10, it showed the distance from L_3 to O_3 was 8.00 mm.

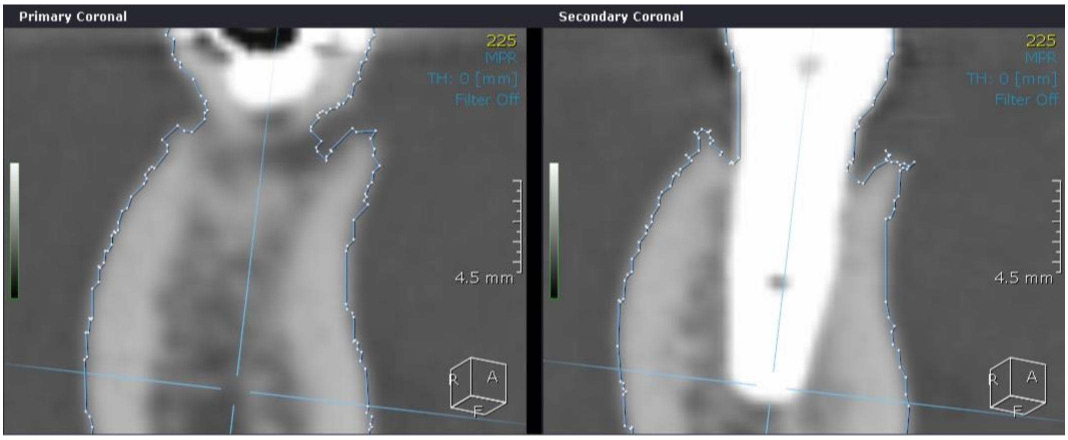


Figure 2–8. Automatically marking the alveolar bone margin on target coronal images by tool 'area' based on the grey level of the pixels.

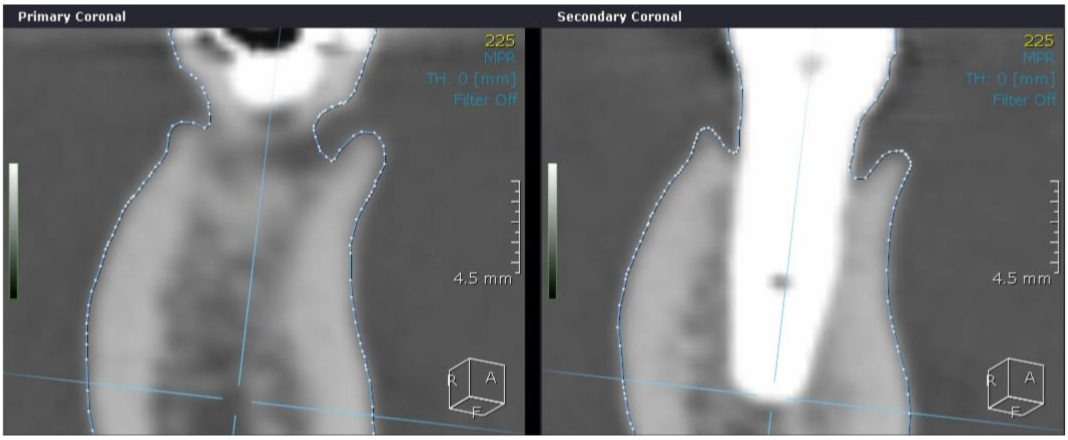


Figure 2–9. Manually adjustment of marking the alveolar bone margin on target coronal images.

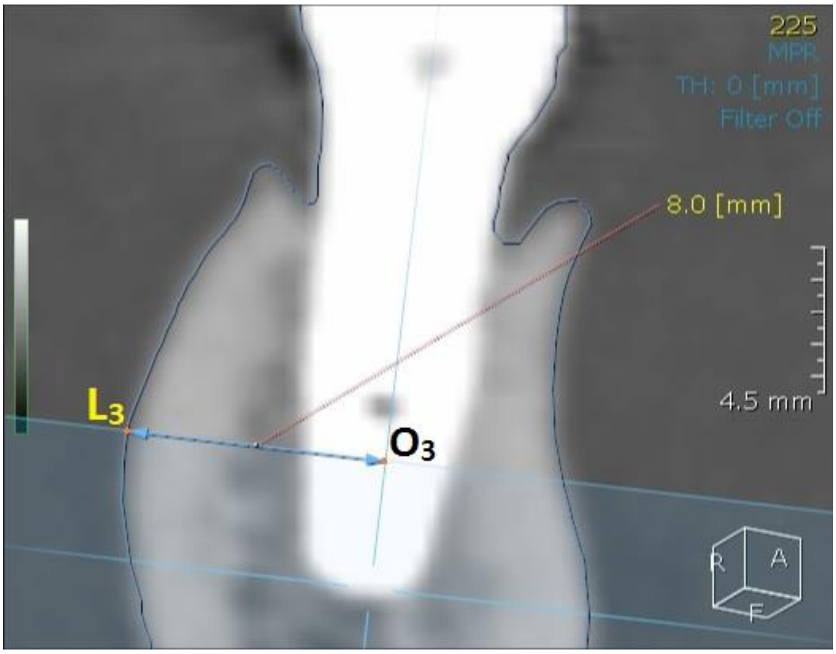


Figure 2–10. The distance between L_3 to O_3 measured by 'ruler' tool was 8.00mm.

It is obviously that the method based on image grey shade could be influenced by image contrast and examiner's judgment, which could lead to high deviation of the results.

2.2.2.2.2 Method based on grey value

Further attempt was made to identify the boundary of the alveolar bone based on grey value. The grey value at each pixel was based on the density of the object, a higher grey value to a higher density substance, and vice versa. They were fixed values irrespective to the window brightness, the window width and window level.

The measurement tool 'profile' shows the pixel value on a line and distance between two points which could be chosen based on the image grey value intensity. In Figure 2–11, on the line between A to $O_{3,}$ the grey value intensity in irregularly ladder-type increased from soft tissue to cortical bone, then decreased from cortical bone to sponge bone, and increased again from sponge bone to implant. The distance from A to O_3 was 10.80 mm.

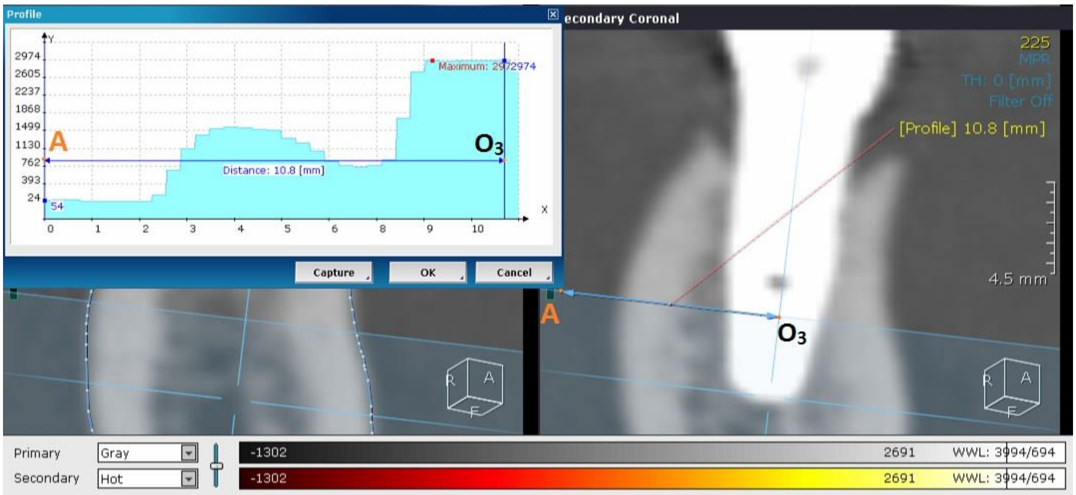
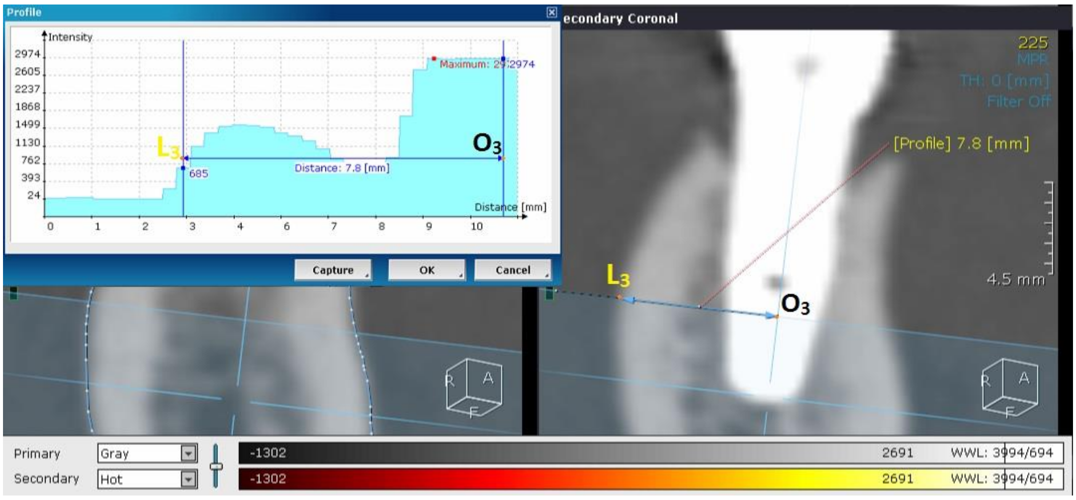


Figure 2–11. Tool 'profile' shows the pixel value and distance on a double headed arrow line (A to O_3) from soft tissue to the center axis of implant.

There are bundles of strong collagenous fibres connecting periosteum to bone, which are part of the outer fibrous layer of periosteum and enter into the outer interstitial lamellae of bone tissue. It means the margin of bone is mixed by soft tissue and bone tissue. So the grey value intensity of bone margin should be approximate to the average intensity value of these two tissues. After using tool 'profile' to get the intensity value of cortical bone and that of soft tissue, the position of target intersection points on bone margin were determined by the average intensity value of cortical bone and soft tissue. Meanwhile, making another point of 'profile' line overlap with the intersection point on sagittal line, the tool 'profile' could automatically show the value of the distance between two target intersection points. Using this procedure, all the values of the thicknesses and heights of lingual and buccal bone could be obtained. In Figure (Figure 2–12), the 'profile' showed the distance of L_3O_3 was 7.80 mm.



Primary: Gray -1302 2691 WWL: 3994/694

Secondary: Hot -1302 2691 WWL: 3994/694

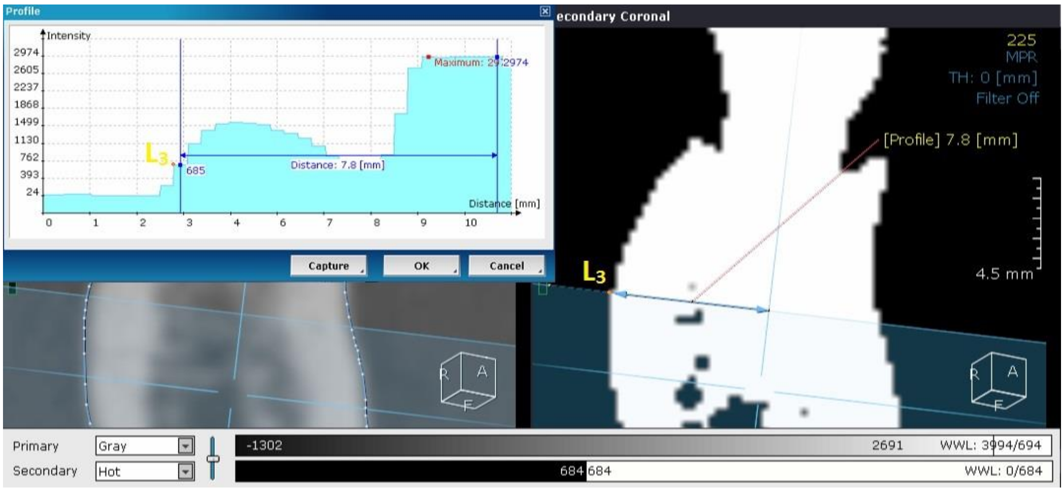
Figure 2–12. Intensity value 685 was used to mark intersection point L_3 by tool 'profile', which illustrated the distance from L_3 to O_3 was 7.80 mm.

2.2.2.2.3 Methods based on both grey value and grey shade

It seems the methods based on grey value excluded the influence of image contrast and examiner's subjective judgment. However, the CBCT is taken with a sampling interval, as consequence the grey value profile had stepping edges. The definition of the position could be only selected on the step and not in between. Therefore, the error of the position of bone margin is the size of the step which is related to the voxel size and thickness of reconstructed images. For example, if the voxel size is 0.125 mm, the distance of each jump is 0.23 mm.

To overcome the defects from both grey shade and grey value along, a method combined grey shade and grey value was established. In this way, the stepping effect from the grey value could be compensated by the smooth curve of the grey shade. It is effectively played the role of interpolation between the steps.

First, window width and window level of the image should been adjusted on the WWL bar, according to the intensity value of the target ladder. In the example, when defining the edge of L_3 point on target coronal images, window width was closed to 0 and window level was adjusted to 684. Because the initial intensity value on the target ladder was 685 and, after the adjustment of window width and window level, the image turned into monochrome and the contrast threshold of dark and white was the intensity of 684. Therefore on the image, the areas those intensity values were smaller than 684 would turn into dark and those bigger than 684 would turn into white. After this process, a clear intersection point 'L_3' could be detected on the paralleled line. It could be noticed the position of L_3 was out of the range of the 'profile' double headed arrow line (Figure 2–13).



Primary Gray WWL: 3994/694

Secondary Hot WWL: 0/684

Figure 2–13. On the monochrome image, the areas those intensity values were smaller than 684 turned into black and those bigger than 684 turned into black. The position of L_3 was out of the range of the 'profile' double headed arrow line. Please note the contract threshold on window level of 684 and window width of zero as shown in the bar.

Then, using 'ruler' to measure the distance between L_3 and O_3, value 7.90 mm would be recorded as the length of L_3O_3 (Figure 2–14). For each intersection point on the margin of bone, the initial grey value on 'profile' graph would show different intensity value. So the adjustment for each point, on the WWL bar, should base on its own intensity value.

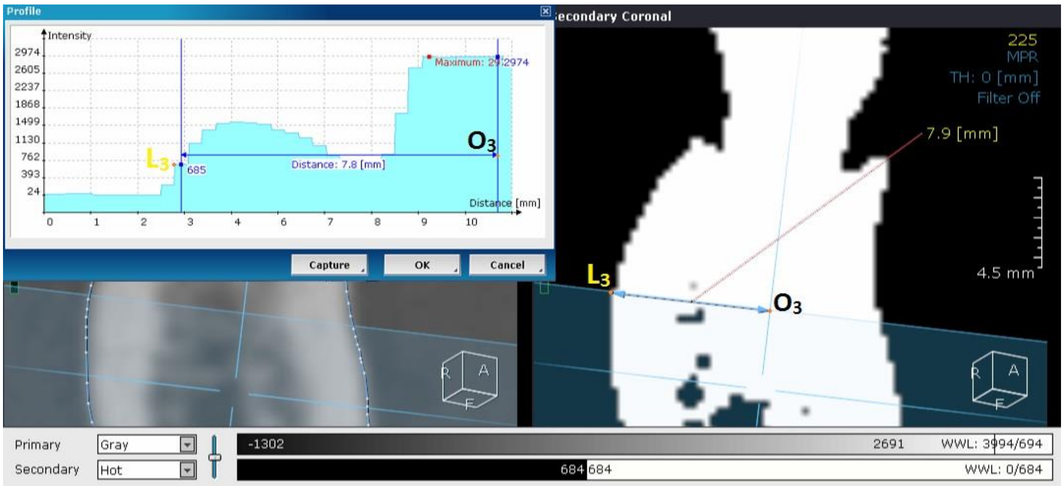


Figure 2–14. The value 7.90 mm was the distance from L_3 to O_3, measured by 'ruler' after adjusting the image window width (0) and window level (684) in the bar.

This method has more accurately defined within one step of 'profile' graph; therefore the error was eliminated further to be less than half of a sample interval.

2.2.3 Reproducibility and precision of the measurement strategy of bone changes

A dry mandible with missing teeth was acquired from the Museum of Bart's and The London School of Medicine and Dentistry. A Standard Plus implant (Straumann, Switzerland) with diameter of 3.3 mm and length of 12 mm was used for uncertainty and precision tests.

2.2.3.1 Measurement of bone changes on dry mandible with and without implant

This Standard Plus implant was placed in the distal socket of lower left 6 on the dry mandible. The implant has thread on its surface, so the outer diameter was

3.3 mm and the inner diameter was 2.8 mm. Three CBCT images (0.12 mm resolution) of the dry mandible were taken by the CBCT (Vatech PaX-Reve3D) in Bart's and The London Dental Hospital. One image was taken before implant placement, two images were taken after the implant placement under two CBCT settings of standard (STD) and metal artefact reduction (MAR).

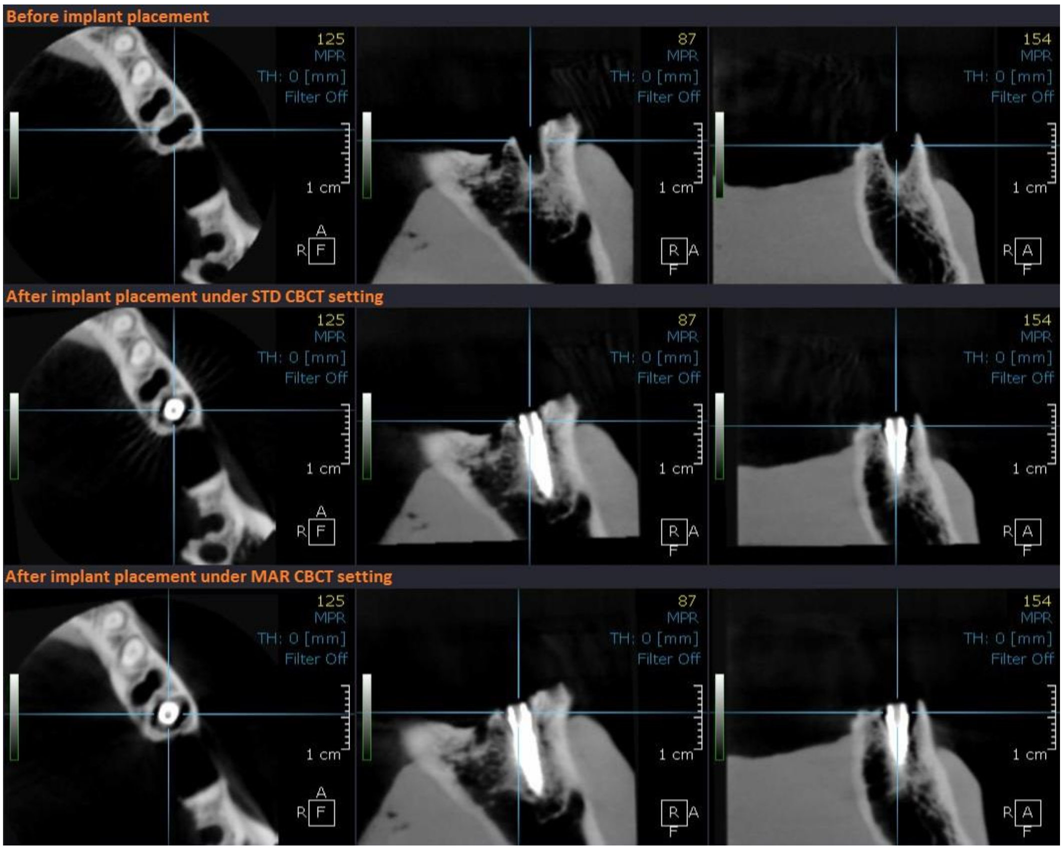


Figure 2–15. CBCT images of the dry mandible without implant, and with implant under STD and MAR settings.

Three CBCT data sets of the dry mandible were superimposed to guarantee the measurements taken on the same position of different data sets. The measurement steps used to determine the target images for bone changes assessment were same as those mentioned in section 2.2.2 above. Figure 2–16 showed the definition of measurement sections for bone thickness and height.

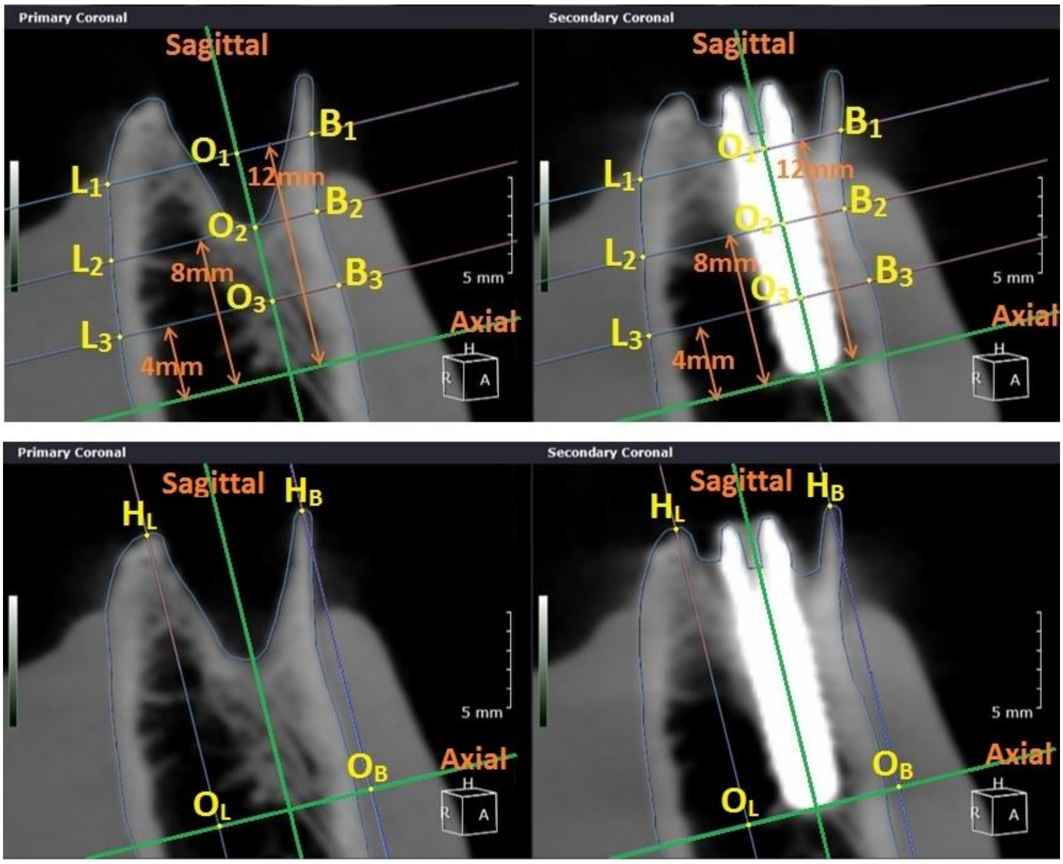


Figure 2–16. Measurement sections of bone thickness and height on the dry mandible with and without implant

All the three methods were applied and repeated three times to measure the bone changes on the images with and without implant once a week. Since this is a dry mandible, the bone changes on each measurement section should be zero. Any value of ΔL_1O_1, ΔL_2O_2, ΔL_3O_3, ΔB_1O_1, ΔB_2O_2, ΔB_3O_3, ΔH_L and ΔH_B indicated the error of measurement strategy.

2.2.3.2 Measurement of diameter of implant image

Furthermore, CBCT images of the dry mandible with implant were taken under four combinations of CBCT parameter settings (Figure 2–17). They were selected in low resolution (0.20 mm) and high resolution (0.12 mm); standard (STD) setting and metal artifact reduction (MAR) setting. Three scans were taken on each combination of settings.

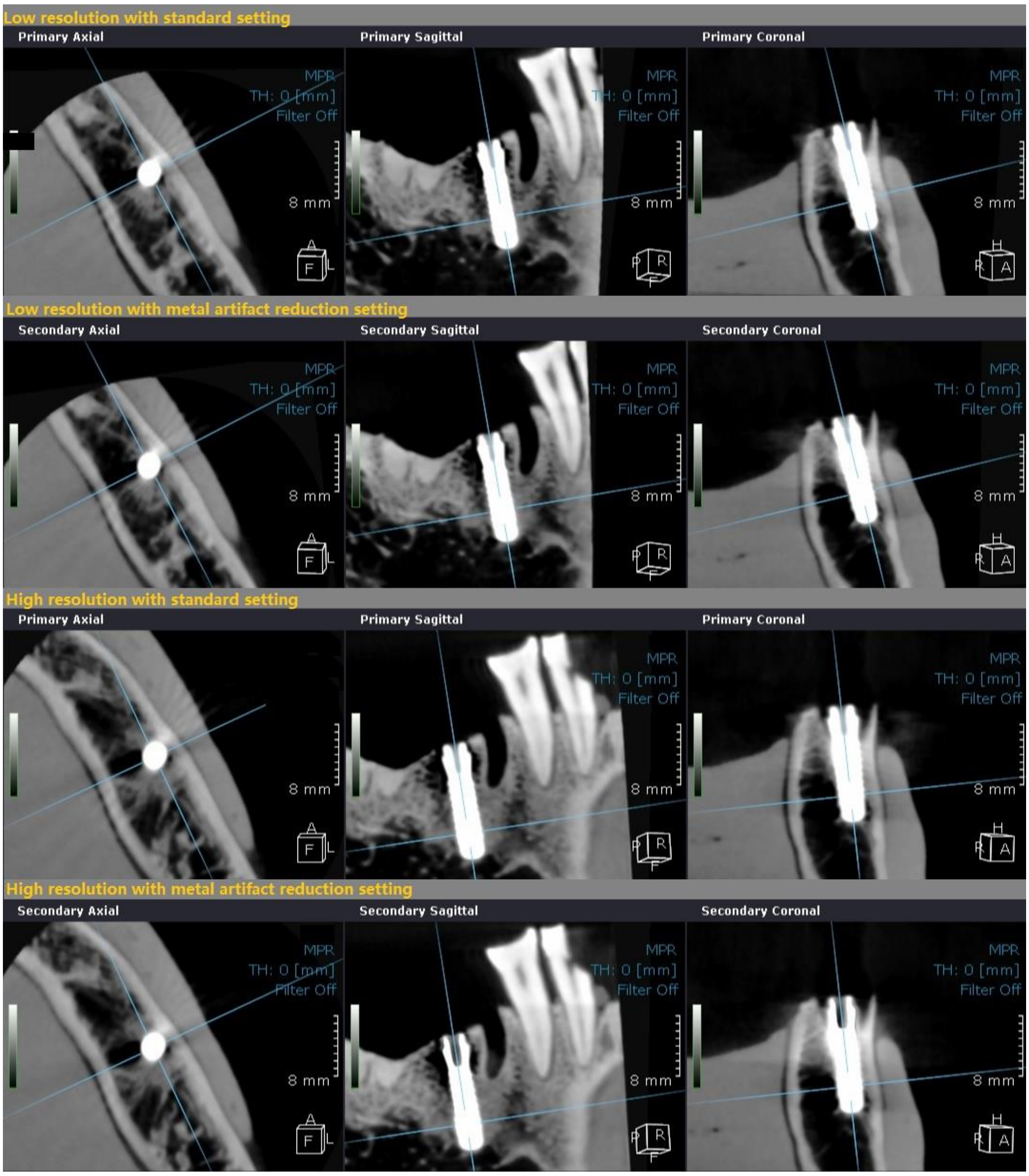


Figure 2–17. CBCT images of the implant under four settings: low resolution with STD setting, low resolution with MAR setting, high resolution with STD setting, and high resolution with MAR setting.

The measurement procedure followed the established steps as above. The difference here was to measure the implant body. Therefore, the direction of coronal plane was adjusted perpendicular to the edge of buccal bone. The direction of axial plane was then adjusted perpendicular to the centre axis of implant and crossed the bottom of implant. The direction of sagittal plane was perpendicular to axial plane automatically. The slice numbers and rotation degree of axial, sagittal and coronal planes were recorded for repeating measurements. The coronal plane was the target image for measurement.

The axial axis which crossed the bottom of implant was defined as the datum. The diameter of the implant was accessed on the position of 12, 8, and 4 mm coronal to the datum (Figure 2–18).

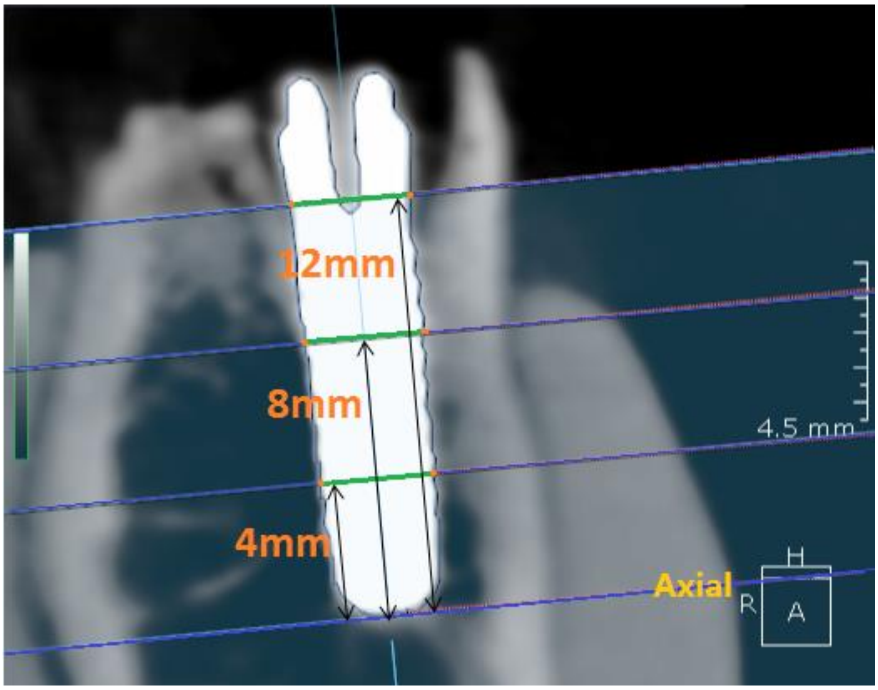


Figure 2–18. Measurement sections of implant diameter on 12, 8, and 4 mm coronal to the axial axis.

The method based on grey shade (Figure 2–19), method based on grey value (Figure 2–20), and method combined grey shade and grey value (Figure 2–21), which were established to determine the intersection points for bone measurements, were also applied to identify the margin of implant on the image.

In the first method based on grey shade, the tool ‘area’ marked the outline of implant image and ‘ruler’ showed the implant diameter was 3.45 mm on the section 4 mm coronal to the datum (Figure 2–19).

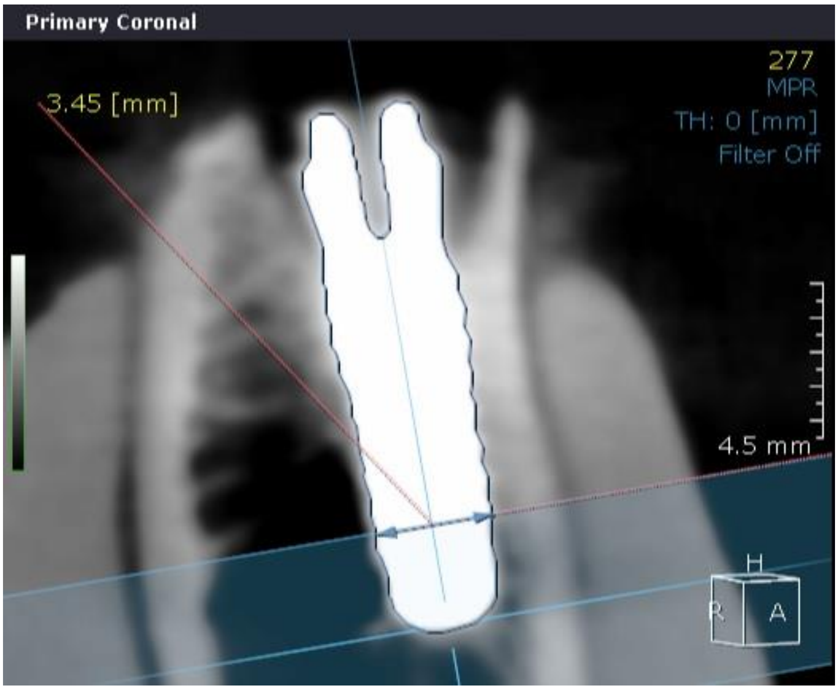


Figure 2–19. Based on grey shade, the implant diameter was 3.45 mm on the section 4 mm.

In the method based on grey value, the intensity value of implant margin need to be identified. Since there is thread on the surface of implant (outer diameter 3.3 mm and inner diameter 2.8 mm), the surface of implant should be mixed with sponge bone and metal. Therefore, the highest intensity value should be the image of implant main body and the first decreased ladder were used to determine implant margin (Figure 2–20).

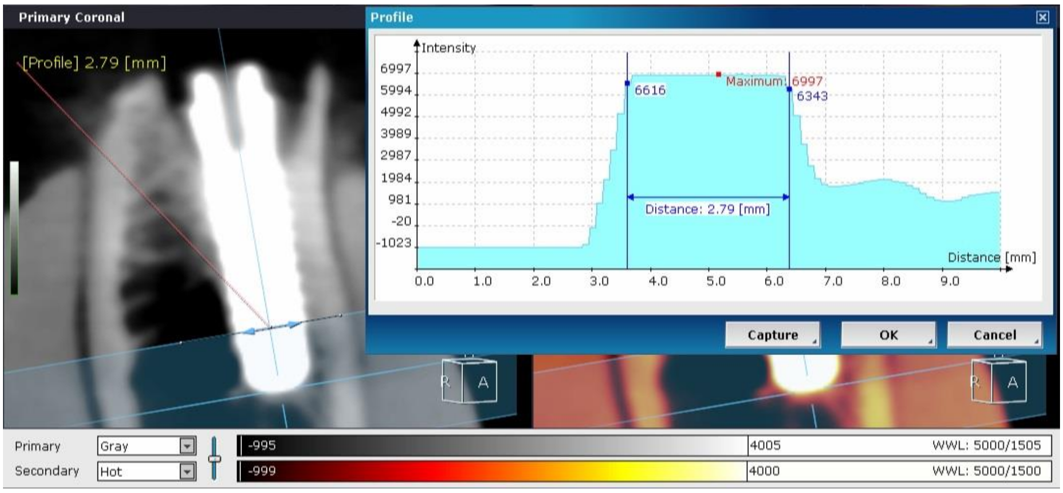
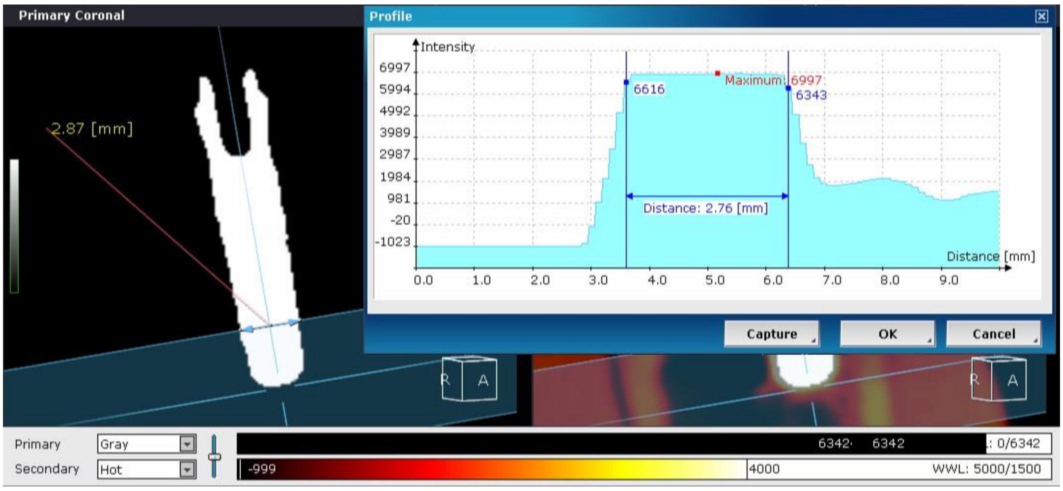


Figure 2–20. Tool ‘profile’ showed the implant diameter was 2.79 mm on the section 4 mm.

On the ‘profile’ graph, the ladder of 6616 intensity value was choose as the margin of implant image at lingual side and the ladder 6343 was that at buccal side. It showed the implant diameter was 2.79 mm on the section 4 mm coronal to the datum.

In the method of combined grey shade and grey value, there were two intersection points to be identified for each measurement section. In the example, 6615 intensity value was used to determine the intersection points at lingual side while 6342 was used to obtain the point at buccal side. Then the tool ‘ruler’ showed the distance between these two points was 2.87 mm (Figure 2–21).



Primary Gray
Secondary Hot

Figure 2–21. The value 2.87 mm was measured with method combined grey value and grey shade on the section 4 mm.

The same measurement procedures were done once a week and repeated 3 times on all CBCT data sets. The mean values of 3 reputations were used for analysis, which were compared with the true value of implant diameter that was between 2.8 mm (the inner shred diameter) to 3.3 mm (the outer shred diameter).

2.2.4 Statistical analysis

Statistical Package for Social Science software (SPSS, version 18.0) was used for statistical analysis. The function of General Linear Model (GLM) - Repeated Measures was used to evaluate the difference between low and high resolution, STD and MAR settings.

2.3 Results

2.3.1 Implant diameter assessment

Totally, 12 CBCT data sets of the implant were taken under 4 CBCT settings (low resolution STD, low resolution MAR, high resolution STD, high resolution MAR). Three CBCT data sets were scanned under each setting. And three repetition measurements were done to each CBCT data set. Table 2–1 and Table 2–2 showed the value of implant diameter on CBCT images from three times scanning under low resolution STD and MAR settings, while the results from high resolution STD and MAR settings were illustrated in Table 2–3 and Table 2–4.

Table 2–1. Value of implant diameters of three times measurements on three sections of implant CBCT images which were scanned under low resolution STD setting for three times.

Scan times Sections of measurement	1st scan					2nd scan					3rd scan				
	1st Measure (mm)	2nd Measure (mm)	3rd measure (mm)	Mean (mm)	SD (mm)	1st measure (mm)	2nd measure (mm)	3rd measure (mm)	Mean (mm)	SD (mm)	1st measure (mm)	2nd measure (mm)	3rd measure (mm)	Mean (mm)	SD (mm)
Grey shade															
4	3.34	3.28	3.48	3.37	0.10	3.42	3.24	3.30	3.32	0.09	3.21	3.39	3.24	3.28	0.10
8	3.66	3.37	3.40	3.48	0.16	3.54	3.47	3.26	3.42	0.15	3.56	3.32	3.40	3.43	0.12
12	3.98	3.80	3.86	3.88	0.09	3.91	3.82	4.04	3.92	0.11	3.84	4.01	3.88	3.91	0.09
Grey value															
4	2.66	2.80	2.76	2.74	0.07	2.68	2.66	2.76	2.70	0.05	2.74	2.76	2.63	2.71	0.07
8	2.80	2.96	2.90	2.89	0.08	2.88	2.86	3.02	2.92	0.09	2.88	2.88	3.04	2.93	0.09
12	3.24	3.22	3.14	3.20	0.05	3.10	3.12	3.24	3.15	0.07	3.18	3.26	3.12	3.19	0.07
Combined grey shade and grey value															
4	3.00	3.00	3.08	3.03	0.05	3.06	2.99	3.01	3.02	0.04	2.99	3.06	3.00	3.02	0.04
8	2.84	2.84	2.96	2.88	0.07	2.92	2.92	2.86	2.90	0.04	2.84	2.94	2.96	2.91	0.06
12	3.30	3.33	3.26	3.30	0.04	3.35	3.34	3.28	3.32	0.04	3.26	3.34	3.26	3.29	0.05

Table 2–2. Value of implant diameters of three times measurements on three sections of implant CBCT images which were scanned under low resolution MAR setting for three times.

Scan times / Sections of measurement	1^{st} scan					2^{nd} scan					3^{rd} scan				
	1^{st} Measure (mm)	2^{nd} Measure (mm)	3^{rd} measure (mm)	Mean (mm)	SD (mm)	1^{st} measure (mm)	2^{nd} measure (mm)	3^{rd} measure (mm)	Mean (mm)	SD (mm)	1^{st} measure (mm)	2^{nd} measure (mm)	3^{rd} measure (mm)	Mean (mm)	SD (mm)
Grey shade															
4	3.28	3.26	3.4	3.31	0.08	3.36	3.28	3.41	3.35	0.07	3.40	3.31	3.37	3.36	0.05
8	3.59	3.48	3.38	3.48	0.11	3.53	3.4	3.34	3.42	0.10	3.58	3.36	3.45	3.46	0.11
12	3.93	4.11	4.10	4.05	0.10	3.95	4.13	4.13	4.07	0.10	3.96	4.04	4.14	4.05	0.09
Grey value															
4	3.08	2.94	3.02	3.01	0.07	2.94	3.06	3.05	3.02	0.07	2.96	3.08	3.09	3.04	0.07
8	2.71	2.89	2.79	2.80	0.09	2.70	2.80	2.76	2.75	0.05	2.79	2.71	2.80	2.77	0.05
12	3.22	3.36	3.28	3.29	0.07	3.26	3.32	3.16	3.25	0.08	3.29	3.16	3.34	3.26	0.09
Combined grey shade and grey value															
4	3.00	2.88	2.90	2.93	0.06	2.99	2.98	2.88	2.95	0.06	2.88	2.86	2.96	2.90	0.05
8	3.14	3.05	2.98	3.06	0.08	3.05	3.09	3.02	3.05	0.04	3.00	2.98	3.07	3.02	0.05
12	3.28	3.36	3.24	3.29	0.06	3.30	3.31	3.22	3.28	0.05	3.22	3.38	3.26	3.29	0.08

Table 2–3. Value of implant diameters of three times measurements on three sections of implant CBCT images which were scanned under high resolution STD setting for three times.

Scan times	1st scan					2nd scan					3rd scan				
Sections of measurement	1st Measure (mm)	2nd Measure (mm)	3rd measure (mm)	Mean (mm)	SD (mm)	1st measure (mm)	2nd measure (mm)	3rd measure (mm)	Mean (mm)	SD (mm)	1st measure (mm)	2nd measure (mm)	3rd measure (mm)	Mean (mm)	SD (mm)
Grey shade															
4	3.46	3.34	3.54	3.45	0.10	3.53	3.49	3.4	3.47	0.07	3.47	3.54	3.30	3.44	0.12
8	3.70	3.49	3.7	3.63	0.12	3.74	3.5	3.69	3.64	0.13	3.56	3.78	3.70	3.68	0.11
12	4.24	4.18	4.00	4.14	0.13	4.26	4.20	4.00	4.15	0.14	4.26	4.20	4.08	4.18	0.09
Grey value															
4	2.90	3.08	2.98	2.99	0.09	2.92	2.88	2.94	2.91	0.03	2.94	2.87	3.00	2.94	0.07
8	2.92	2.94	3.04	2.97	0.06	2.92	3.06	2.99	2.99	0.07	2.94	3.02	3.10	3.02	0.08
12	3.20	3.22	3.11	3.18	0.06	3.20	3.12	3.23	3.18	0.06	3.29	3.18	3.12	3.20	0.09
Combined grey shade and grey value															
4	2.94	3.06	3.05	3.02	0.07	2.96	3.06	2.96	2.99	0.06	2.96	3.12	3.06	3.05	0.08
8	3.02	3.05	3.07	3.05	0.03	3.04	3.16	3.04	3.08	0.07	3.07	3.02	3.07	3.05	0.03
12	3.33	3.28	3.23	3.28	0.05	3.32	3.23	3.34	3.30	0.06	3.23	3.26	3.30	3.26	0.04

Table 2–4. Value of implant diameters of three times measurements on three sections of implant CBCT images which were scanned under high resolution MAR setting for three times.

Scan times / Sections of measurement	1st scan					2nd scan					3rd scan				
	1st Measure (mm)	2nd Measure (mm)	3rd measure (mm)	Mean (mm)	SD (mm)	1st measure (mm)	2nd measure (mm)	3rd measure (mm)	Mean (mm)	SD (mm)	1st measure (mm)	2nd measure (mm)	3rd measure (mm)	Mean (mm)	SD (mm)
Grey shade															
4	3.36	3.28	3.45	3.36	0.09	3.46	3.26	3.30	3.34	0.11	3.45	3.42	3.28	3.38	0.09
8	3.60	3.42	3.38	3.47	0.12	3.56	3.46	3.34	3.45	0.11	3.39	3.60	3.54	3.51	0.11
12	3.90	3.72	3.75	3.79	0.10	3.96	3.72	3.79	3.82	0.12	3.72	3.80	3.96	3.83	0.12
Grey value															
4	2.80	2.66	2.84	2.77	0.10	2.78	2.84	2.88	2.83	0.05	2.83	2.69	2.82	2.78	0.08
8	2.68	2.68	2.83	2.73	0.09	2.76	2.78	2.91	2.82	0.08	2.70	2.68	2.83	2.74	0.08
12	2.94	2.93	3.04	2.97	0.06	2.93	2.86	3.03	2.94	0.09	2.88	2.98	3.01	2.96	0.07
Combined grey shade and grey value															
4	3.07	3.02	3.01	3.03	0.03	3.03	3.02	2.99	3.01	0.02	3.00	3.00	3.04	3.01	0.02
8	2.89	2.78	2.89	2.85	0.06	2.80	2.86	2.98	2.88	0.09	2.90	2.90	2.82	2.87	0.05
12	3.07	3.14	3.01	3.07	0.07	2.98	2.98	3.12	3.03	0.08	3.12	3.04	2.98	3.05	0.07

The mean value and standard deviation (SD) of the implant diameter measured by three methods under each CBCT setting were shown in Table 2–5.

Table 2–5. Mean value of diameters and SD on three sections of implant images measured by methods based on grey shade, grey value and combined grey shade and grey value under four CBCT settings.

Method / Sections	Grey shade		Grey value		Combined grey shade and grey value	
	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)
Low resolution STD						
4	3.32	0.09	2.72	0.06	3.02	0.04
8	3.44	0.13	2.91	0.08	2.90	0.05
12	3.90	0.09	3.18	0.06	3.30	0.04
Low resolution MAR						
4	3.34	0.06	3.02	0.06	2.93	0.06
8	3.46	0.09	2.77	0.06	3.04	0.05
12	4.05	0.09	3.27	0.07	3.29	0.06
High resolution STD						
4	3.45	0.09	2.95	0.07	3.02	0.06
8	3.65	0.11	2.99	0.07	3.06	0.04
12	4.16	0.11	3.19	0.06	3.28	0.04
High resolution MAR						
4	3.36	0.08	2.79	0.07	3.02	0.02
8	3.48	0.10	2.76	0.08	2.87	0.06
12	3.81	0.10	2.96	0.06	3.05	0.07

Figure 2–22 compared the mean value of implant diameter among three methods and four CBCT settings, while Figure 2–23 compared the SD of three times measurements among three methods. Four curved lines represent four different CBCT settings when taking the CBCT scans, three values are the measurement of the diameters at three sections along the implant, and the two dotted horizontal lines are the inner (2.8 mm) and outer (3.3 mm) diameters of

the thread along the implant. The diameters at each measurement sections of the three could be landed at any positions of the thread, however the diameter value has to be within the inner and outer diameter of the thread.

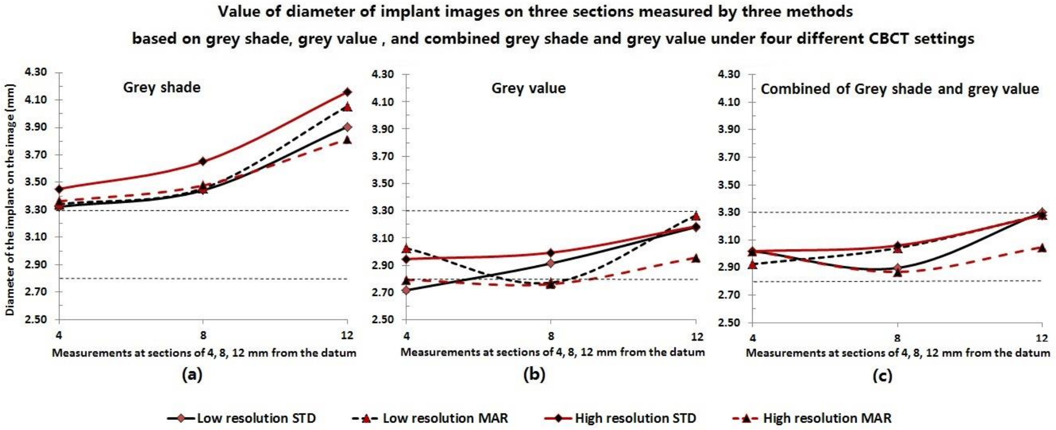


Figure 2–22. The measurements of the combination method (c) under four CBCT settings were the best method with smallest measurement deviation compared to the other two methods.

The results clearly exhibited that the measurement method of combined grey shade and grey value was the most accurate one as shown in Figure 2–22 (c). All of the measurements at three sections along the entire implant are within the bandwidth of the implant dimensions.

It also showed that the method based on grey value was better than grey shade. Only four values of diameter measured by grey value were slightly smaller than 2.80 mm, while other values were within the bandwidth. On section 4 mm, the value was 2.72 mm under low resolution STD setting and 2.79 mm under high resolution MAR setting. On section 8 mm, it was 2.77 mm under low resolution MAR setting and 2.76 mm under high resolution MAR setting. However, all the values of diameter measured by the methods based grey shade were bigger than 3.30 mm, especially on the section 12 mm. The largest deviated value was 4.16 mm on section 12 mm under high resolution STD setting.

Compared the results of low resolution and high resolution settings, there is no significant difference in terms of measurements accuracy at each measurement section (*p>0.05*). However, it is noticeable that the measurement taken from the image with high resolution setting was worse than low resolution. The images with high resolution STD setting showed highest deviation when the diameter was measured by the method based on grey shade. The red full curve in Figure 2–22 (a) illustrated clearly. The accuracy of measurements was varied in different sections and worse results were obtained at 12 mm to the datum. But no obviously difference could be found among the results measured by grey shade from other three CBCT settings. Furthermore, there was also no significant difference could be concluded between the CBCT images with STD and MAR settings (*p>0.05*).

The reproducibility of three different measurement methods was related with the SD of the diameter values which was measured repeatedly for three times under each CBCT data setting. The SD values were from 0.024 mm to 0.127 mm on three sections of the images with different CBCT setting. Among three methods, the combined method (in green curve) relatively had the least SD at three measurement sections under each CBCT settings, except on section 12 mm with high resolution MAR setting. On this section 12 mm, the combined method showed SD of 0.07 mm, while SD of method based on grey value was 0.064 mm. Additionally, the SD of the grey shade method (in blue curve) was the largest at three measurement sections under each CBCT settings, except on section 4 mm with low resolution MAR setting (Figure 2–23). On this section 4 mm, the grey shade method showed SD of 0.06 mm, while SD of method based on grey value was 0.07 mm. In generally, method combined grey shade and grey value played best reproducibility than the other two methods.

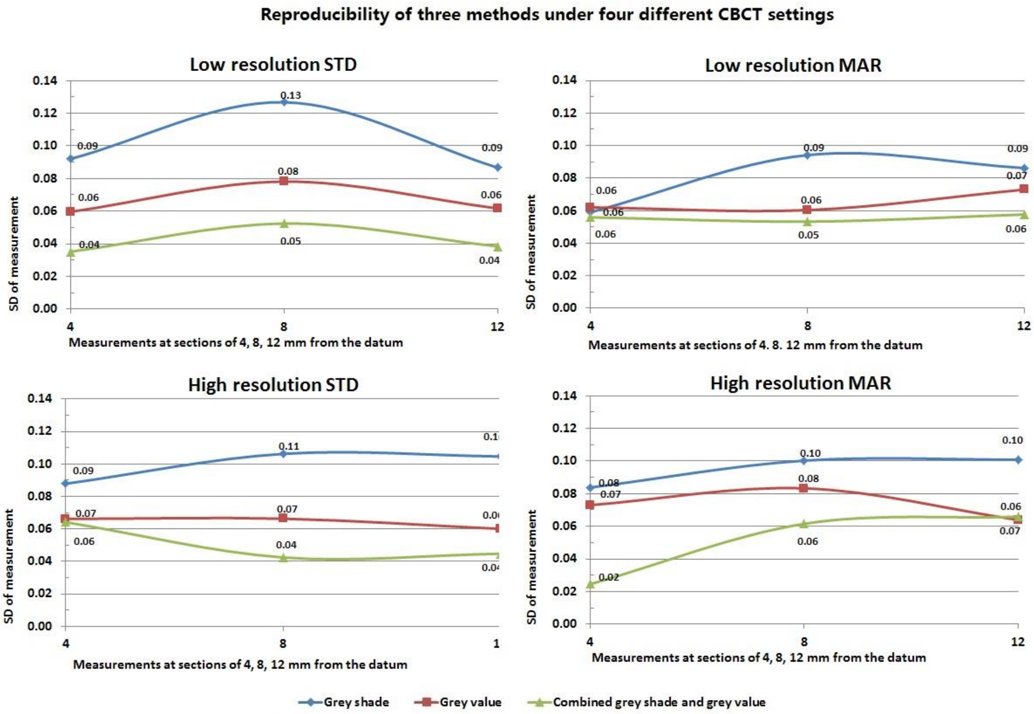


Figure 2–23. The combined method had the least SD at three measurement sections under four different CBCT settings.

2.3.2 Quantification of bone changes

2.3.2.1 Bone difference on the dry mandible with and without implant

The bone thickness and height on the CBCT images with and without the implant were compared under STD and MAR settings. And 3 repetition measurements were done to each CBCT data set. Table 2–6 showed the value, mean and SD of the bone changes.

Table 2–6. Value of bone change on each section of the images with and without implant measured by methods based on grey shade, grey value and combined grey shade and grey value under STD and MAR CBCT settings

	STD setting					MAR setting				
	1st Measure (mm)	2nd Measure (mm)	3rd measure (mm)	Mean (mm)	SD (mm)	1st Measure (mm)	2nd Measure (mm)	3rd measure (mm)	Mean (mm)	SD (mm)
Grey shade										
ΔL_1O_1	-0.01	0.05	0.09	0.04	0.05	-0.01	-0.04	0.00	-0.02	0.02
ΔL_2O_2	0.03	-0.04	0.06	0.02	0.05	0.08	0.01	-0.06	0.01	0.07
ΔL_3O_3	0.04	-0.04	0.06	0.02	0.05	-0.04	-0.05	0.03	-0.02	0.04
ΔB_1O_1	-0.04	0.01	0.03	0.00	0.04	-0.05	-0.05	0.01	-0.03	0.04
ΔB_2O_2	0.07	0.00	0.00	0.02	0.04	-0.04	-0.07	0.07	-0.01	0.07
ΔB_3O_3	0.04	0.06	0.05	0.05	0.01	-0.06	0.12	0.07	0.04	0.09
ΔH_L	0.01	0.03	-0.09	-0.02	0.06	0.02	-0.02	-0.07	-0.02	0.05
ΔH_B	-0.06	0.01	0.05	0.00	0.06	-0.08	0.01	-0.07	-0.05	0.05
Grey value										
ΔL_1O_1	-0.07	0.03	0.00	-0.01	0.05	-0.01	-0.08	0.04	-0.02	0.06
ΔL_2O_2	0.11	0.02	0.00	0.04	0.06	-0.06	0.03	0.03	0.00	0.05
ΔL_3O_3	-0.08	0.09	0.05	0.02	0.09	-0.03	0.09	0.03	0.03	0.06
ΔB_1O_1	-0.07	-0.09	-0.03	-0.06	0.03	-0.10	0.03	-0.10	-0.06	0.08
ΔB_2O_2	0.15	-0.16	0.15	0.05	0.18	-0.03	0.06	-0.05	-0.01	0.06
ΔB_3O_3	0.06	-0.01	-0.09	-0.01	0.08	0.06	-0.01	0.01	0.02	0.04
ΔH_L	-0.04	-0.03	0.03	-0.01	0.04	-0.09	-0.11	-0.09	-0.10	0.01
ΔH_B	0.02	0.12	-0.03	0.04	0.08	0.07	-0.01	0.10	0.05	0.06
Combined grey shade with grey value										
ΔL_1O_1	0.01	0.01	-0.05	-0.01	0.04	-0.05	-0.05	0.04	-0.02	0.05
ΔL_2O_2	0.02	0.01	0.00	0.01	0.01	0.05	0.03	-0.03	0.02	0.04
ΔL_3O_3	0.02	0.01	0.03	0.02	0.01	0.02	-0.04	0.04	0.01	0.04
ΔB_1O_1	0.01	0.02	-0.02	0.00	0.02	-0.02	-0.01	-0.01	-0.01	0.01
ΔB_2O_2	0.02	-0.04	0.04	0.01	0.04	-0.05	-0.06	-0.06	-0.06	0.01
ΔB_3O_3	0.01	0.01	-0.04	-0.01	0.03	-0.01	0.03	0.02	0.01	0.02
ΔH_L	-0.04	0.01	-0.04	-0.02	0.03	-0.02	0.04	0.02	0.01	0.03
ΔH_B	0.03	-0.02	0.05	0.02	0.04	0.04	0.05	-0.04	0.02	0.05

The mean value of bone changes at each section measured by three methods were between -0.06 mm to 0.05 mm under STD and MAR settings (Figure 2–24).

And, there was no significant difference in measurement precision could be concluded between STD and MAR CBCT settings at each measurement section (*p>0.05*).

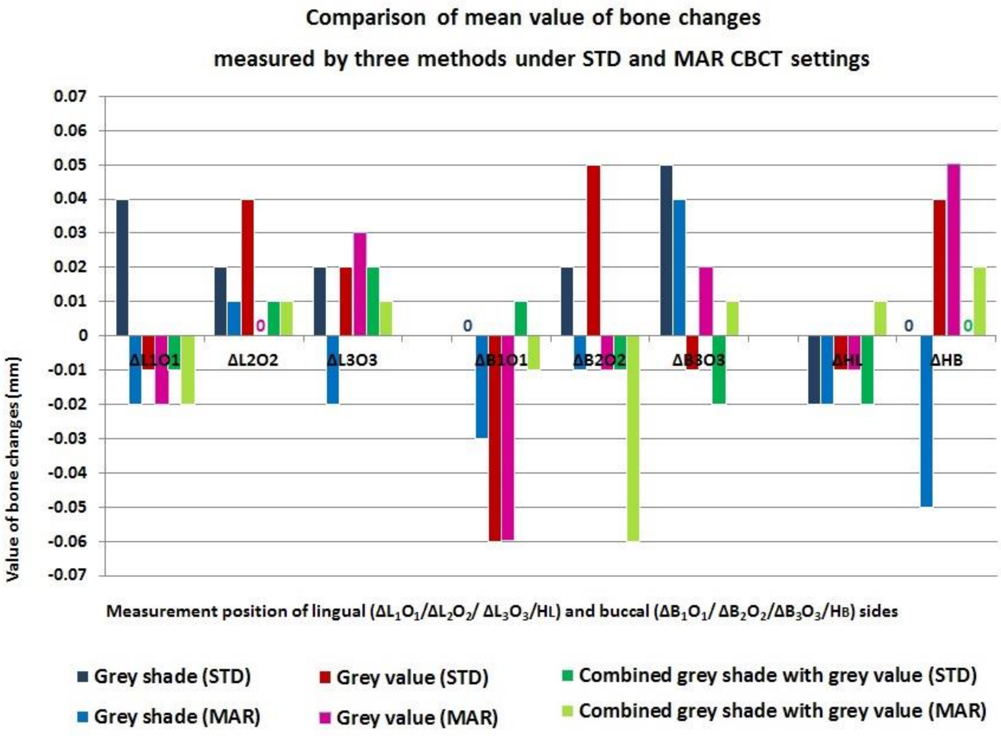


Figure 2–24. The bone changes in thickness and height measured by three methods were between -0.06 mm to 0.05 mm under STD and MAR CBCT settings.

The results of reproducibility of measuring bone changes from three measurement methods is shown in Figure 2–25, that the combined method had the best reproducibility at most measurement sections. The largest error was still measured by the grey shade method. This was same as the results of measuring implant diameter.

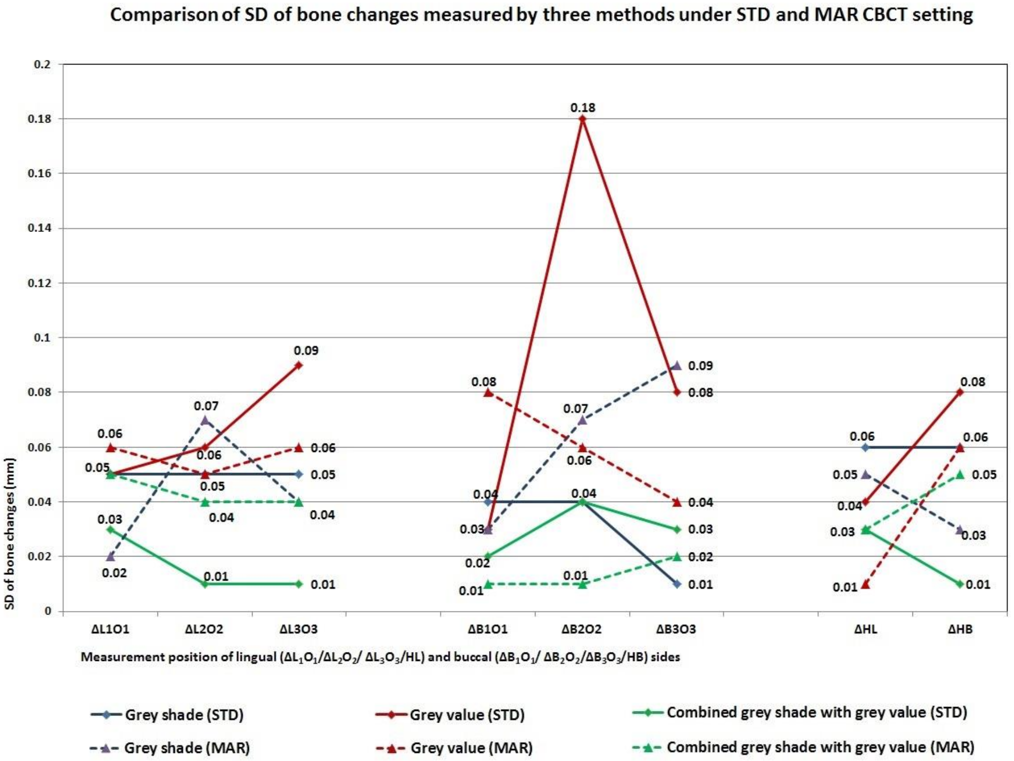


Figure 2–25. The combined method had the least SD at most measurement sections under STD and MAR CBCT settings.

As it was knew that the bone changes of the dry scull were zero on all sections, therefore the error of the measurement strategy based on combining grey shade and grey value was the maximum value of the difference between the measurement value and the true value, –0.06 mm. This error was the sum of the every error on the measurement chain through the complete measurement procedure, of taking CBCT, Dicom data reconstruction, paired CBCT images registration, boundary identification and measurements of thickness and height, and the measurement uncertainty was the maximum value of the standard deviation ±0.05 mm.

2.3.2.2 Bone changes of the clinical case

Although the reproducibility and precision had been tested on the simulation model, the real clinical cases was differ to the dry mandible, due to the alveolar bone surrounding with soft tissue and more artifact caused by dental crown. Therefore the reproducibility was tested further on the clinical case.

Table 2–7 showed the results of bone thickness and height measured with three methods on each defined sections of CBCT images scanned before implantation and one year after implantation. Each method was done three times.

Figure 2–26 compared the results of bone thickness among three methods, while Figure 2–27 provided the comparison for bone height. Both Figures showed the value measured by method based on grey shade was biggest on each measurement section and that measured by method based on grey value was the smallest among three methods.

Table 2–7. The results of bone thickness and height measured with three methods on each section of CBCT images scanned before and one year after implant placement

Method Sections of measurement	Grey shade					Grey value					Combined grey shade and grey value				
	1st Measure (mm)	2nd Measure (mm)	3rd measure (mm)	Mean (mm)	SD (mm)	1st measure (mm)	2nd measure (mm)	3rd measure (mm)	Mean (mm)	SD (mm)	1st measure (mm)	2nd measure (mm)	3rd measure (mm)	Mean (mm)	SD (mm)
Before implant placement															
L_1O_1	4.14	4.20	4.12	4.15	0.04	4.08	4.04	4.04	4.05	0.02	4.12	4.10	4.08	4.10	0.02
L_2O_2	5.26	5.17	5.11	5.18	0.08	5.03	5.06	5.10	5.06	0.04	5.16	5.17	5.12	5.15	0.03
L_3O_3	7.82	7.82	7.74	7.79	0.05	7.74	7.70	7.69	7.71	0.03	7.77	7.76	7.80	7.78	0.02
B_1O_1	4.73	4.91	4.83	4.82	0.09	4.60	4.70	4.68	4.66	0.05	4.70	4.70	4.65	4.68	0.03
B_2O_2	5.31	5.47	5.32	5.37	0.09	5.25	5.20	5.28	5.24	0.04	5.29	5.31	5.25	5.28	0.03
B_3O_3	7.96	8.09	8.07	8.04	0.07	7.80	7.89	7.92	7.87	0.06	7.86	7.90	7.96	7.91	0.05
H_L	12.73	12.70	12.83	12.75	0.07	12.67	12.60	12.70	12.66	0.05	12.70	12.67	12.74	12.70	0.04
H_B	13.60	13.73	13.70	13.68	0.07	13.55	13.59	13.49	13.54	0.05	13.57	13.60	13.62	13.60	0.03
One year after implant placement															
L_1O_1	3.67	3.73	3.56	3.65	0.09	3.40	3.49	3.52	3.47	0.06	3.59	3.54	3.63	3.59	0.05
L_2O_2	5.09	5.11	5.01	5.07	0.05	5.02	4.89	5.01	4.97	0.07	5.10	5.04	5.05	5.06	0.03
L_3O_3	7.82	7.70	7.68	7.73	0.08	7.69	7.62	7.65	7.65	0.04	7.70	7.71	7.74	7.72	0.02
B_1O_1	3.80	4.05	3.95	3.93	0.13	3.68	3.90	3.80	3.79	0.11	3.92	3.83	3.79	3.85	0.07
B_2O_2	5.20	5.32	5.19	5.24	0.07	5.18	5.16	5.12	5.15	0.03	5.18	5.24	5.18	5.20	0.04
B_3O_3	7.94	8.02	8.04	8.00	0.05	7.80	7.82	7.90	7.84	0.05	7.83	7.88	7.92	7.88	0.05
H_L	12.49	12.36	12.53	12.46	0.09	12.26	12.33	12.36	12.32	0.05	12.40	12.36	12.45	12.40	0.05
H_B	12.50	12.58	12.39	12.49	0.09	12.26	12.43	12.30	12.33	0.09	12.46	12.40	12.35	12.40	0.06

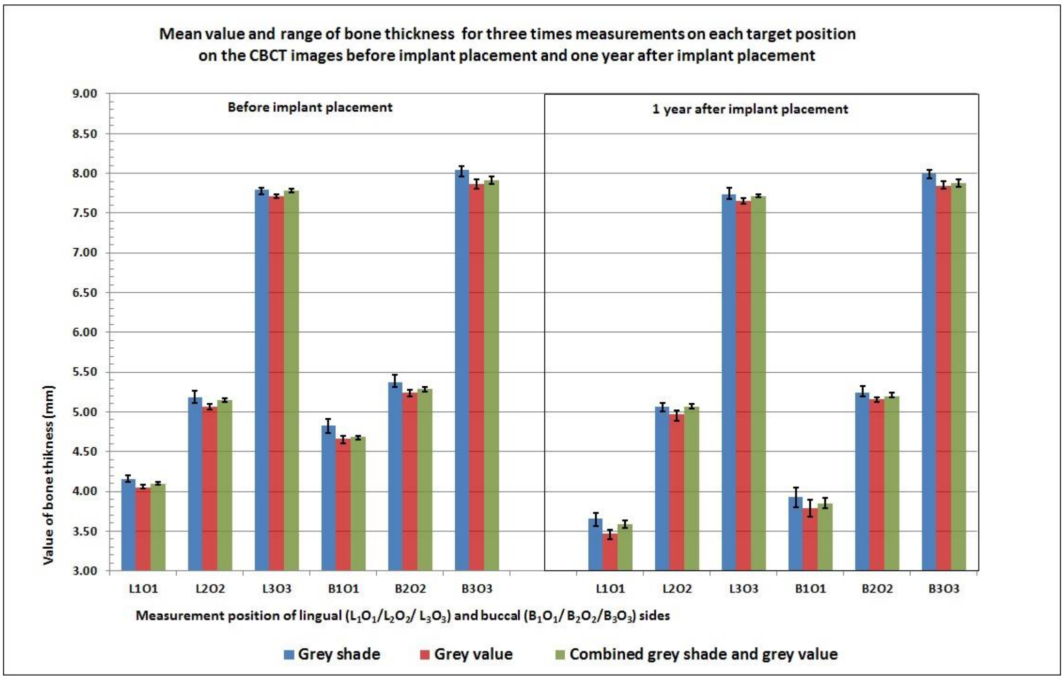


Figure 2–26. **Mean value and range of the bone thicknesses measured three times with methods based on grey shade, grey value, and combined grey shade and grey value.**

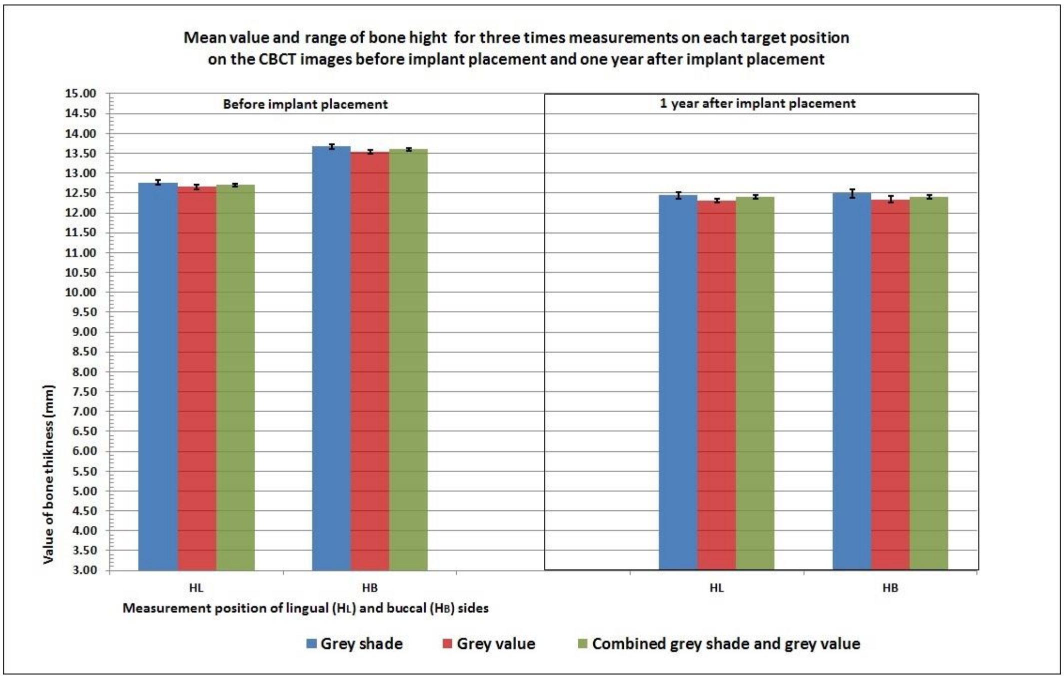


Figure 2–27. **Mean value and range of the bone height measured three times with methods based on grey shade, grey value, and combined grey shade and grey value.**

The SD of each method was showed in Figure 2–28. That the methods based on the combination of grey shade and grey value showed a least measurement deviation of three repeated measurements in both pre- and post- implantation images, except on the B_2O_2 section of image after implant placement. On this section, SD of method based on grey value was 0.031 mm and it was 0.035 mm for the combined method.

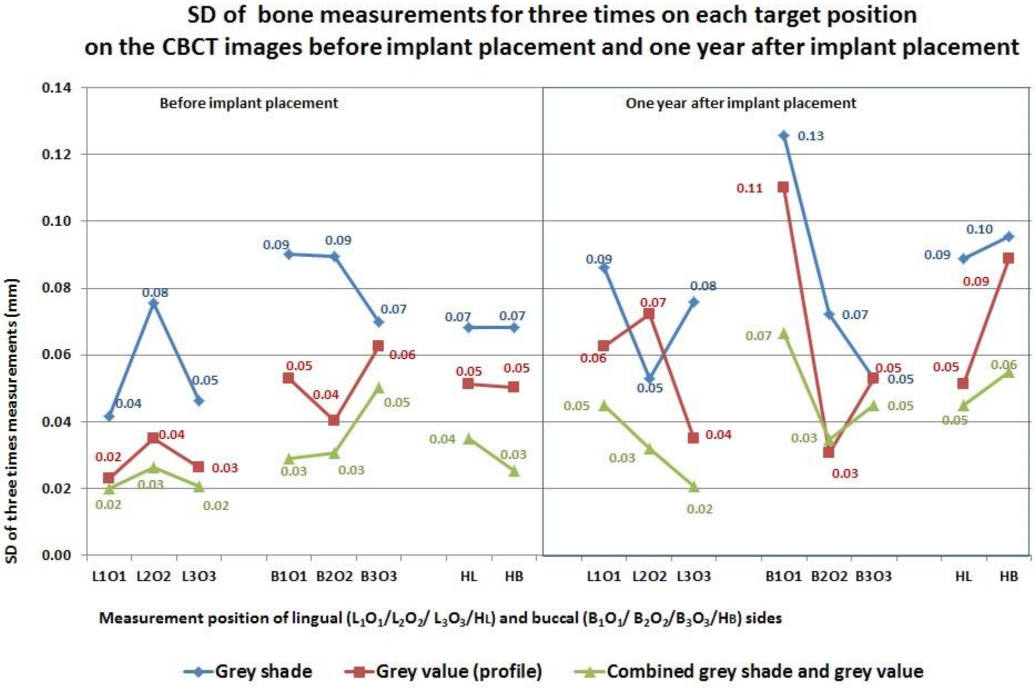


Figure 2–28. The combined method had the least SD at each measurement sections on both pre- and post- implant placement CBCT images.

Additionally, compared the values between the image before and after implant placement, in generally, the values of SD on pre- implantation image were smaller than those on post- implantation image. On the pre- implantation image, the SD value was random distribution among all those measurement sections. But, on the post- implantation image, the most distinct deviation happened on B_1O_1 section where the bone was thin and easily influenced by the metal artifact.

So, the method combined grey shade and grey value showed highest reproducibility, which was the same as the results from the dry mandible and implant diameter measurement. And the results of measuring dry mandible also indicated that the methods combined grey shade and grey value showed least measurement error and uncertainty. Therefore, according to the results measured by the combined method, the mean values of bone changes in thickness at lingual side were ΔL_1O1, ΔL_2O_2, ΔL_3O_3 as -0.51 mm, -0.09 mm, -0.06 mm, while those at buccal side were ΔB_1O_1, ΔB_2O_2, ΔB_3O_3 as -0.84 mm, -0.08 mm, -0.03 mm respectively. And the values of bone changes in height were -0.30 mm at ΔH_L and -1.20 mm at ΔH_B.

2.4 Discussion

2.4.1 Strengths and weakness of the measurement strategy

The comparative 3-D measurement of bone changes related to dental implant based on the CBCT has several challenges: (1) the quality of CBCT images, particularly if metal artifact was involved from implant or metal filling materials; (2) the measurements need to be taken at the same position with the same orientation between two images taken at the different time points; (3) the identification of the boundary of the cortical bone where the measurements took place. Several studies of the measurements of the bone thickness around dental implant based on CBCT images were published (Degidi et al. 2012, Roe et al. 2012, Vera et al. 2012). However, those measurements were embedded with limitations of metal artifacts, due to the measurements were relayed on the identification of bone margin of the outer contour of implant where it is inevitably influenced by the distortion, moreover the measurements were based on the grey shade for the definition of the cortical bone margin, this again brought the subjective element of examiner’s judgment and lead to an less reproducible results. And no report in any of the publications had studied measurement accuracy and uncertainty. Therefore it was impossible to work out the measurement error within the reported results.

The measurement strategy established from this study has improved measurement accuracy and reproducibility in two aspects. One is obviated the metal artifact by avoided the measurement at the edge of the implant where the metal artifact took place; the other increased the accuracy and reproducibility of the identification of the boundary of alveolar bone from the surrounding tissues.

The first part of the measurement strategy was superimposing paired CBCT data sets which could ensure the bone measurement done on the same position of alveolar bone. This made the comparison in time feasibly and the subtracted value of pre- and post- implant placement satisfyingly demonstrated the exact value of bone changes on each defined measurement section.

The second part focused on shifting the axes of paired CBCT data sets to the same position and direction. All slice number and rotated degree of three axes were recorded. Then the axes on the target paired coronal images were used as the reference line and datum to define the bone thickness and height. Because the metal artefact of the titanium dental implant makes the bone-to-implant boundary distorted. It is not accurate to perform measurements from implant surface to outer contour of the bone (Parsa et al. 2014). The definition of the measurement sections avoided any part of anatomical structure images and implant image which were lack of sharpness or influenced by artifact. Therefore, it not only made repetition and comparison of the measurement position in time feasibly and more accurate, but also provided more precise value of the bone quantity around implant. This step was similar with the method used by Slagter et al. In their research, two different software were utilized to locate the central line of the implant which was set as the reference line to define the bone thickness and bypass the scattering area on bone-to-implant boundary (Slagter et al. 2015). The bone actual thickness of bone was the subtraction value of the know radius of implant. However, it was not longitudinal comparative measurements and no report on the measurement uncertainty. In present study, the similar step can be done by the software (OnDemand3D) and the reference lines were the sagittal and axial axes on the coronal images, which could provide simpler operation and higher measurement precision. Furthermore, only the actual values of bone changes would be the interest values to do the further data analysis for clinical trial.

The third part was about the identification of bone boundary. This was done and assessed with three different methods in order to achieve a high precision. The method based on grey shade was influenced by image contrast that could be adjusted by the operator. Therefore it depends upon the operator’s judgment and the measurement results were varied within different examiners. This was in lined with the results of this study that was illustrated as the worst reproducibility. And, it also gave out the worst results of the implant diameter. The method based on the grey value which eliminated operator dependency, but it was influenced by interval of the sampling, which appeared as steps in the grey value profile. If the resolution is 0.125 mm, through the image reconstruction procedure, the distance of each step would be 0.23 mm. Therefore, definition of the edge of the bone was possible to have an error up to 0.23 mm. In addition, the results of implant diameter revealed that this method tended to underestimate the real value.

With the method of combined grey shape and grey value, it eliminated the defects from both previous methods. By closing the window width to zero and modifying the window level according to the grey value at each measurement section could provide clear monochrome images for determine the edge of bone. Although it displayed best accuracy and reproducibility among three methods, it should be noted that the mean values of diameter on three sections of the images with 3 CBCT settings was from 2.87 mm to 3.30 mm by this combined method. The range was wide and indicted it was not properly to measure the bone thickness from the edge of implant to that of bone. It could be explained that metal artifact distorted the bone-to-implant boundary and the grey value intensity of implant edge couldn't be displayed precisely by tool 'profile' graph. However, the measurement of bone thickness and height displayed small SD of three repeated measurements on each section. It could be explained that the image of bone edge was away from the implant and less influenced by the scattering area.

It had to be noted that the accuracy assessment in this study was based on the simulation model which made in-house as close as possible to the real case for the measurements. However, it had its limit, particularly with the dimensional measurements of the implant. A small variation in the diameter of the implant was due to the randomization of the across-section allocation, and this variation was within a dimensional range between 2.8mm to 3.3mm. Strictly speaking, this was not good enough to be qualified as accuracy measurement. But it was the closest possible object which could be managed within this study. It would be much better if a simulation phantom could be developed to reflect the bone structure and the implant, in terms of materials (density), shapes and dimensions. Therefore the accuracy in each stage down the line could be tested, such as the accuracies of CBCT performance, software performance, and the performance of measurement strategy.

2.4.2 Quantification of bone changes related to dental implant

The bone difference on the CBCT image of the dry mandible with and without implant suggested that measurement error of the measurement strategy established was up to 0.06 mm and the measurement uncertainty was ±0.05mm, both on horizontal and vertical dimensions. This was in line with the study reported by Benninger et al (Benninger et al. 2012). They made the measurement of tooth dimensions using direct measurements on the extracted teeth and their CBCT images. The difference of two methods was 0.098±0.059mm in vertical dimension, 0.009±0.006 mm in the facial to lingual dimension, and 0.009±0.006mm in the mesial to distal dimension, resulted in no statistically significant difference in each dimension. While other studies reported the measurements got slightly higher error margins, such as Timock et al. measured buccal alveolar bone height and thickness from 65 teeth on CBCT (i-CAT, 0.3 mm voxel size) images of twelve embalmed cadaver heads and compared with direct measurements made by dissection (Timock et al. 2011). The mean absolute differences were 0.30 mm (range -0.77 mm to 0.81 mm) in buccal bone height and 0.13 mm (range -0.32 mm to 0.38 mm) in buccal bone thickness. The buccal bone height measurements were closer than buccal bone thickness measurements, and no significant difference between the results of two methods. Therefore they concluded CBCT could be used for buccal bone height and thickness measurements. And Moshfeghi et al. reported the mean differences between the two methods were 0.14±1.44 mm in the axial section and 0.02±1.4 mm in the coronal section with 0.15 resolution setting, when measured 22 anatomic landmarks in four dry human skulls using a digital caliper and CBCT images (Newtom VG) (Moshfeghi et al. 2012). No statistically significant difference was found between the two methods. Additionally, Kamburoğlu et al. made a further effort to investigate the reliability of CBCT images on a simulation models with cylindrical peri-implant defects prepared next to 69 implants which inserted into cadaver mandibles (Kamburoğlu et al. 2011). The measurement results were qualitative as defect were detected, almost detect, and not detect on CBCT images rather than quantitative. They concluded that the value of depth, width and volume of the peri-implant defects measured on various CBCT images were correlated highly with physical measurements (Kamburoğlu et al. 2014).

2.4.3 Issues about CBCT data settings

Several study suggested that better images could be obtained with metal artefact reduction setting, such as less streak-like artefacts and related shadows (Meilinger et al. 2011, Bechara et al. 2012). However, the result of implant images showed there was no difference between STD and MAR settings, which was similar to the research done by Sonoda et al. (Parsa et al. 2014, Sonoda et al. 2015). They said MAR setting did not performed better on scans of dental prostheses, especially in the area 1 cm from the edge of the implant.

Furthermore, there was no conclusion in measurement accuracy between low and high resolution setting in this study, although some study illustrated high resolution could lead to more accurate volumetric quantifications (Razavi et al. 2010, Maret et al. 2012, Ponder et al. 2013). In the researches carried out by Torres et al. and Hekmatian et al., they both stated that no significant differences of the mandibular thickness measurements could be found in using different voxel sizes (Moshfeghi et al. 2012, Torres et al. 2012, Hekmatian et al. 2014). And, it was suggested that it would be more reasonable to use 0.30 mm voxel size instead of 0.15 mm voxel size to avoid unnecessary radiation exposure, since there is no general protocol defined for CBCT examination of specific diagnostic tasks in dentistry (Moshfeghi et al. 2012, Spin-Neto et al. 2013a, Hekmatian et al. 2014).

The result of bone changes around immediate implant in the clinical case suggested that the height and thickness of bone decreased on both sides. No matter in horizontal or vertical dimension, the bone absorbed and more at buccal side. And the bone thickness decreased most obviously on L_1O_1 and B_1O_1 section. This was only data from one case and further study would be carried out with enough sample size. And the results of bone changes related to dental implant would be discussed and compared with previous researches in Chapter 3.

In conclusion, following all these steps of measurement strategy, a reproducible and precise measurement approach was clearly established. It provided qualified data in the quantification of bone changes related to implant placement based on 3D CBCT images. This measurement strategy could be applied to clinical researches to get valuable information of bone remodeling after dental implant placement.

3. An Investigation of Bone Changes in 44 Type 1 and 25 Type 4 Cases

3.1 Introduction

Type 1 implant placement protocol is the placement of an implant into a tooth socket synchronously with the tooth extraction, while Type 4 is placement of an implant into a fully healed ridge. The success rates of Type 1 and Type 4 are no difference according to many researches (Schwartz-Arad & Chaushu 1997, Chen et al. 2004, Penarrocha et al. 2004, Fugazzotto 2005, Quirynen et al. 2007, Esposito et al. 2010, Annibali et al. 2011).

It was suggested that Type 1 counteract the hard tissue resorption that occurs following tooth extraction (Denissen et al. 1993, Watzek et al. 1995, Wheeler et al. 2000, Botticelli et al. 2004a). Thus, if the implant is placed early during the socket healing process, one of potential advantages is that the amount of alveolar bone loss which occurs physiologically during the remodelling stage of the extraction socket might be reduced (Zitzmann et al. 1999, Block et al. 2009, 2009, Esposito et al. 2010). On contrary, several animal studies stated that Type 1 could lead the buccal socket wall underwent bone resorption appeared to be more pronounced at the implant sites than the site left to heal spontaneously (Araujo & Lindhe 2005, 2006a, 2006b, Vignoletti et al. 2012).

Besides, by clinical studies and reviews, there was no significant difference in the level of bone changes between Type 1 and Type 4 with delayed loading (Paolantonio et al. 2001, Schropp et al. 2003a, Lindeboom et al. 2006, Jaffin et al. 2007, Palattella et al. 2008, Block et al. 2009, Deng et al. 2010, Esposito et al. 2010, Pal et al. 2011, Heinemann et al. 2013, Esposito et al. 2015, Felice et al.

2015, Gomez-Roman & Launer 2016). In addition, several researches agreed mean crestal bone level was significant better in Type 1 than Type 4 at the time of 12 months after implantation with delayed loading (Kan et al. 2007, Raes et al. 2011, Kinaia et al. 2014).

Overall, although it has often been stated that one of the rationales of immediate implant placement is to prevent or at least minimize the bone loss hard at the extraction socket, there are controversies exist on this issue whether the different timings of implant placement after extraction may lead to various bone remodelling results.

In order to find out more evidence of bone changes after implant placement between Type 1 and Type 4, in this chapter, retrospective CBCT data sets from Type 1 and Type 4 cases were collected and the measurement appoach established in Chapter 2 was applied to assess the bone changes after implant placement.

3.2 Materials and methods

3.2.1 CBCT data sets recruitment criteria

Building on the collaboration between The Institute of Dentistry, QMUL and Shanghai 9th People’s Hospital, Shanghai, China, and an agreement was signed for exchange permitted research findings. This has made the usage of the CBCT data become ethical and possible.

This was a retrospective study, it was planned to collect CBCT data sets from CBCT database in Shanghai 9th People’s Hospital.

The inclusion criteria for data recruitment:

(1) From patients who were aged between 18 to 65 years old.

(2) From patients who received treatments for non-adjacent single-unit implant restoration at sites of premolar and molar within quarter dentition under Type 1 or Type 4 implant placement protocols in Oral and Maxillary Surgery Department.

(3) From patients who were requested two CBCT data sets under the same setting of CBCT machine (NewTom VG, 0.125 mm resolution) before October 2015, one before implant placement and the other one year after implant placement.

The excluded criteria for data recruitment:

(1) From patients who were smokers, have active periodontitis or systemic diseases.

(2) The image quality is poor for measurement such as serious artifacts that affecting measurements.

The corresponding medical records were obtained from the medical record database while each CBCT data set was collected.

3.2.2 Sample size

A sample size formula (Röhrig et al. 2010, Sakpal 2010) which used to calculate the appropriate sample size for comparing means in two independent groups was utilized.

$$\mathbf{N = 2\,(\,Z_{\alpha} + Z_{\beta}\,)^2 \,/\, (\,\Delta\,)^2}$$

In this formula, N is the sample size required in each group; $Z\alpha$ depends on level of significance, which is 1.96 for 5% level in this study. Z_{β} depends on power, which is 0.84 for 80% power; and Δ can be thought of as the standardized difference between two means, the magnitude of clinical difference of interest and the standard deviation are combined into a single quantity.

Numerous studies were published (Paolantonio et al. 2001, Schropp et al. 2003a, Lindeboom et al. 2006, Jaffin et al. 2007, Kan et al. 2007, Palattella et al. 2008, Block et al. 2009, Deng et al. 2010, Esposito et al. 2010, Pal et al. 2011, Raes et al. 2011, Heinemann et al. 2013, Kinaia et al. 2014, Esposito et al. 2015, Felice et al. 2015, Gomez-Roman & Launer 2016). in the dimensional changes of peri-implant bone between Type 1 and Type 4 over one year. Those reported changes were influenced multi-factorial, as there were no control in surgery site, loading time, evaluation time, and measurement position etc. It is difficult to select a value of the difference of bone changes between Type 1 and Type 4. In this study, the value powered as bone changes was based on a systematic review (Lang et al. 2012), which reported marginal bone loss generally less than 1 mm in the first year after implant placement. And based on this systematic review, Slagter et al. powered 0.9 mm to detect a difference of bone changes between Type 1 and Type 4 (Slagter et al. 2016). Therefore, 0.9 mm was powered to calculate to sample size in previous research as well, which gave out that N is 20.

3.2.3 Ethical clearance and data transfer

The ethical approval was issued by Ethics Committee of Shanghai 9th People’s Hospital affiliated to Shanghai Jiaotong University School of Medicine (2015/40) (Appendix 1).

Our research team had comprehensive discussion with the collaboration party (Oral and Maxillary Surgery Department, Shanghai 9th people’s hospital), regarding the usage of the CBCT data sets and the corresponding medical records. Due to the common interest from the both parties, an agreement was signed by both parties, that suitable CBCT data sets to the inclusion criterion would be shared for quantifying the dimensional change of the bones surrounding implant. This investigation aimed to understand the differences related to the implant operational protocol, in order to improve the quality of treatment and benefit the patients (Appendix 2).

The CBCT images were taken from a group of patients who were medically justified for taking CBCT as part of the treatment procedure. All of the CBCT data sets were encrypted into a removable hard disk from the CBCT database in Shanghai 9th People's Hospital and transferred to the password protected PC which would be used to carry out the bone measurement by the investigator. All the data sets were only accessible to the main investigator and the supervisor.

3.2.4 Measurement strategy

The measurement strategy established in Chapter 2 was utilized for the bone measurement. With *in vivo* cases, to provide more clinical relevant information, the measurement sections of bone thickness were slightly shifted based on the size of the implant.

The intersection points for bone thickness measurement were determined as follows:

First, the bottom of implant on the image should be detected, using the methods combined with grey shade and grey value which described on Chapter 2. In Chapter 2, the first decrease step was defined for the implant edge because of the threads on the implant surface. But on the bottom of implant there is no thread. So the highest ladder was marked as the edge of implant bottom. For example, the highest intensity of 2944 showed by tool ‘profile’ was marked as the edge of implant bottom (Figure 3–1).

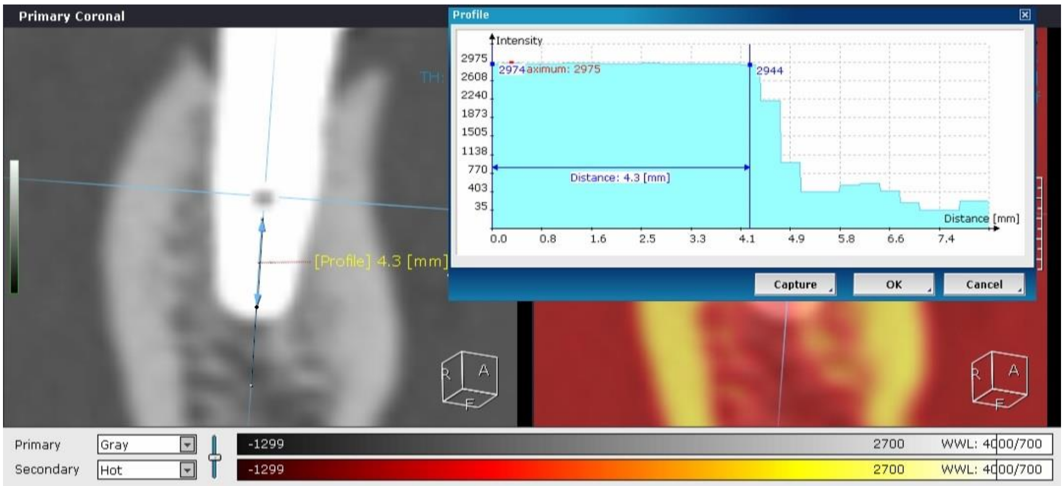


Figure 3–1. Tool ‘profile’ showed intensity of 2944 as the grey value intensity of implant bottom.

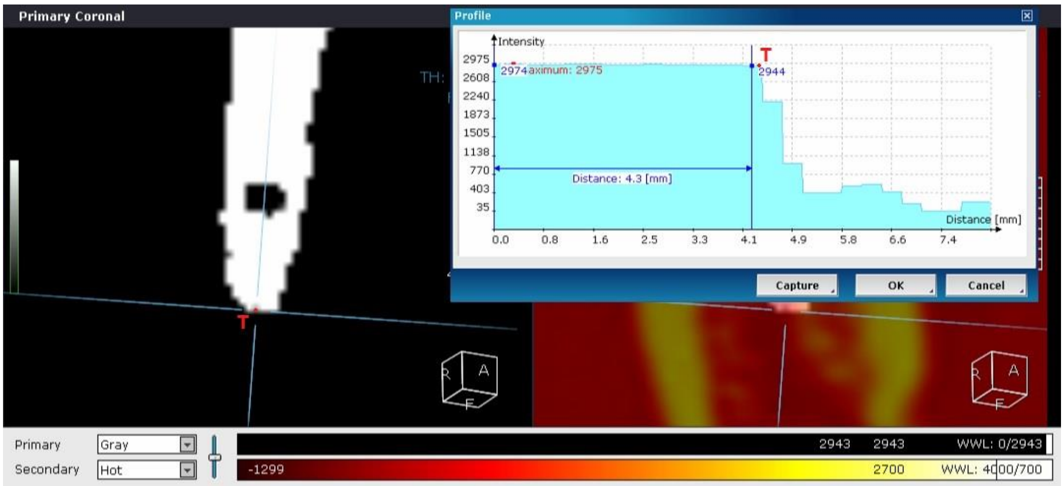


Figure 3–2. After closing window width to 0 and adjust window level to 2943, the image turned monochrome. Point ‘T’ was marked on sagittal axis as the implant bottom and the axial axis was shifted to across it.

Then, after closing window width to 0 and adjust window level to 2943, the image turned monochrome. The areas those intensity values were bigger than 2943 turned into white. Point ‘T’ was marked on sagittal axis as the implant bottom and the axial axis was shifted to across it (Figure 3–2).

Second, four parallel lines were drawn to the axial axis. The distance from the first line to the axial axes was the value of the implant length. For example, if the implant length was 13 mm, the first parallel line was 13 mm coronal to the axial axis. The second line was 1 mm below the first line, the third line was 3 mm below the second line, and the fourth line was also 3 mm below the third line. All the lines were across the sagittal axis and bone edge of lingual and buccal boundaries. The intersection points at buccal side were marked as B_0, B_1, B_2, B_3 (13, 12, 9, 6 mm coronal to the axial axis), while those at lingual side were L_0, L_1, L_2, L_3 and those on sagittal axis were O_0, O_1, O_2, O_3. The distances (B_0O_0, B_1O_1, B_2O_2, B_3O_3) between B_{0-3} and O_{0-3} were defined as the bone thicknesses at buccal side, while those (L_0O_0, L_1O_1, L_2O_2, L_3O_3) between L_{0-3} and O_{0-3} were bone thicknesses at lingual side (Figure 3–3).

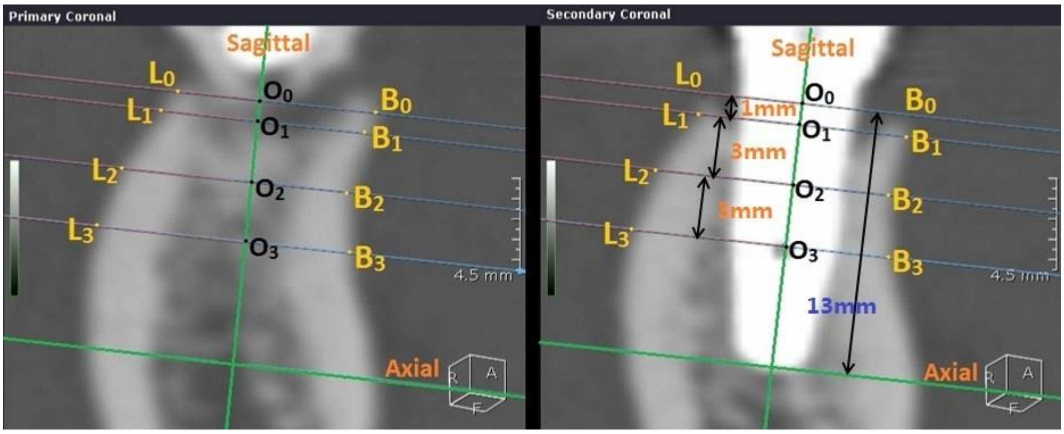


Figure 3–3. The measurement sections of bone thickness at buccal (B_0O_0, B_1O_1, B_2O_2, B_3O_3) and lingual (L_0O_0, L_1O_1, L_2O_2, L_3O_3) sides.

As described in Chapter 2, all the intersection points on the correspondent primary coronal image (before implant placement) could be obtained synchronously and marked in the same way to define the bone thickness.

The value of bone changes in thickness were calculated in the same way illustrated in Chapter 2. The subtraction values of ΔB_0O_0, ΔB_1O_1, ΔB_2O_2, ΔB_3O_3 and ΔL_0O_0, ΔL_1O_1, ΔL_2O_2, ΔL_3O_3 were defined as the bone change in thickness at buccal and lingual sides on each section.

Since the implant length was varied in these cases according to medical records, the distances of the sections to the baseline were different which was based on the length of the implant. Therefore, the top measurement section was always placed at the top of the implant. However, there were cases that at the top section have no existing bone to be intersected with the first section line at lingual and/or buccal sides due to the bone remodeling. In clinical cases, there would be three situations: (1) there was no existing bone intersected with the first section line in both images before and one year after implantation; (2) there was no existing bone intersected with the first section line in the images before implantation, but bone existing in the image one year after implantation; (3) there was existing bone intersected with the first section line in the images before implantation, but no bone in the image one year after implantation. These three situations was classified as A, B, and C in this study. For example, in Figure 3–3, it was clear that the position of the first parallel line was higher than the bone crest in the image after implantation and there were no yellow dots marked at the intersection points L_0 and B_0, while in the image before implantation there were existing bone. Therefore, at section $L_0O_0B_0$, the subtraction value of ΔL_0O_0 and ΔB_0O_0 would be marked as ‘C’.

Third, the intersection points to determine the bone height at lingual and buccal sides which were defined in Chapter 2 was also applied in these cases. In Figure 3–4, the distance (H_BO_B) between H_B and O_B was defined as the bone height at buccal side, while that (H_LO_L) between H_L and O_L was the bone height at lingual side. The subtraction value ΔH_L and ΔH_B was the bone changes in height at lingual and buccal sides.

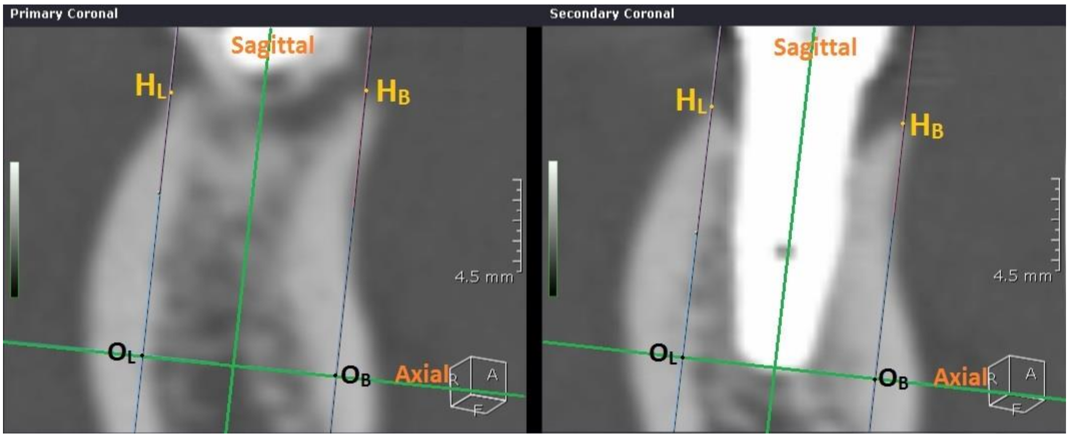


Figure 3–4. Measurement positions of bone height at lingual and buccal bone on target coronal image.

3.2.5 Statistical analysis

SPSS 18.0 was used for data analysis. The raw data was confidentially inputted into a laptop that is password controlled. A database file was made for further analysis.

First, the data analysis included descriptive statistics looking at the mean, SD, range of bone dimensional changes on all sections of thickness and height in Type 1 and Type 4 groups.

Secondly, *t*-test was conducted to assess difference of bone dimensional changes on every section of thickness and height (1) between lingual and buccal sides separately in two groups of Type 1 and Type 4; (2) between maxilla and mandible separately in two groups of Type 1 and Type 4; (3) between groups of Type 1 and Type 4, in terms of thickness and height at lingual and buccal aspects; (4) between groups of Type 1 and Type 4 separately in maxilla and mandible.

3.3 Results

3.3.1 Clinical information of the 69 cases

In total, 69 paired CBCT data sets were collected from 63 patients (34 male and 29 female) aged 18 to 64 years old. All the data sets were taken in Shanghai 9th People's Hospital from May 2011 to October 2015.

There were 44 Type 1 cases which included 31 cases (17 male, 14 female) on mandible and 13 cases (6 male, 7 female) on maxilla, while there were 25 Type 4 cases including 15 cases (9 male, 6 female) on mandible and 10 cases (5 male, 5 female) on maxilla.

For 44 Type 1 cases, the bone thickness under the apex of the residual tooth was more than 3 mm and no requirement of the buccal bone. The implant of NobelReplace Tapered Groovy was used for all Type 1 cases. Normally implant diameter of 3.5 mm or 4.3 mm were chosen for premolar area, while 4.3 mm or 5 mm were chosen for molar area. The implant length was 13 mm in most case, except some second molar implant cases using implant of 10 mm length. In 25 Type 4 cases, Alpha Bio ATID system, NobelReplace Tapered Groovy, and NobelSpeed Replace were used. The implant diameter was 4.3 mm or 5 mm in most cases, only one case with 3.5 mm implant diameter. The implant length was 10 mm or 11.5 mm.

Bio-oss was used for bone grafting during implant placement, this was applied to all of Type 1 cases, except one case with a very short residual tooth root where has sufficient supporting bone. If the bone wall at buccal side of the residual tooth well preserved, no flap surgery was applied and 0.25 g Bio-oss was used for bone grafting. If defect of bone wall at buccal side was more than 3 mm in height, Bio-Gide of the size 13*25 mm^2 was utilized for flap surgery and the bone grafting surgery needed 0.25~0.5 g Bio-oss. In Type 4 cases, 0.25~0.5g Bio-oss was used in the cases, of which the bone quantity was not enough. No flap surgery was applied to Type 4 cases.

In both groups, the top of the implant was placed at the same level of alveolar ridge. Additionally, under the premise of achieving good occlusion, the position of the implant was slightly lingual in order to leave at least 2 mm buccal bone. The implant and adjacent tooth should be 1.5 mm at least. The loading of implant was 4 month after implantation.

The details of all the CBCT data sets such as patients' number, gender, age, type of implant placement, site of implant placement, information of implant, bone grafting or flapless surgery applied or not, and the data of CBCT data sets were illustrated in Appendix 3.

3.3.2 Measurement results of 44 Type 1 cases

The measurements were taken from 44 paired CBCT images of Type 1 following established method (Chapter 2), the results were illustrated in the Table 3–1, with four sections of bone changes in thickness (ΔL_0O_0, ΔL_1O_1, ΔL_2O_2, ΔL_3O_3) and one in height (ΔH_L) at lingual site, and the same followed at buccal side (ΔB_0O_0, ΔB_1O_1, ΔB_2O_2, ΔB_3O_3, ΔH_B). All the data were categorised into the mandible cases (31 cases) at the first section and maxilla cases (13 cases) at lower section in the table. The value of mean and SD were calculated according to the value of each group firstly, then the mean and SD for all cases were showed in the last two rows in Table 3–1.

Within the table, the maximum value of bone increment in each column were marked in yellow colour; the smallest value in each column was marked in green colour, which indicated the maximum bone absorption; and all of the 0 value were marked in blue colour which indicated no dimensional changes. The ‘A’ was marked for the case where no existing bone can be identified on the sections in both images taken before and after implant placement. Furthermore, where marked ‘B’ meant that no intersection point was detected on that measurement section of the image before implant placement, but it could be get on the image after implant placement. This situation indicated that the bone augmentation procedure helped the bone rebuilding around the implant. On the contrary, ‘C’ show no bone could be found on that section of the image after implant placement, but it could be found on the image before implant placement. This implied that the bone augmentation procedure didn’t work effectively and Bio-oss and the original crest bone partly absorbed after the surgery.

Table 3–1. Value of bone changes on each measurement section in 44 Type 1 cases.

Sections Patients No	ΔL_0O_0 (mm)	ΔL_1O_1 (mm)	ΔL_2O_2 (mm)	ΔL_3O_3 (mm)	ΔB_0O_0 (mm)	ΔB_1O_1 (mm)	ΔB_2O_2 (mm)	ΔB_3O_3 (mm)	ΔHL (mm)	ΔHB (mm)
Cases on mandible										
1.BLH	**A**	1.35	-0.10	0.00	**A**	1.35	-0.50	-0.90	1.40	4.20
2.CC	**B**	1.50	-0.10	0.00	**A**	0.10	2.60	1.20	1.60	4.20
3.CJY	**C**	-0.70	0.00	0.00	**C**	-0.80	-0.50	-0.10	-1.00	-1.50
4.GH	0.00	-0.14	-0.82	-0.05	**A**	1.79	0.00	0.00	-0.22	1.41
5.GLY	**A**	NA	-0.70	0.00	**A**	-0.60	0.60	0.50	0.40	-0.20
6.GR	**C**	-2.40	-0.50	-0.20	**C**	-1.10	-0.30	0.00	-0.70	-2.10
7.GWL	-1.00	-0.20	0.00	0.00	1.50	-1.50	-0.60	0.00	-0.80	2.40
8.GWX	**A**	-0.90	0.00	0.00	0.50	0.80	2.90	0.50	0.00	-0.20
9.HDQ	**A**	-0.10	0.00	0.10	**A**	-0.40	-0.10	0.00	0.30	0.40
10.HHW	**A**	-0.20	0.00	0.00	**C**	-1.60	-1.50	0.00	0.30	-0.40
11.JY	**A**	-0.40	-0.10	0.00	-0.40	-0.40	-0.40	-1.00	-0.60	0.00
12.JYa	**A**	-0.50	0.10	0.00	**B**	2.00	-0.50	0.00	0.10	2.20
13.LYL	**A**	3.10	0.40	0.00	0.00	-0.20	0.00	0.00	-0.30	0.00
14.MBL	0.00	0.00	0.00	0.00	-1.65	-1.20	-1.00	0.00	-0.20	-2.30
15.MXL	**A**	-0.90	0.00	0.00	0.40	0.90	1.80	0.50	0.00	-0.20
16.QJW	0.00	0.00	0.00	0.00	**C**	-1.40	-1.20	0.00	-0.30	-2.60
17.SJF	**A**	-0.40	0.00	0.00	1.00	2.30	-0.50	0.00	0.20	2.40
18.WHY	**A**	0.30	-0.10	0.00	**A**	-0.60	-0.40	0.00	0.30	0.70
19.WM	**C**	-0.20	0.00	0.00	**B**	-1.50	-0.60	0.00	-0.60	2.30
20.WW	**A**	-0.40	-0.60	-0.30	**C**	-0.80	-1.00	-0.50	0.20	-0.50
21.WX	**A**	0.30	-0.10	-0.10	**A**	-0.40	-0.40	0.00	0.50	0.80
22.XJY	**A**	-0.50	0.10	0.00	1.00	1.50	-0.50	0.00	0.10	2.00
23.XLM	**A**	-0.10	0.00	0.10	**A**	-0.40	-0.10	0.00	0.20	0.30
24.XM	**A**	0.30	-0.10	0.00	**A**	-0.40	-0.40	0.00	0.40	1.00
25.YYP	-1.50	-0.90	-0.40	-0.30	**C**	0.30	0.80	0.00	-2.00	-2.30
26.ZJJ	**A**	-0.20	0.00	0.00	-2.80	-1.40	-1.30	0.00	0.40	-0.50
27.ZMJ	-1.20	-0.40	-0.40	-0.30	-1.60	0.40	0.70	0.00	-2.00	-2.50
28.ZXN	**C**	0.00	-0.20	-0.10	**C**	0.30	0.40	0.00	0.00	-0.20
29.ZXZ	-2.00	-0.60	0.00	0.00	-2.40	-0.70	-0.40	-0.10	-1.00	-1.60
30.ZY	**A**	0.00	0.00	0.00	**C**	-0.70	-0.50	-0.50	0.00	-0.80
31.ZZW	**C**	0.00	0.00	0.10	**C**	-0.30	-0.10	0.00	-0.30	-1.20
Mean	**-0.81**	**-0.11**	**-0.12**	**-0.03**	**-0.40**	**-0.15**	**-0.10**	**-0.01**	-0.12	0.17
SD	**0.82**	**0.91**	**0.25**	**0.10**	**1.48**	**1.08**	**1.00**	**0.39**	0.76	1.83
Cases on maxilla										
1.GQYa	**A**	-0.50	-0.10	-0.10	**C**	-0.60	-0.60	-0.80	-0.50	-0.90
2.BWJ	**A**	-0.60	-0.10	0.00	-0.50	-0.50	-1.20	-1.00	-0.50	0.50
3.CO	-0.40	-0.60	-0.30	-0.10	0.50	1.00	1.70	1.40	-2.30	-1.20
4.CZH	-1.15	-0.50	-0.10	0.00	-1.20	-0.70	0.00	-0.10	-0.80	0.00
5.FH	**A**	0.54	0.00	0.00	-2.30	-2.55	-1.30	-0.54	-0.44	-0.40
6.GQYb	**A**	**A**	-0.30	-0.10	2.75	-0.20	0.00	-0.40	-0.40	0.70
7.RG	**A**	-0.60	-0.10	0.00	-0.50	-0.50	-1.20	-1.00	-0.50	0.50
8.WF	-1.45	-0.40	-0.40	-0.40	**C**	-1.20	-1.30	-1.30	-2.00	1.80
9.WKQ	**C**	-0.50	-0.10	0.00	-1.20	-0.70	0.00	1.10	-0.80	0.00
10.ZBK	**A**	-0.60	-0.30	0.00	**A**	0.45	0.60	0.00	0.20	-0.20
11.ZMA	**A**	-0.60	-0.30	0.00	**A**	0.35	0.40	0.00	0.10	-0.20
12.ZPA	**A**	0.80	0.00	-0.04	**C**	-3.08	-1.64	-0.99	0.00	-0.84
13.ZPB	**A**	1.49	-1.22	-0.38	**A**	1.77	-0.81	-1.13	0.42	3.00
Mean	**-1.00**	**-0.17**	**-0.26**	**-0.09**	**-0.35**	**-0.50**	**-0.41**	**-0.37**	**-0.58**	**0.21**
SD	**0.54**	**0.71**	**0.32**	**0.14**	**1.16**	**1.31**	**0.96**	**0.84**	**0.79**	**1.15**
All cases										
Mean	**-0.87**	**-0.13**	**-0.16**	**-0.05**	**-0.38**	**-0.25**	**-0.19**	**-0.12**	**-0.25**	**0.18**
SD	**0.72**	**0.85**	**0.28**	**0.12**	**1.49**	**1.15**	**0.99**	**0.57**	**0.79**	**1.64**

(‘**A**’: no existing bone identified both in pre- and post- images; ‘**B**’: no intersection point detected in pre-image, but it could be get in post- image; ‘**C**’: no intersection point detected in post- image, but it could be get in pre- image.)

3.3.2.1 General analysis of bone changes on each measurement section in Type 1 group

First, the frequent distribution of ‘A’, ‘B’ and ‘C’, positive bone changes, negative bone changes on each measurement section in 44 Type 1 cases were calculated and displayed in Table 3–2.

Table 3–2. Frequent distribution of ‘A’, ‘B’ and ‘C’, positive bone changes, negative bone changes on each measurement section in 44 Type 1 cases.

Variables / Sections	‘A’ N (%)	‘B’ N (%)	‘C’ N (%)	No bone changes N (%)	Bone increases N (%)	Bone decrease N (%)
ΔL_0O_0	27 (61%)	1 (25)	6 (14%)	3 (7%)	0	7 (16%)
ΔL_1O_1	1 (2%)	0	0	5 (11%)	8 (18%)	31 (71%)
ΔL_2O_2	0	0	0	17 (39%)	3 (7%)	24 (54%)
ΔL_3O_3	0	0	0	22 (50%)	3 (7%)	19 (43%)
ΔB_0O_0	12 (27%)	3 (7%)	10 (23%)	1 (2%)	7 (16%)	10 (23%)
ΔB_1O_1	0	0	0	0	15 (34%)	29 (66%)
ΔB_2O_2	0	0	0	5 (11%)	10 (23%)	29 (66%)
ΔB_3O_3	0	0	0	23 (52%)	6 (14%)	15 (34%)
ΔHL	0	0	0	5 (11%)	17 (39%)	22 (50%)
ΔHB	0	0	0	3 (7%)	19 (43%)	22 (50%)

Totally, 40 cells were marked with ‘A’, 27 (61%) cases (18mandibular cases and 7 maxillary cases) on L_0O_0 section; 12 (27%) cases (9 mandibular cases and 3 maxillary cases) on B_0O_0 section; 1 (2%) cases (mandibular case) on L_1O_1 section. 6 (14%) cases were marked with ‘C’ on L_0O_0 section (5 mandibular cases and 1 maxillary case). Plus the cases marked with ‘A’ on L_0O_0 section, it stated there was no lingual bone on the level of implant top one year after immediate implant placement in 33 (75%) cases. And, 10 (23%) cases were marked with ‘C’ on B_0O_0 section (7 mandibular cases and 3 maxillary cases). Plus the cases marked with ‘A’ on B_0O_0 section, it stated there was no buccal bone on the level of implant top one year after immediate implant placement in 22 (50%) cases. On the contrary, there was only 1 case (mandibular case) marked with ‘B’ on L_0O_0 section and 3 cases (2 mandibular cases and 1 maxillary case) on B_0O_0 section. It indicated that bone gain occurred at lingual and/or buccal sides at the level of implant top one year after implantation with bone augmentation procedure in this case.

Except the B_1O_1 section, no bone changes were assessed on all other sections in some cases, 3 cases (mandibular cases) on L_0O_0 section; 5 cases (mandibular cases) on L_1O_1 section; 17 cases (15 mandibular cases and 2 maxillary cases) on L_2O_2 section; 22 cases (mandibular cases) on L_3O_3 section; 1 cases (mandibular cases) on B_0O_0 section; 5 cases (2 mandibular cases and 3 maxillary cases) on B_2O_2 section; 23 cases (22 mandibular cases and 3 maxillary cases) on B_3O_3 section; 5 case (4 mandibular cases and 1 maxillary case) on H_L section; and 3 case (2 mandibular cases and 1 maxillary case) on H_B section. It should be noted that 50% cases showed no bone changes on L_3O_3 section and all the bone changes were less than 0.4 mm on this section. 52% cases showed no bone changes on B_3O_3 section.

Furthermore, on all sections, some cases showed bone increase and some cases suffered bone decrease. Bone gain was most distinct of bone height and buccal bone thickness, 17 (39%) cases on H_L section, 19 (43%) cases on H_B section, 7 (16%) cases on B_0O_0 section, 15 (34%) cases on B_1O_1 section, and 10 (23%) cases on B_2O_2 section.

Second, the mean value and range of the bone changes in thickness and height in Type 1 group were illustrated in Figure 3–5 and Figure 3–6. And the difference of bone changes on each section between lingual and buccal sides was analysed by *t*-test. However, there were 61% cases on L_0O_0 section and 27% cases on B_0O_0 section which were marked 'A'. Due to these large missing data on section $L_0O_0B_0$ section, no *t*-test was done at this section.

In Figure 3–5, the mean value of bone changes in thickness on each measurement sections was negative number. However, the range of the changes was wide from positive numbers to negative numbers, which mean there was big difference in bone changes in thickness among these Type 1 cases.

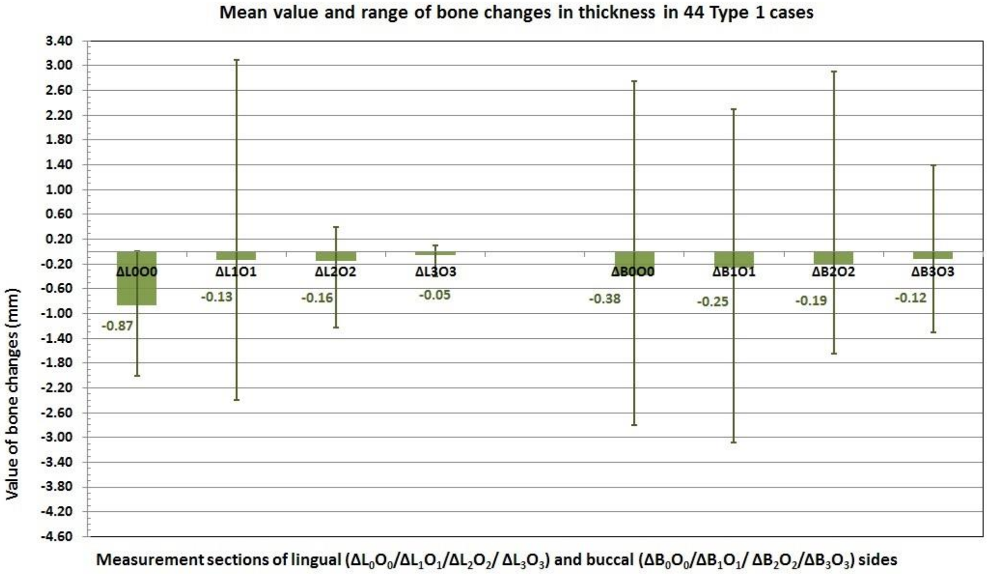


Figure 3–5. Mean value and range of bone changes in thickness on each measurement section in 44 Type 1 cases.

The maximum mean value of bone change in thickness was -0.87 mm on L_0O_0 section (range from -2.00 mm to 0 mm); then -0.38 mm on B_0O_0 (range from -2.80 mm to 2.75 mm); then -0.25 on B_1O_1 (range from -3.08 mm to 2.30 mm); -0.19 mm on B_2O_2 (range from -1.64 mm to 2.90 mm); -0.16 mm on L_2O_2 (range from -1.22 mm to 0.4 mm); -0.13 mm on L_1O_1 (range from -2.40 mm to 3.10 mm); -0.12 mm on B_3O_3 (range from -1.30 mm to 1.40 mm); -0.05 mm on L_3O_3 (range from -0.3 mm to 0.1 mm).

The maximum SD of bone changes in thickness was 1.49 mm on B_0O_0 section; then 1.15 mm on B_1O_1 section; 0.99 mm on B_2O_2 section; 0.85 mm on L_1O_1 section; 0.72 mm on L_0O_0 section; 0.57 mm on B_3O_3 section; 0.28 mm on L_2O_2 section; and 0.12 mm on L_3O_3 section.

In Type 1 group, the result of *t*-test showed there was significant difference in bone changes in thickness between lingual and buccal sides L_1O_1-B_1O_1 section (*p<0.05*); L_2O_2-B_2O_2 section (*p<0.01*); L_3O_3-B_3O_3 section (*p<0.*01) (Table 3–3). It could be conclude that bone changes in thickness decreased significantly less at lingual side than buccal side on other three sections.

In Figure 3–6, the mean value of bone changes in height at lingual side was -0.25 mm (range from -2.30 mm to 1.60 mm) and at buccal side was 0.18 mm (range from -2.60 mm to 4.20 mm). 22 (50%) cases showed bone height decrease on both lingual and buccal sides. 17 (39%) case showed bone increased at lingual side and 19 (43%) cases at buccal side.

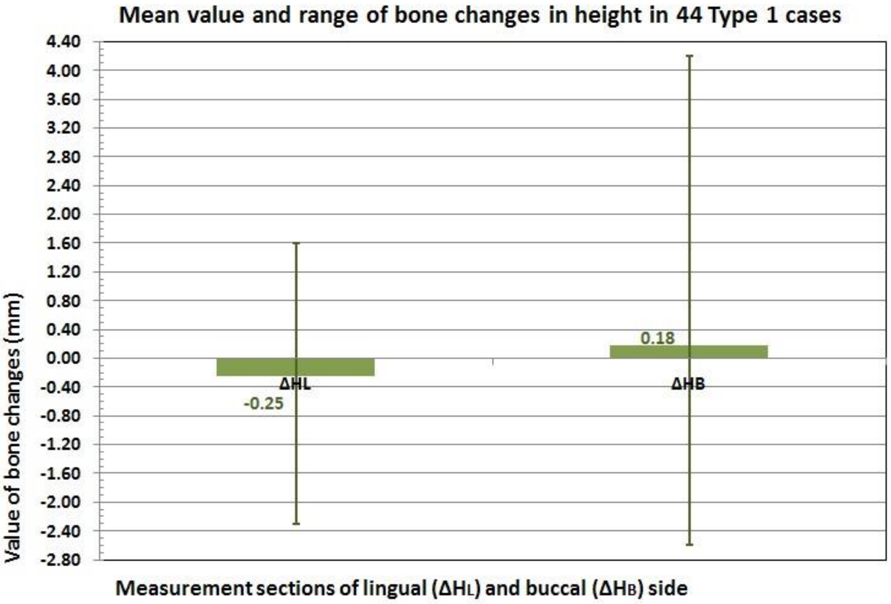


Figure 3–6. Mean value and range of bone changes in height in 44 Type 1 cases.

The SD of bone changes in height on H_B section (1.64 mm) was larger than that on H_L section (0.79 mm).

The result of *t*-test showed bone changes in height increased significantly more at buccal sides than lingual sides in Type 1 group with bone augmentation procedure (*p<0.01*) (Table 3–3).

Table 3–3. Difference of bone changes between lingual and buccal sides on each measurement section in 44 Type 1 cases.

Sections	Variables	Mean (mm)	SD (mm)	*P value*
0	**ΔL_0O_0**	-1.15	1.23	NA
	ΔB_0O_0	-0.76	1.76	
1	**ΔL_1O_1**	-0.13	0.85	<0.05
	ΔB_1O_1	-0.25	1.15	
2	**ΔL_2O_2**	-0.16	0.28	<0.01
	ΔB_2O_2	-0.19	0.99	
3	**ΔL_3O_3**	-0.05	0.12	<0.01
	ΔB_3O_3	-0.12	0.57	
H	**ΔHL**	-0.25	0.79	<0.01
	ΔHB	0.18	1.64	

3.3.2.2 Comparison of bone changes between 31 mandibular cases and 13 maxillary cases in Type 1 group

There were 31 mandibular cases and 13 maxillary cases in Type 1 group. Figure 3–7 showed the comparison of the mean value and range of bone changes in thickness between mandibular cases and maxillary cases. The mean value of bone changes in thickness on each measurement section was negative number both on mandible and maxilla. And the range of bone changes in thickness was from negative number to positive number on all sections, except on L_0O_0 section in maxillary cases where bone decreased in all cases.

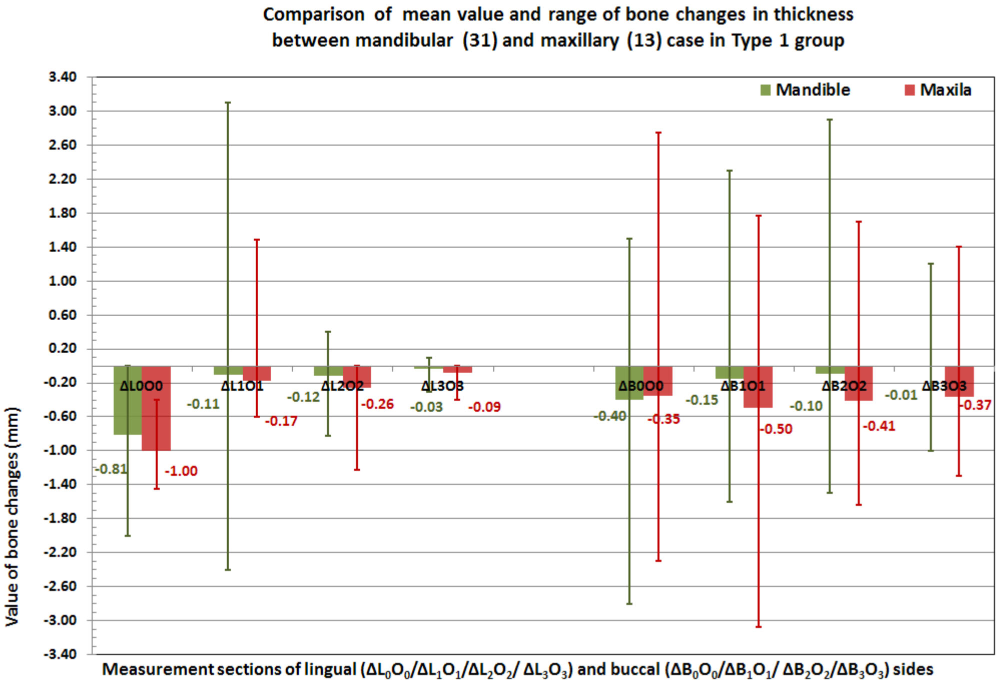


Figure 3–7. Comparison of mean value and range of bone changes in thickness between 31 mandibular cases and 13 maxillary cases in Type 1 group.

According to the result of *t*-test, in Type 1 group there was no significant difference in bone changes in thickness between mandibular and maxillary cases on L_1O_1 section (*p=0.997*); L_2O_2 section (*p=0.792*); L_3O_3 section (*p=0.301*); B_1O_1 section (*p=0.879*); B_2O_2 section (*p=0.629*). But on B_3O_3 section (*p<0.01*), bone changes in thickness decreased less in mandibular case than maxillary cases. Additionally, there were only 4 maxillary cases had the subtraction value on L_0O_0 section. The comparison might be invalid on L_0O_0 section due to such a small sample size.

Figure 3–8 showed the comparison of the mean value and range of bone changes in height between mandibular cases and maxillary cases. The mean value of bone changes showed bone height decreased at lingual side both on mandible and maxilla, while it increased at buccal side. But the range of bone changes was still from negative number to positive number on both sides.

According to the result of t-test, in Type 1 group there was no significant difference in bone changes in height between mandibular and maxillary cases on both lingual side (*p=0.985*) and buccal side (*p=0.087*).

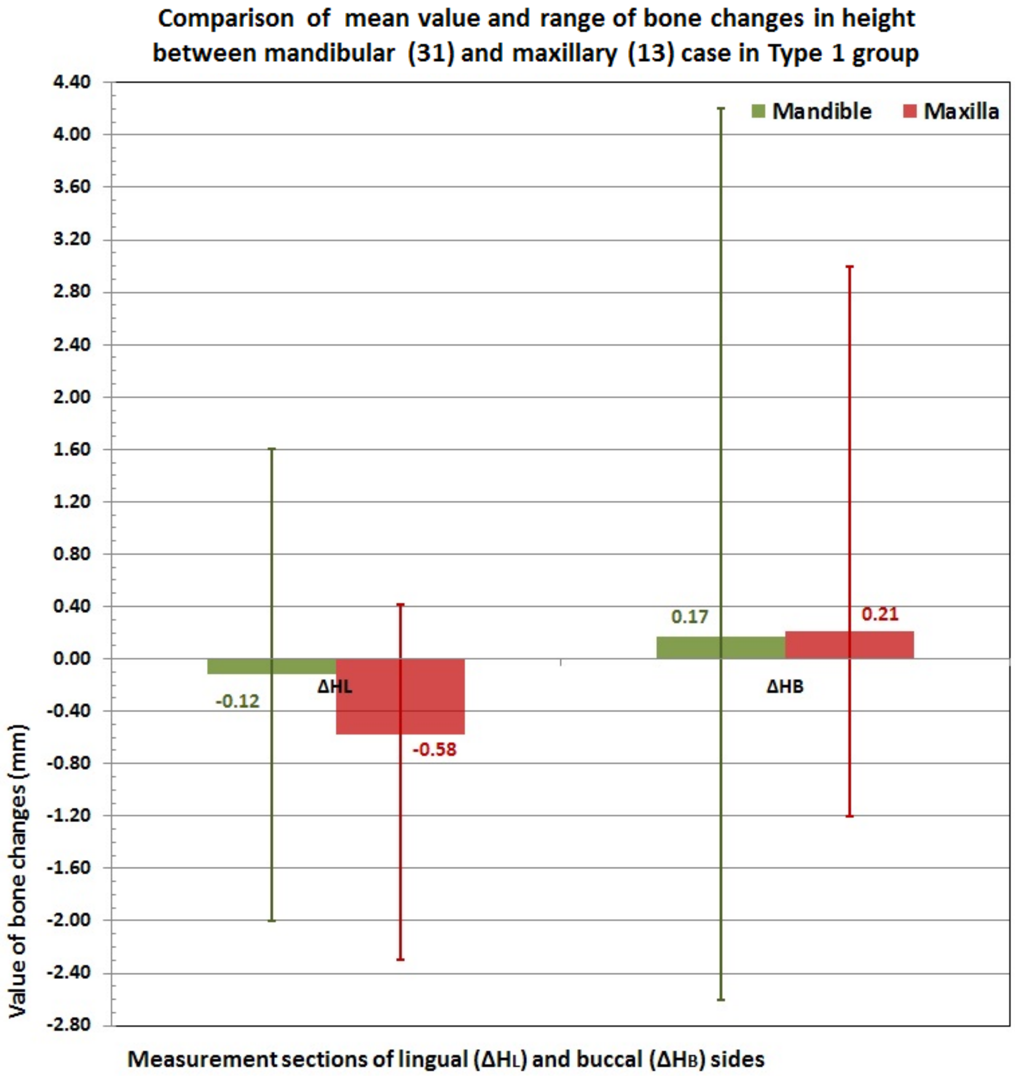


Figure 3–8. Comparison of mean value and range of bone changes in height between 31 mandibular cases and 13 maxillary cases in Type 1 group.

3.3.3 Measurement results in 25 Type 4 cases

The results of the bone changes in 25 paired CBCT images of Type 4 cases were illustrated in the Table 3–4. The data were categorised into the cases on mandible and case on maxilla as well. All the definition of coloured cells, ‘A’, ‘B’ and ‘C’ were as same as those defined for Type 1 cases in Table 3–1.

Table 3–4. Value of bone changes on each measurement section in 25 Type 4 cases.

Sections Patients No.	ΔL_0O_0 (mm)	ΔL_1O_1 (mm)	ΔL_2O_2 (mm)	ΔL_3O_3 (mm)	ΔB_0O_0 (mm)	ΔB_1O_1 (mm)	ΔB_2O_2 (mm)	ΔB_3O_3 (mm)	ΔHL (mm)	ΔHB (mm)
Cases on mandible										
1.CGF	**A**	0.00	-0.43	0.00	-0.19	-0.88	-0.86	-0.29	-0.15	-0.34
2.CJY	**A**	-0.70	-0.50	-0.60	**C**	0.00	-0.30	-0.60	-0.50	-0.40
3.CLP	**A**	0.00	-0.43	0.00	-0.19	-0.78	-0.86	-0.79	-0.28	-0.38
4.CYB	-0.30	-0.70	0.00	0.00	**A**	0.60	-0.30	0.00	0.00	-0.50
5.GLY	**A**	2.25	-0.10	-0.20	**A**	0.60	0.30	0.20	-1.00	0.00
6.GM	**B**	1.08	0.01	0.04	0.10	0.00	-0.70	-0.10	1.86	-0.13
7.LJG	0.10	0.00	0.00	0.10	-0.05	-0.29	-0.10	0.00	-0.20	-0.50
8.WFAa	**A**	0.40	-0.10	0.00	**A**	0.20	0.80	0.10	-0.10	1.90
9.WFAb	-0.20	-0.70	0.00	0.00	**A**	0.40	-0.30	0.00	0.00	2.80
10.XJL	0.60	-0.05	0.00	0.36	**A**	-0.93	-0.96	-0.44	-0.07	0.05
11.XL	**A**	0.00	-0.34	0.00	**C**	-2.09	-0.15	0.00	-0.13	0.60
12.XYA	0.19	0.00	0.00	0.18	-0.05	-0.29	-0.10	-0.05	-0.20	-0.34
13.XYX	0.30	0.14	0.00	-0.15	0.19	0.00	0.00	0.00	0.00	0.10
14.YH	**A**	-0.60	-0.40	-0.60	-0.40	0.00	-0.30	-0.50	-0.40	0.00
15.ZPL	**A**	-0.20	0.00	0.14	**A**	-0.73	-0.84	-0.35	-0.10	-0.30
Mean	**0.12**	**0.06**	**-0.15**	**-0.05**	**-0.08**	**-0.28**	**-0.31**	**-0.19**	**-0.08**	**0.17**
SD	**0.33**	**0.77**	**0.20**	**0.26**	**0.20**	**0.71**	**0.48**	**0.29**	**0.60**	**0.95**
Cases on maxilla										
1.CO	**A**	0.45	-0.20	0.00	**A**	1.90	1.00	0.20	1.90	1.20
2.CJ	0.85	0.31	0.00	0.00	-0.21	-0.23	-0.01	0.00	1.11	-0.47
3.MRY	**A**	0.00	-0.03	-0.02	**A**	-0.06	-0.06	-0.01	0.00	-0.42
4.SLY	**A**	-0.53	-0.01	0.00	-0.10	-0.27	-0.01	1.92	-0.13	0.00
5.WXM	**A**	0.53	-0.33	-0.04	**A**	-0.51	-0.28	-0.01	0.08	-0.09
6.WYH	**C**	-0.35	-0.02	0.03	-1.09	-1.03	-0.76	-0.33	-0.53	-1.56
7.XWJ	**A**	0.00	0.05	0.00	-0.05	0.91	-0.63	-0.46	-0.40	0.00
8.YHA	**A**	0.56	-0.19	0.00	**A**	-0.48	-0.48	-0.30	0.76	-0.59
9.YSX	**A**	0.14	0.00	0.00	**A**	-0.03	-0.32	0.00	0.33	0.09
10.ZBK	**A**	-0.20	0.00	0.00	**C**	0.10	-0.40	0.00	-0.40	-0.40
Mean	**0.85**	**0.09**	**-0.07**	**0.00**	**-0.36**	**0.03**	**-0.20**	**0.10**	**0.27**	**-0.22**
SD	**NA**	**0.38**	**0.12**	**0.02**	**0.49**	**0.82**	**0.49**	**0.67**	**0.78**	**0.69**
All cases										
Mean	**0.22**	**0.07**	**-0.12**	**-0.03**	**-0.19**	**-0.16**	**-0.26**	**-0.07**	**0.06**	**0.01**
SD	**0.41**	**0.63**	**0.18**	**0.20**	**0.34**	**0.76**	**0.48**	**0.49**	**0.68**	**0.86**

(‘**A**’: no existing bone identified both in pre- and post- images; ‘**B**’: no intersection point detected in pre- image, but it could be found in post- image; ‘**C**’: no intersection point detected in post- image, but it could be found in pre- image.)

3.3.3.1 General analysis of bone changes on each measurement section in Type 4 cases

First, the frequent distribution of ‘A’, ‘B’ and ‘C’, positive bone changes, negative bone changes on each measurement section in 25 Type 4 cases were calculated and displayed in Table 3–5

Table 3–5. Frequent distribution of ‘A’, ‘B’ and ‘C’, positive bone changes, negative bone changes on each measurement section in 25 Type 4 cases.

Variables Sections	‘A’ N (%)	‘B’ N (%))	‘C’ N (%)	No bone changes N (%)	Bone increases N (%)	Bone decrease N (%)
ΔL_0O_0	16 (64%)	1 (4%)	1 (4%)	0	5 (20%)	2 (8%)
ΔL_1O_1	0	0	0	7 (28%)	8 (32%)	10 (40%)
ΔL_2O_2	0	0	0	10	6 (24%)	9 (36%)
ΔL_3O_3	0	0	0	13 (52%)	6 (24%)	6 (24%)
ΔB_0O_0	11 (44%)	0	3 (12%)	0	2 (8%)	9 (36%)
ΔB_1O_1	0	0	0	4 (16%)	7 (28%)	14 (56%)
ΔB_2O_2	0	0	0	1 (4%)	3 (6%)	20 (80%)
ΔB_3O_3	0	0	0	8 (32%)	4 (16%)	12 (48%)
ΔHL	0	0	0	4 (16%)	6 (24%)	15 (60%)
ΔHB	0	0	0	4 (16%)	7 (28%)	14 (56%)

Totally, 27 cells were marked with ‘A’ in Table 3–4, 16 (64%) cases (8 mandibular cases and 8maxillary cases) on L_0O_0 section and 11 (44%) cases (4 mandibular case and 4 maxillary cases) on B_0O_0 section.

1 (4%) cases were marked with ‘C’ on L_0O_0 section (maxillary case). Plus the cases marked with ‘A’ on L_0O_0 section, it stated there was no lingual bone on the level of implant top one year after immediate implant placement in 17 (68%) cases. And, 3 (12%) cases were marked with ‘C’ on B_0O_0 section (2 mandibular cases and 1 maxillary case). Plus the cases marked with ‘A’ on B_0O_0 section, it stated

there was no buccal bone on the level of implant top one year after immediate implant placement in 14 (56%) cases. On the contrary, there was only 1 case (mandibular case) marked with 'B' on L_0O_0 section which indicated that bone gain occurred at lingual sides at the level of implant top one year after implantation with bone augmentation procedure in this case.

Except on L_0O_0 and B_0O_0 sections, bone showed no changes on all other sections in some cases, 7 cases (5 mandibular cases and 2 maxillary cases) on L_1O_1 section; 10 cases (7 mandibular cases and 3 maxillary cases) on L_2O_2 section; 13 cases (6 mandibular cases and 7 maxillary cases) on L_3O_3 section; 4 cases (mandibular cases) on B_1O_1 section; 1 cases (mandibular cases) on B_2O_2 section; 8 cases (5 mandibular cases and 3 maxillary cases) on B_3O_3 section; 4 case (3 mandibular cases and 1 maxillary case) on H_L section; 4 case (2 mandibular cases and 2 maxillary case) on H_B section. It should be noted that 52% cases showed no bone changes on L_3O_3 section and all the bone changes were less than 0.7 mm on this section. 32% cases showed no bone changes on B_3O_3 section.

Furthermore, on all sections, some cases showed bone increase and some cases suffered bone decrease. 7 (28%) cases on H_B section, 6 (24%) cases on H_L section, 8 (32%) cases on L_1O_1 section, and 7 (28%) cases on B_1O_1 section showed bone increased.

Second, the mean value and range of the bone changes in Type 4 group were illustrated in Figure 3–9 and Figure 3–10. And the difference of bone changes on each section between lingual and buccal was analysed by *t*-test. Due to these large missing data on section $L_0O_0B_0$ section, no *t*-test was done at this section as well.

In Figure 3–9 , except L_0O_0 and L_1O_1 sections, the mean value of bone changes in thickness on other measurement sections was negative number. However, the range of the changes was wide from positive numbers to negative numbers, which was same as the results of Type 1 group.

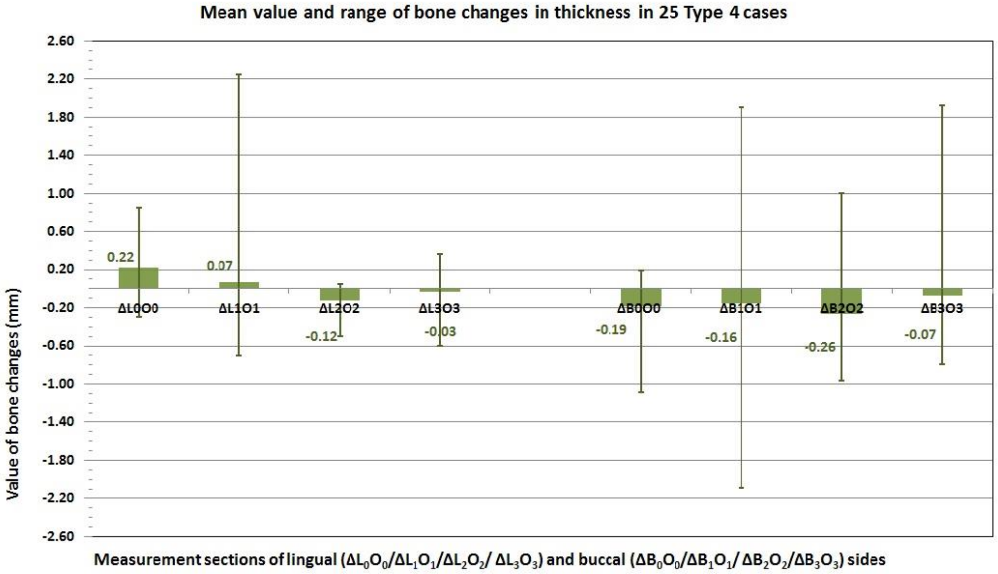


Figure 3–9. Mean value and range of bone changes in thickness on each measurement section in 25 Type 4 cases.

The maximum value of bone increase in thickness was 0.22 mm on L_0O_0 section (range from -0.30 mm to 0.85 mm); then 0.07 mm on L_1O_1 (range from -0.70 mm to 2.25 mm). The maximum value of bone decrease in thickness was -0.19 mm on B_0O_0 (range from -1.09 mm to 0.19 mm); then -0.26 mm on B_2O_2 (range from -0.96 mm to 1 mm); -0.16 mm on B_1O_1 (range from -2.09 mm to 1.90 mm); -0.12 mm on L_2O_2 (range from -0.50 mm to 0.05 mm); -0.07 mm on B_3O_3 (range from -0.79 to 1.92 mm) and -0.03 mm on L_3O_3 (range from -0.60 mm to 0.36mm).

The maximum SD of bone changes in thickness was 0.76 mm on B_1O_1 section; then 0.63 mm on L_1O_1 section; 0.49 mm on B_3O_3 section; 0.48 mm on B_2O_2

section; 0.41 mm on L_0O_0 section; 0.34 mm on B_0O_0 section; 0.18 mm on L_2O_2 section, and 0.20 mm L_3O_s section.

In this Type 4 group, the result of *t*-test (Table 3–6) showed there was no significant difference in bone changes in thickness between lingual and buccal sides on L_1O_1-B_1O_1 section (*p=0.416*); L_2O_2-B_2O_2 section (*p=0.05*); L_3O_3-B_3O_3 section (*p=0.069*).

Table 3–6. Difference of bone changes between lingual and buccal sides in 25 Type 4 cases

Sections	Variables	Mean (mm)	SD (mm)	*P value*
0	**ΔL_0O_0**	0.28	0.64	NA
	ΔB_0O_0	-0.41	0.59	
1	**ΔL_1O_1**	0.07	0.63	0.416
	ΔB_1O_1	-0.16	0.76	
2	**ΔL_2O_2**	-0.12	0.18	0.05
	ΔB_2O_2	-0.26	0.48	
3	**ΔL_3O_3**	-0.03	0.20	0.069
	ΔB_3O_3	-0.07	0.49	
H	**ΔHL**	0.06	0.68	0.647
	ΔHB	0.01	0.86	

In Figure 3–10, the mean value of bone changes in height was 0.06 mm (range from -1.00 mm to 1.90 mm) at lingual side and 0.01 mm (range from -1.56 mm to 2.80 mm) at buccal side. The large range of bone changes indicated large diversity in bone changes in height exited among these Type 4 cases. Additionally, 15 cases (60%) showed bone height decrease at lingual sides and 13 cases (52%) at buccal side. 6 (24%) case showed bone increased at lingual side and 7 (28%) cases at buccal side.

The SD of bone changes in height on H_B section (0.86 mm) was more than that on H_L section (0.68 mm).

The result of *t*-test (Table 3–6) showed there was no significant difference in bone changes in height between lingual and buccal sides (*p=0.647*) in Type 4 group.

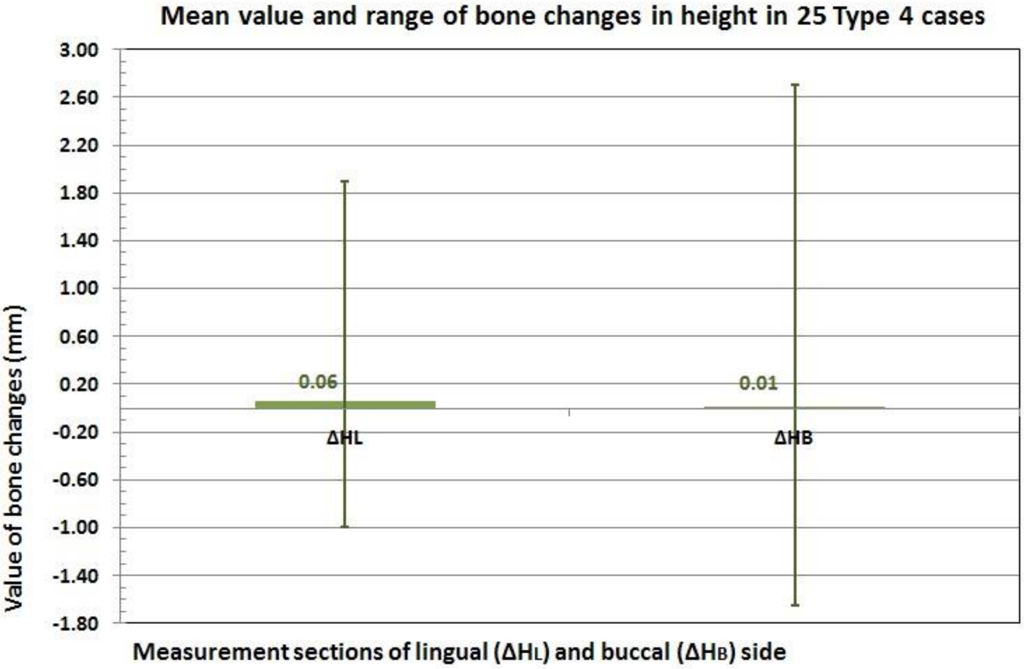


Figure 3–10. Mean value and range of bone changes in height in 25 Type 4 cases.

3.3.3.2 Comparison of bone changes between15 mandibular cases and 10 maxillary cases in Type 4 group

There were 15 mandibular cases and 10 maxillary cases in Type 4 group. Figure 3–11 showed the comparison of the mean value and range of bone changes in thickness between mandibular cases and maxillary cases. In 15 mandibular cases, the mean value of bone changes in thickness showed bone increase on L_0O_0 and

L_1O_1 sections, and decreased on other sections. In 10 maxillary cases, the mean value of bone changes in thickness showed bone increase on L_0O_0, L_1O_1, B_3O_3 and B_1O_1 sections, no changes on L_3O_3 section, and decreased on other sections. The range of bone changes was still from negative number to positive number on all sections, except on B_0O_0 section in maxillary cases where bone decreased in all cases.

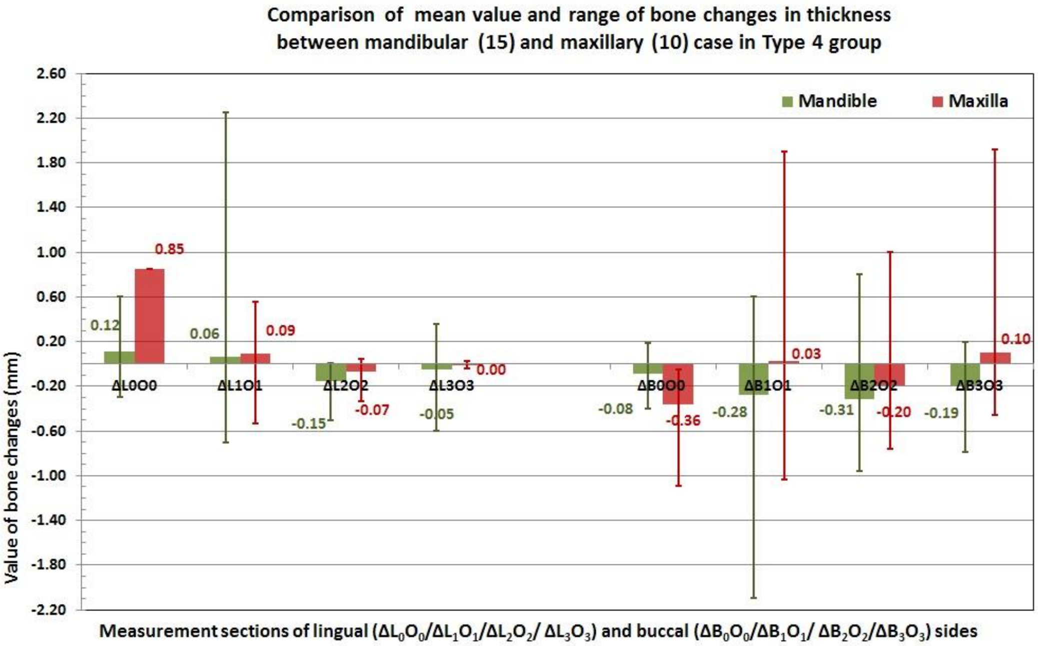


Figure 3–11. Comparison of mean value and range of bone changes in thickness between 15 mandibular cases and 10 maxillary cases in Type 4 group.

According to the result of *t*-test, in Type 4 group there was no significant difference in bone changes in thickness between mandibular and maxillary cases on L_1O_1 section ($p=0.366$); B_1O_1 section ($p=0.899$); B_2O_2 section ($p=0.910$); B_3O_3 section ($p=0.345$); L_2O_2 section ($p=0.06$). But on L_3O_3 section ($p<0.01$), bone thickness decreased significantly more in mandibular cases then maxillary cases.

Figure 3–12 showed the comparison of the mean value and range of bone changes in height between mandibular cases and maxillary cases. In 15 mandibular cases, the mean value of bone changes showed bone increase at buccal side, but decreased at lingual side. In 10 maxillary cases, the mean value of bone changes showed bone increase at buccal side, but decreased at lingual side. And the range of bone changes was still from negative number to positive number on both sides.

According to the result of *t*-test, in Type 4 group there was no significant difference in bone changes in height between mandibular and maxillary cases on both lingual side (*p=0.136*) and buccal side (*p=0.491*).

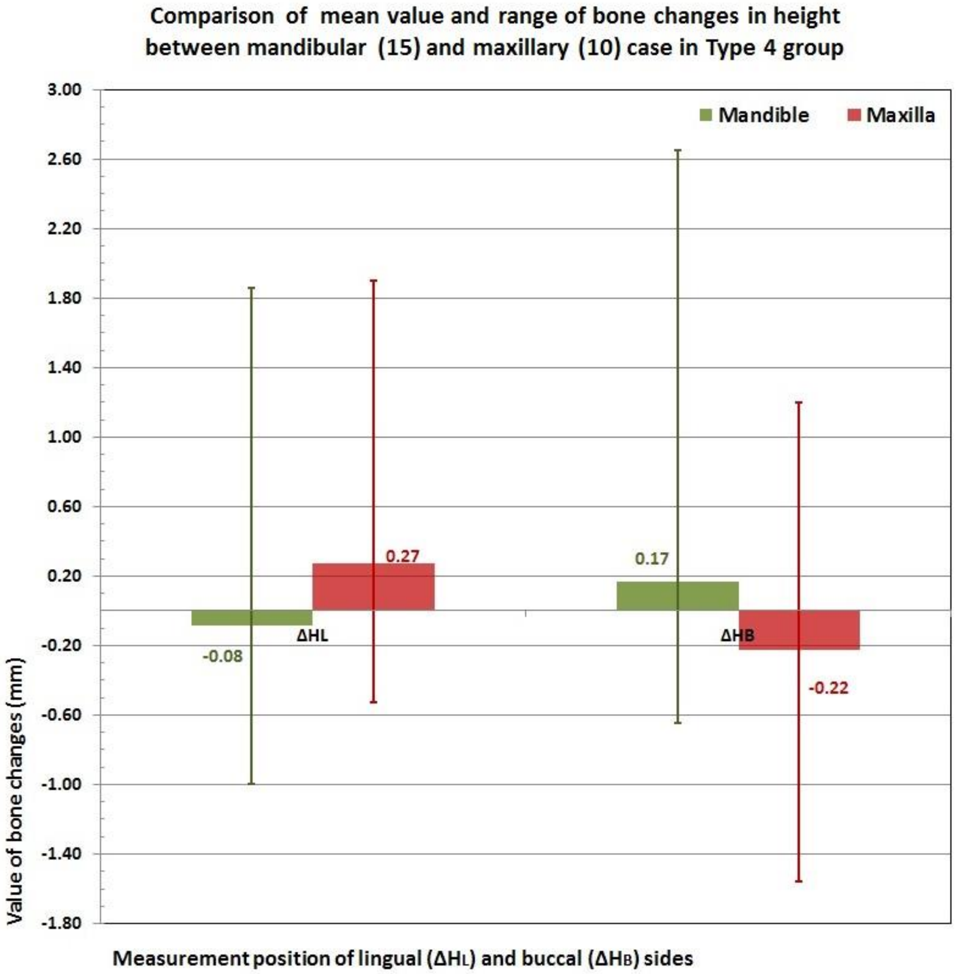


Figure 3–12. Comparison of mean value and range of bone changes in height between 15 mandibular cases and 10 maxillary cases in Type 4 group.

3.3.4 Comparison of bone changes between Type 1 and Type 4 implant placement protocols

3.3.4.1 Comparison of 44 Type 1 cases and 25 Type 4 cases

Figure 3–13 showed the mean value and range of bone changes in thickness on each measurement section of Type 1 and Type 4 cases together. And as describes above, there were only 9 Type 4 cases had subtraction value of bone changes on L_0O_0 section. Therefore, the analysis of comparison in bone changes between Type 1 and Type 4 excluded L_0O_0 section because of the small sample size, although it was still showed in the Figure 3–13.

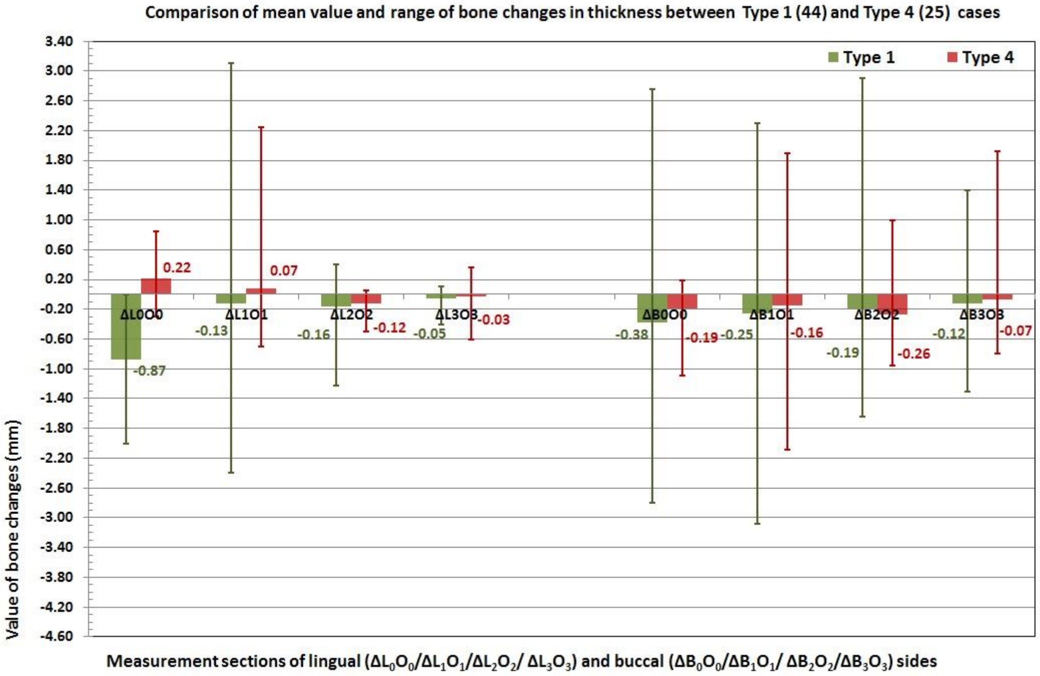


Figure 3–13. Comparison of mean value and bone changes in thickness between 44 Type 1 cases and 25 Type 4 cases.

It could be seem that the mean of bone changes in thickness decreased more in Type 1 than Type 4 on most measurement sections except B_2O_2 section. And the range of bone changes was wider in Type 1 than Type 4 on most sections, except L_3O_3 section. It should be noted the bone changes were very little on L_3O_3 section in all cases.

According to the result of *t*-test in Table 3–7, there was significant difference in bone changes in thickness between Type 1 and Type 4 on B_0O_0 section ($p<0.01$); B_1O_1 section ($p<0.05$); and B_2O_2 section ($p<0.05$). It showed bone thickness decreased more in Type 1 than Type 4 on B_0O_0 and B_1O_1 sections, but less on B_2O_2 section. And there was no significant difference in bone changes in thickness between Type 1 and Type 4 on L_1O_1 section ($p=0.383$); L_2O_2 section ($p=0.213$); L_3O_3 section ($p=0.284$); and B_3O_3 section ($p=0.250$).

Table 3–7. Difference of mean value of bone changes on each section between 44 Type 1 and 25 Type 4 cases.

Variables Sections	Type	Mean (mm)	SD (mm)	*P value*
ΔL_0O_0	Type 1	-1.15	1.23	NA
	Type 4	0.28	0.64	
ΔL_1O_1	Type 1	-0.13	0.85	0.383
	Type 4	0.07	0.63	
ΔL_2O_2	Type 1	-0.16	0.28	0.213
	Type 4	-0.12	0.18	
ΔL_3O_3	Type 1	-0.05	0.12	0.284
	Type 4	-0.03	0.20	
ΔB_0O_0	Type 1	-0.76	1.76	<0.01
	Type 4	-0.41	0.59	
ΔB_1O_1	Type 1	-0.25	1.15	<0.05
	Type 4	-0.16	0.76	
ΔB_2O_2	Type 1	-0.19	0.99	<0.05
	Type 4	-0.26	0.48	
ΔB_3O_3	Type 1	-0.12	0.57	0.250
	Type 4	-0.07	0.49	
ΔH_L	Type 1	-0.25	0.79	0.339
	Type 4	0.06	0.68	
ΔHB	Type 1	0.18	1.64	<0.01
	Type 4	0.01	0.86	

Figure 3–14 showed the mean value and range of bone changes in height of 44 Type 1 cases and 25 Type 4 cases together. The bone height tended to increase more at buccal side, but decrease more at lingual side in Type 1 cases compared

with Type 4 cases. And the range of bone changes in height was also wider in Type 1 than in Type 4 on both lingual and buccal sides.

According to the result of *t*-test in Table 3–7, there was no significant difference in bone changes in height between Type 1 and Type 4 cases at lingual side (*p=0.339*), but at buccal side (*p<0.01*) bone changes in height increased significantly more in Type 1 than Type 4 cases with bone augmentation procedure.

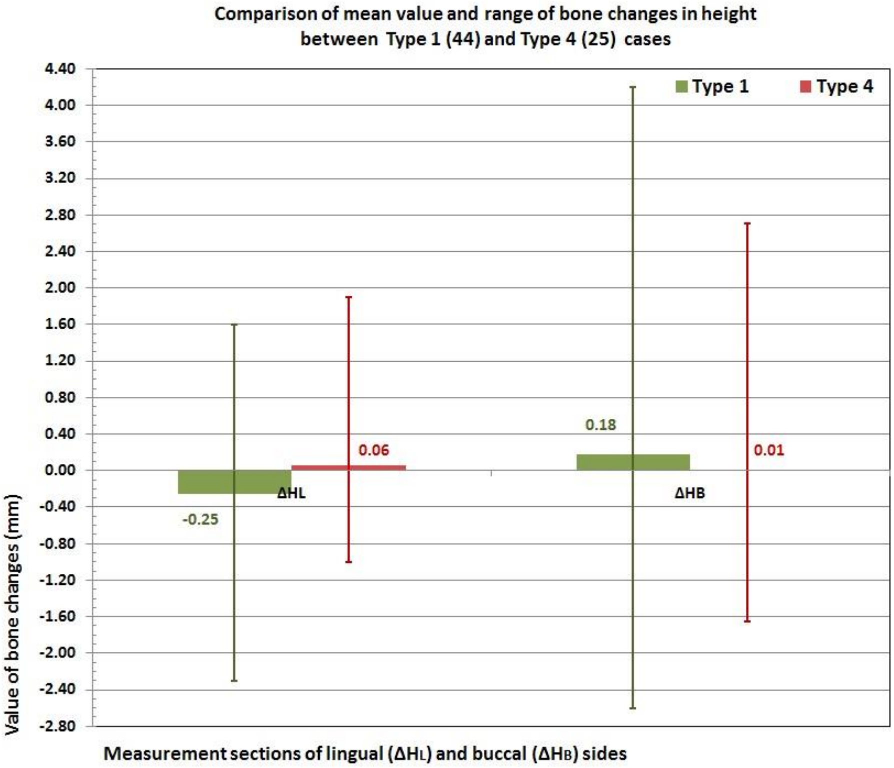


Figure 3–14. Comparison of mean value and bone changes in height between 44 Type 1 cases and 25 Type 4 cases.

In addition, SD of bone changes on most measurement sections of Type 1 cases was greater than Type 4 cases.

3.3.4.2 Comparison of Type 1 and Type 4 cases on mandible

In addition, all the data were categorized into mandible group and maxilla group. The assessment of difference in bone changes between Type 1 and Type 4 could then be located into maxilla and mandible separately. The L_0O_0 section was still excluded in the analysis, although it was still on the Figure 3–15 and Figure 3–17. Figure 3–15 displayed the mean value and range of bone changes in thickness of 31 Type 1 cases and 15 Type 4 cases on mandible.

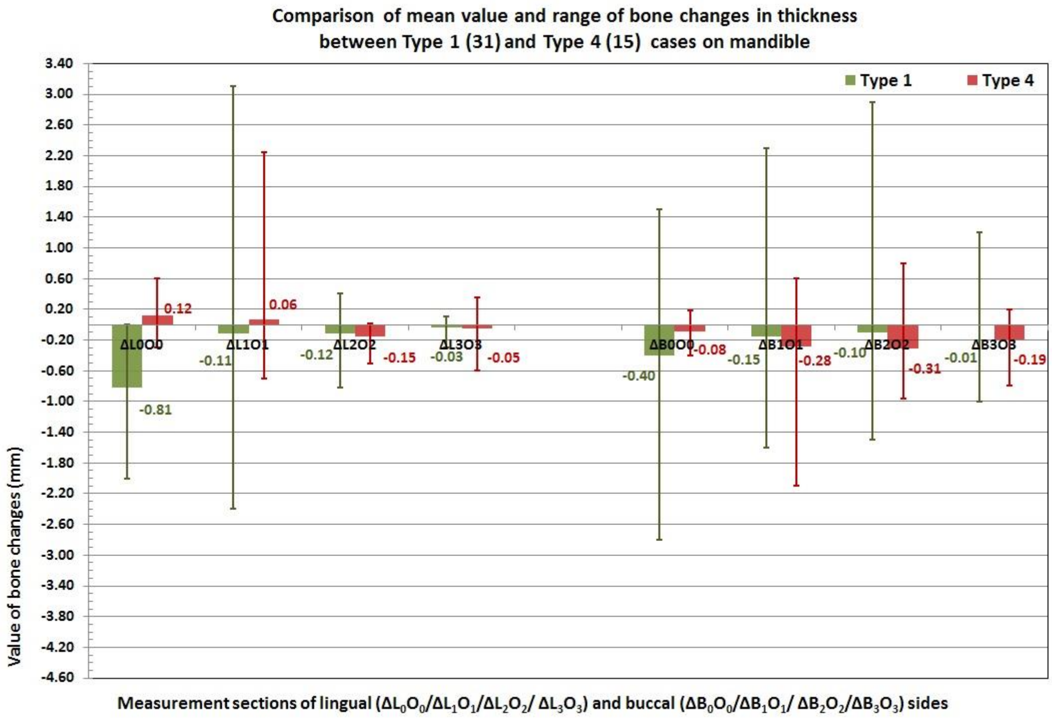


Figure 3–15. Comparison of mean value and bone changes in thickness between 31 Type 1 cases and 15 Type 4 cases on mandible.

It could be seem that bone thickness decreased more in Type 1 cases than Type 4 cases on mandible at B_0O_0 and L_1O_1section. On other sections, bone thickness decreased more in Type 4. According to the result of *t*-test in Table 3–8, there was significant difference in bone changes in thickness on mandible between Type 1 and Type 4 cases on B_0O_0 section (*$p<0.01$*) and L_3O_3 section (*$p<0.01$*). It showed bone thickness decreased more in Type 1 than Type 4 on B_0O_0 section, but less on L_3O_3 section. No significant difference was found between Type 1 and

Type 4 cases on L_1O_1 section (*p=0.831*); L_2O_2 section (*p=0.957*); and B_1O_1 section (*p=0.081*); B_2O_2 section (*p=0.095*); B_3O_3 section (*p=0.577*).

Table 3–8. Difference of bone changes on each section between 31 Type 1 and 15 Type 4 cases on mandible.

Variables / Sections	Type	Mean (mm)	SD (mm)	*P value*
ΔL_0O_0	Type 1	-1.18	1.40	NA
	Type 4	0.31	0.61	
ΔL_1O_1	Type 1	-0.11	0.91	0.831
	Type 4	0.06	0.77	
ΔL_2O_2	Type 1	-0.12	0.25	0.957
	Type 4	-0.15	0.20	
ΔL_3O_3	Type 1	-0.03	0.10	<0.01
	Type 4	-0.05	0.26	
ΔB_0O_0	Type 1	-0.92	1.70	<0.01
	Type 4	-0.27	0.43	
ΔB_1O_1	Type 1	-0.15	1.08	0.081
	Type 4	-0.28	0.71	
ΔB_2O_2	Type 1	-0.10	1.00	0.095
	Type 4	-0.31	0.48	
ΔB_3O_3	Type 1	-0.01	0.39	0.577
	Type 4	-0.19	0.29	
ΔH_L	Type 1	-0.12	0.76	0.127
	Type 4	-0.08	0.60	
ΔHB	Type 1	0.17	1.83	<0.05
	Type 4	0.17	0.95	

Figure 3–16 showed the mean value and range of bone changes in height of 31 Type 1 cases and 15 Type 4 cases on mandible together. The mean of bone changes in height increased at buccal side, but decrease at lingual side both in Type 1 Type 4 cases on mandible. And the range of bone changes in height was still wider in Type 1 cases than in Type 4 cases on both lingual and buccal sides. According to the result of *t*-test in Table 3–8, there was no significant difference in bone changes in height on mandible between Type 1 and Type 4 cases at

lingual side (*p=0.127*), but at buccal side (*p<0.05*) bone height increased significant more in Type 1 cases than Type 4 cases with bone augmentation procedure.

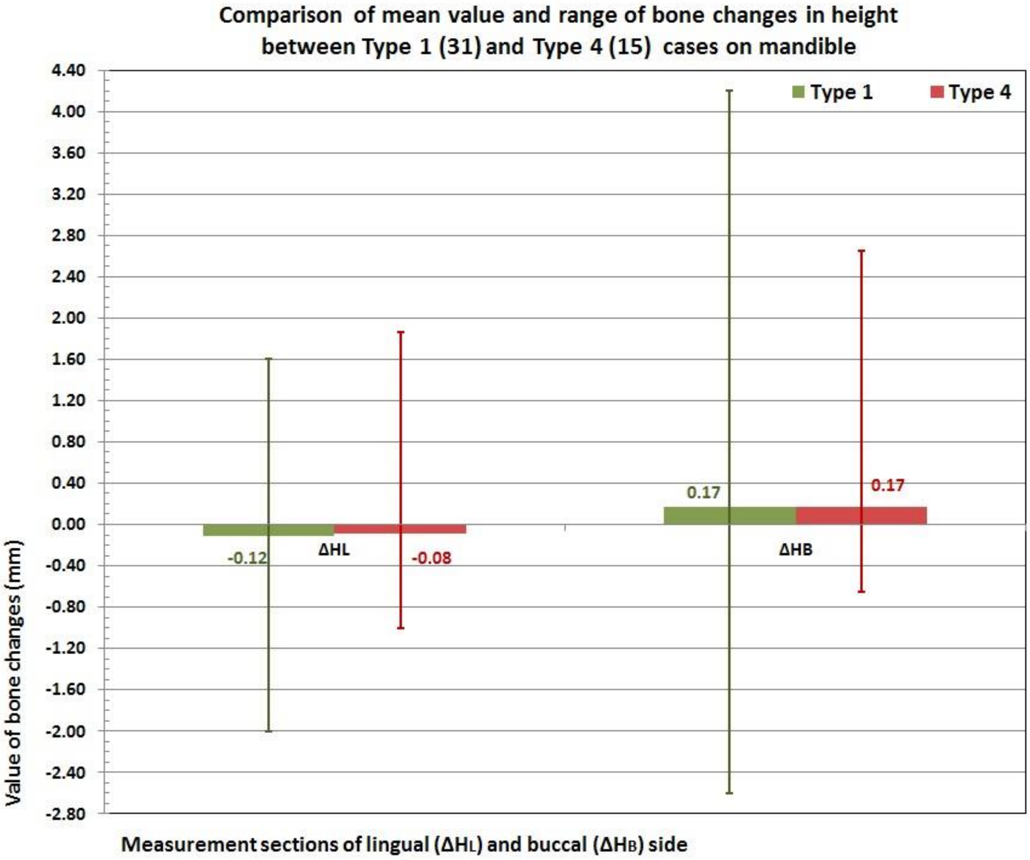


Figure 3–16. Comparison of mean value and bone changes in height between 31 Type 1 cases and 15 Type 4 cases on mandible.

3.3.4.3 Comparison of Type 1 and Type 4 cases on maxilla

Figure 3–17 displayed the mean value and range of bone changes in thickness of 13 Type 1 cases and 10 Type 4 cases on maxilla. It could be seem that the mean of bone changes in thickness decreased more in Type 1 cases than Type 4 cases on most sections, except B_0O_0 section. The range of bone changes was wider in Type 1 cases than in Type 4 cases on all sections.

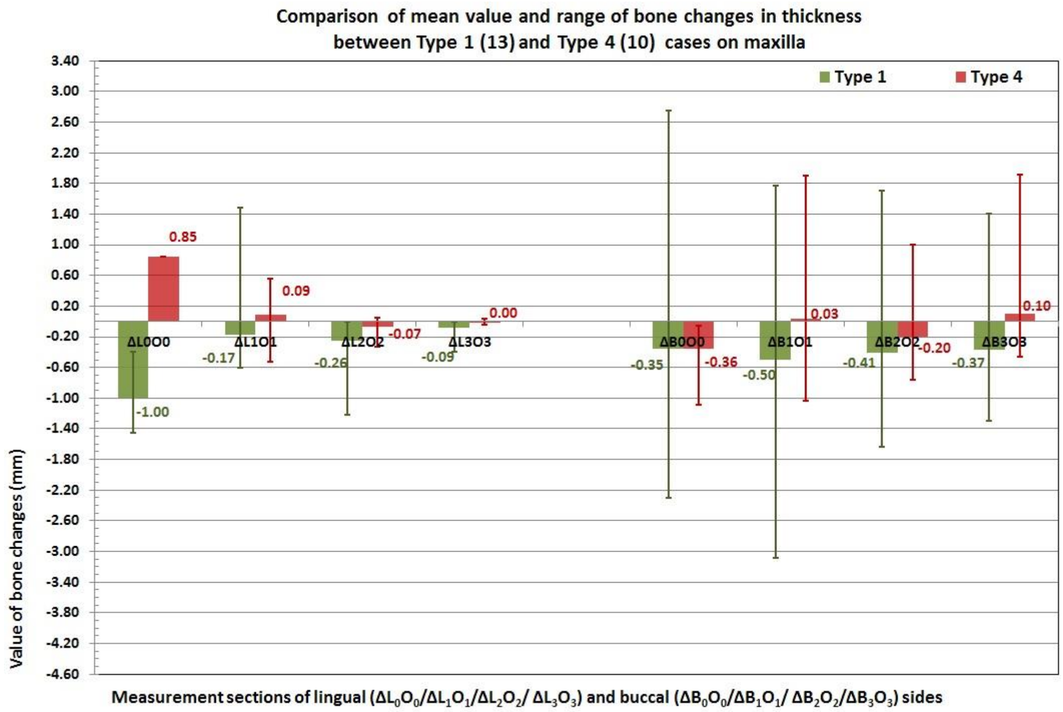


Figure 3–17. Comparison of mean value and bone changes in thickness between 13 Type 1 cases and 10 Type 4 cases on maxilla.

According to the result of *t*-test in Table 3–9, there was significant difference in bone changes in thickness on maxilla between Type 1 and Type 4 cases on B_0O_0 section ($p<0.05$); B_2O_2 section ($p<0.05$); L_3O_3 section ($p<0.01$). It showed bone thickness decreased more in Type 1 than Type 4 on B_2O_2 and L_3O_3 sections, but less on B_0O_0 section. And there was no significant difference between Type 1 and Type 4 cases on L_1O_1 section ($p=0.132$); L_2O_2 section ($p=0.227$); and B_1O_1 section ($p=0.320$); B_3O_3 section ($p=0.299$).

Table 3–9. Difference of bone changes on each section between 13 Type 1 and 10 Type 4 cases on maxilla.

Variables / Sections	Type	Mean (mm)	SD (mm)	*P value*
ΔL_0O_0	Type 1	-1.04	0.45	NA
	Type 4	0.15	0.99	
ΔL_1O_1	Type 1	-0.17	0.71	0.132
	Type 4	0.09	0.38	
ΔL_2O_2	Type 1	-0.26	0.31	0.227
	Type 4	-0.07	0.12	
ΔL_3O_3	Type 1	-0.09	0.14	<0.01
	Type 4	0.00	0.02	
ΔB_0O_0	Type 1	-0.40	1.92	<0.05
	Type 4	-0.66	0.79	
ΔB_1O_1	Type 1	-0.50	1.31	0.320
	Type 4	0.03	0.82	
ΔB_2O_2	Type 1	-0.41	0.96	<0.05
	Type 4	-0.20	0.49	
ΔB_3O_3	Type 1	-0.37	0.84	0.229
	Type 4	0.10	0.67	
ΔH_L	Type 1	-0.58	0.79	0.814
	Type 4	0.27	0.78	
ΔHB	Type 1	0.21	1.15	0.187
	Type 4	-0.22	0.69	

Figure 3–18 showed the mean value and range of bone changes in height of 13 Type 1 cases and 10 Type 4 cases on maxilla together. The mean of bone changes in height tended to increase at buccal side, and decrease at lingual side in Type 1 cases， but opposite in Type 4 cases. The range of bone changes in height was still wider in Type 1 cases than in Type 4 cases on both lingual and buccal sides.

According to the result of *t*-test in Table 3–9, there was no significant difference in bone changes in height on maxilla between Type 1 and Type 4 cases both at lingual and buccal side (*p=0.814*), and buccal side (*p=0.187*).

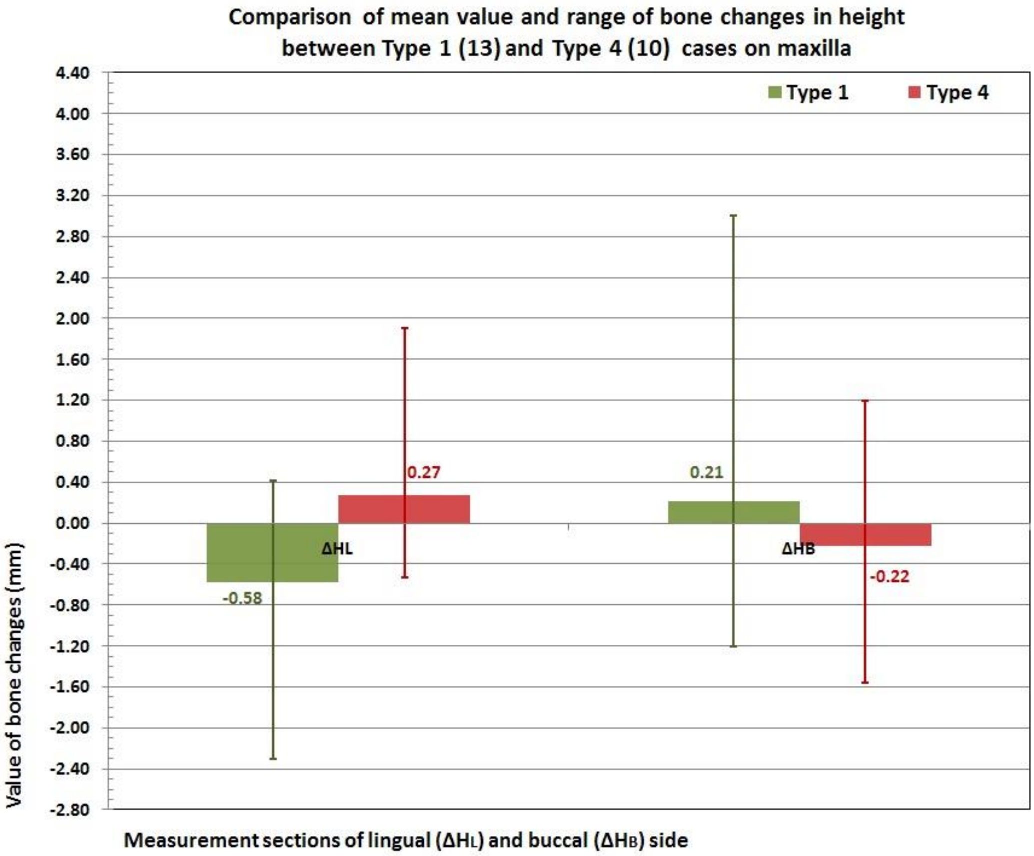


Figure 3–18. Comparison of mean value and bone changes in height between 13 Type 1 cases and 10 Type 4 cases on maxilla.

3.4 Discussion

The discussion was composed of four sections. The first and second sections discussed the results of each implant protocol of Type 1 and Type 4, in the aspects of: (1) changes in bone height; (2) changes in bone thickness; (3) clinical factors related to the results; (4) the comparison of bone changes between lingual and buccal sides; (5) the comparison of bone changes between maxilla and mandible. The third section was about the results of comparing the bone changes between Type 1 and Type 4. The forth section discussed the strength and weakness of this study.

3.4.1 Within Type 1 cases

(1) The results showed that in 44 Type 1 cases, the mean and SD of bone changes in height at lingual side was -0.25±0.79 mm (range -2.30 mm to +1.60 mm) and at buccal side was +0.18±1.64 mm (range from -2.60 mm to +4.20 mm). The SD and range were relatively large comparing to the mean, particularly at buccal side the range was -2.60 mm and +4.20 mm. It could be noticed that the mean of buccal bone changes in height was a positive number in this study. The bone height was found to be increased at 43% (19) cases at buccal side and 39% (17) cases at lingual side. The result was in line with many previous studies, although the bone height was not specified at lingual and buccal side in these researches. Tsuda et al. gave a close result in 10 patients with Type 1 implantation that an overall mean marginal bone changes was +0.10 mm one year after implantation (Tsuda et al. 2011). Additionally, Kan et al. gave a similar result from 23 Type 1 cases that the mean marginal bone change was +1.0±3.6 mm one year after implantation (Kan et al. 2007). Rossi et al. also stated there were substantial variations in alveolar bone and a vertical gain of about +3.2 mm at buccal side 4 months after implantation in 9 Type 1 cases. Botticelli carried out a 5-year follow up research in 18 patients with Type 1 implantation and illustrated overall bone gain amounted to +0.23±0.43 mm, among those, 6 implants (29%) exhibited loss of marginal bone (−0.22±0.22 mm), and 15 implants (71%) gained bone (+0.41±0.35 mm) (Botticelli et al. 2008).

However, not all of the related publications found the mean changes of bone height were increased by Type 1 implantation. Mazzocco et al. evaluated bone changes 6 months after Type 1 implantation in 30 patients and found reduced bone height in buccal and lingual were -0.48±1.35 mm and -0.58±1.51 mm (Mazzocco et al. 2016); similarly Botticelli et al. reported that the vertical bone crest decreased -0.3±0.6 mm at buccal side and -0.6±1.0 mm at lingual side 4 month after implantation in 21 Type 1 implantations (Botticelli et al. 2004a). Gher et al. stated bone resorption was -1.53 mm at the most coronal socket crest for 20 Type 1 with bone grafting cases 6 months after implantation. But crestal bone gain of +1.39 mm was also noted at the most apical socket crest and bone fill from the base of the deepest osseous defect was +5.68 mm (Gher et al. 1994). However with all of these studies, the SD was relatively large to the mean.

(2) The bone changes in thickness were similar as the bone height. Although all the mean value of bone changes in thickness was negative on all measurement sections, the SD was still large on most sections. On all sections, some cases showed bone thickness increase and some cases suffered bone thickness decrease. However, there was 75% (33 cases) at lingual side and 50% (22 cases) at buccal side were found no existing bone at the top of implant level. This result was correlated to the bone changes in height, with 50% cases of bone reduction at both lingual and buccal sides.

The mean value of bone change in thickness was -0.87±0.72 mm, -0.13±0.85 mm, -0.16±0.28 mm, -0.05±0.28 mm on L_0O_0, L_1O_1, L_2O_2, L_3O_3 sections; and -0.38±1.49 mm, -0.25±1.15 mm, -0.19±0.99 mm, -0.12±0.57 mm on B_0O_0, B_1O_1, B_2O_2, B_3O_3 sections. The results were similar to previous researches. Mazzocco et al. found the bone changes 6 months after Type 1 implantation were -0.64±0.81 mm, -0.59±1.36 mm, and -0.52±1.16 mm on section 2, 4 and 6 mm apical to implant platform in 30 patients (Mazzocco et al. 2016). They also showed bone decrease and increase in different cases. And Roe et al. stated that bone changes in thickness were -1.23±0.75 mm, -0.64±0.55 mm, -0.48±0.29 mm, -0.50±0.31 mm, -0.32±0.29 mm on the level of 0, 1, 2, 4, 6, and 9 mm apical to implant platform one year after implantation in 21 patients (Roe et al. 2012). Rossi et al. also investigated bone changes 4 month after implantation in 9 immediate implant cases and illustrated the mean of bone resorption was -1.9 mm, -1.0 mm, and -0.6 mm at buccal side and -0.6 mm, -0.7 mm, and -0.5 mm at lingual side at the measurements performed at 1, 3, and 5 mm apical to the crest, respectively (Rossi et al. 2013). In addition, Botticelli et al. claimed that the horizontal resorption of the buccal bone dimension amounted to about 56%, while it was 30% at lingual bone 4 month after Type 1 implantation (Botticelli et al. 2004a). Although the time points and measurement sections were not exact same in the present study and these cited studies, the tendency of bone changes was consistent. It could be observed the closer the measurement section to the implant top; the more distinct the bone changes and the larger SD could be expected.

(3) Bone grafting was almost used in all Type 1 cases. It has been suggested that bone grafting and flap surgery are possible to achieve an augmentation of bone dehisced sites associated with Type 1 implant placement protocol (Schwartz-Arad & Chaushu 1997, Schlegel & Donath 1998, Chen et al. 2004, Polyzois et al. 2007, Araujo & Lindhe 2009b). Therefore, the result of using bone graft technique was possible the primary reason for the bone increase in height and thickness. Mellati et al. also reported similar results in an animal study and stated the original bone in the coronal 2-3 mm of the buccal crest had completely resorbed and was replaced by a regenerated bone wall consisting of Bio-Oss particles surrounded by newly formed bone. And they also reposted there were one-third of implants exposed the implant surface ≥ 1mm due to the horizontal and vertical resorption of the buccal bone. However, in the present study, there was more cases (50%) having no bone at the level of implant top (Mellati et al. 2015).

The difference of local pathological condition could influence the range of SD in the bone changes in these 44 cases as well. In this study, root fracture and root canal therapy failure were main causes of teeth lost. However, in some cases with chronic infection, the alveolar bone adhered with the resident teeth which increased the difficulty of keeping integrity of alveolar bone during teeth extraction. In the cases of teeth trauma, there could be micro fracture on the buccal or lingual bone which leaded to the difference in bone remodeling in each case.

(4) Bone changes in thickness on each section were significant less at lingual side than buccal side in 44 Type 1 cases. This was similar with some previous studied (Botticelli et al. 2004a, Sanz et al. 2010, Brownfield & Weltman 2012, Degidi et al. 2012, Rossi et al. 2013). Furthermore, in the animal model, the lingual bone was relatively stable after extraction, compared with buccal bone (Araujo & Lindhe 2009a). In this study, although all the Type 1 implants placed “lingual” to keep enough gap for grafting, according to the surgical records, which could lead the implant neck to give pressure on the lingual bone and cause more resorption, the bone changes still showed more stable at lingual side.

With bone changes in height, different to the thickness, the buccal bone increased significantly more than lingual bone with bone augmentation procedure. No similar result was found in previous studies. However, Chen et al. stated that Bio-Oss significantly reduced horizontal resorption of buccal bone (Chen et al. 2007). And it could also be explained the original bone defect was bigger at buccal side than lingual side because of the surgical trauma of the tooth extraction, which required more bone grafting at buccal side. And this was reflected in higher quantity of bone grafting for the bone height re-building.

(5) Additionally, this study also tried to investigate the difference between maxillary cases and mandibular cases in Type1 group. There was no significant difference in bone changes between mandible and maxilla on all sections, except B_3O_3 section ($P<0.01$), although the bone mineral density for the mandible were significantly greater than that of the posterior maxilla (Devlin et al. 1998, Park et al. 2008).

3.4.2 Within Type 4 cases

(1) In these 25 Type 4 cases, one year after delayed implant placement, the mean value of bone changes in height at lingual side was -0.06±0.68 mm (range from -1.00 mm to 1.90 mm) and at buccal side was +0.01±0.86 mm (range from -1.56 mm to 2.80 mm). Some publications reported small mean value of bone changes in height, which was similar to present studies. Atieh et al. stated in a review that the average marginal bone loss was from -0.06 to -0.99 mm around platform-switched implants one year after implantation (Atieh et al. 2010). Felice et al declared that marginal bone lost on average -0.19 mm in 19 Type 4 case one year after loading (Felice et al. 2015). And Propser et al. assessed 60 patients and reported the marginal bone loss was on average of -0.021 mm one year after implantation (Prosper et al. 2009).

Additionally, the bone height was found to be increased in 32% (8) cases at buccal side 24% (7) cases at lingual side in present study. This result was consistent with some researches which also reported some cases with bone increase in height. Kan et al. stated a mean marginal bone loss of -1.6±1.9 mm in 38 Type 4 cases (Kan et al. 2007). A mean marginal bone loss was -0.22±0.47 mm with wide implants one year after implantation was reported by Liaje et al. (Liaje et al. 2012). Additionally, Jeong et al found the mean marginal bone loss was -0.3±0.4 mm one year after implantation in 432 Type 4 cases. And 125 implants experienced no bone loss at all, while 10 implants exhibited bone loss of >1.0 mm (Jeong et al. 2011). Similarly, Wennström et al. conducted a prospective studies of 40 Type 4 cases and reported 50% of the implants exhibited no bone loss after 5 years and that 28% of implants presented an improved bone height (>0.5 mm) (Wennstrom et al. 2005). The percentage of cases exhibited no bone loss is higher than that reported in present study.

However, there were several studied reported relatively large mean value of bone changes in height and no bone gain in Type 4 implantation. Nemli et al. assessed the mean marginal bone losses of -0.35±0.14 mm, -0.47±0.15 mm, and -0.58±0.16 mm at 6 months, 12 months, and 24 months after prosthetic loading in 72 patients (Nemli et al. 2016). Their value was similar to the result of a research carried out by Schincaglia et al in 30 patients. They found mean of radiographic bone loss was -0.54±0.5 mm one year after implantation for delayed loading, respectively (Schincaglia et al. 2016). And Bhat et al. stated that a mean bone loss of -0.61±0.36 mm was noted in the thick gingival group and -1.70±0.36 mm in the thin gingival group one year after implantation (Bhat et al. 2015). But, it could be noted that no bone augmentation procedure was applied in these studies.

(2) The bone changes in thickness were similar to the bone height. At all measurement sections, some cases suffered bone thickness decrease and some cases showed bone thickness increase. However, there was no bone at the level of implant top in 68% (17) cases at lingual side and 56% (14) cases at buccal side. This could also be correlated with the bone changes in height, 60% (15) cases with bone height decrease at lingual side and 48% (12) cases at buccal side.

The mean value of bone changes in thickness was +0.22±0.41 mm, +0.07±0.63 mm, -0.12±0.20 mm, -0.07±0.20 mm on L_0O_0, L_1O_1, L_2O_2, L_3O_3 section; and -0.19±0.34 mm, -0.16±0.76 mm, -0.26±0.48 mm, -0.07±0.49 mm on B_0O_0, B_1O_1, B_2O_2, B_3O_3 sections. There are few studies reported the bone horizontal changes in Type 4 implant placement protocol. Only one similar studies exploring the bone width changes on mandibular molar site at 0, 5, 10 mm below the level of crestal bone 4 year after Type 4 implantation in 13 cases with bone grafting. The average decease was -1.9±1.3 mm in the height and -0.05±0.9 mm in the width on 5 mm below the level of crestal bone. At 10 mm below the bone crest, it showed an average bone gain in width of +0.3±0.7 mm (Block et al. 2015). It also could be observed the closer the measurement section to the implant top; the more distinct the bone changes and the larger SD could be expected.

(3) Compared bone thickness and height changes between lingual and buccal, there was no significant difference on all section. However, the difference between lingual and buccal was found in Type 1 cases. The mean of bone changes in thickness was less at lingual side than buccal side, which could be partly contributed by the bone resorbed more at buccal side after extraction (Atwood 1957, Lekovic et al. 1997, Lekovic et al. 1998, Schropp et al. 2003b, Botticelli et al. 2004b, Araujo & Lindhe 2005, Araujo et al. 2005, Araujo et al. 2008). It should be noted that no previous studies evaluated lingual and buccal bone separately when evaluating the bone changes in height and thickness by Type 4 implantation.

(4) Furthermore, there was no significant difference in bone changes between mandible and maxilla on all sections, except L_3O_3 section. The bone changes on L_3O_3 section were very tiny. This was same to the results of Type 1 cases.

3.4.3 Between Type 1 and Type 4 cases

(1) The results illustrated bone height increased significantly more at buccal side in Type 1 cases than Type 4 cases with bone augmentation procedure. There were several researches and reviews agreed mean crestal bone level at 12 month after implantation was significantly better in Type 1 than Type 4 (Kan et al. 2007, Cooper et al. 2010, Kinaia et al. 2014). Kinaia et al. stated in a systemic review that better preservation of crestal bone level was found in Type 1 than Type 4 at one year after implantation by Meta-analyses (Kinaia et al. 2014). The result of the present study supported this viewpoint. Cooper et al. also found the mean marginal bone gained +1.30±2.52 mm in 58 Type 1 cases and loss -0.40±1.43 mm in 65 Type 4 cases one year after implantation with immediate loading. Kan et al. stated in 23 Type 1 cases the mean marginal bone change was +1.0±3.6 mm and in 15 Type 4 cases it was -1.6±1.9 mm. Furthermore, although Block et al stated no difference on bone changes between two protocols, they found the gingival margin reserved 1 mm more facial gingival margin position in Type 1 compared with Type 4 in 55 patients (Block et al. 2009). This could be explained by the bone gain after bone augmentation procedure in Type 1 cases. And, Raes et al. also observed that a trend towards bone gain was found following insertion in fresh extraction sockets and mean midfacial recession amounted less in 25 Type 1 cases than 23 Type 4 cases (Raes et al. 2013). Similar with the studies reporting marginal bone gain, bone augmentation was all applied during dental implant surgery (Lindeboom et al. 2006, Kan et al. 2007, Deng et al. 2010).

In addition, several reviews had stated that bone augmentation procedure might enhance the bone remodeling process in Type 1 implant placement protocol (Zitzmann et al. 1999, Nemcovsky & Artzi 2002, Chen et al. 2004, Hämmerle et al. 2004, Fugazzotto 2005, Siciliano et al. 2009, Ortega-Martinez et al. 2012). Therefore, the integrity of the socket after tooth extraction and with bone augmentation procedure could explain the positive crestal bone level for Type 1 group. It could be concluded bone augmentation procedures are more successful with Type 1 than Type 4 (Chen et al. 2004, Siciliano et al. 2009).

However, many researches declared that no difference of crestal bone changes between immediate and delayed implant placement (Paolantonio et al. 2001, Schropp et al. 2003a, Lindeboom et al. 2006, Jaffin et al. 2007, Palattella et al. 2008, Block et al. 2009, Deng et al. 2010, Esposito et al. 2010, Pal et al. 2011, Heinemann et al. 2013, Esposito et al. 2015, Felice et al. 2015, Gomez-Roman & Launer 2016). Chen et al. concluded in a review that no significant differences were found in radiographic crestal bone level or in probing depth at implants placed immediately, late, or delayed relative to tooth extraction (Chen et al. 2004). And peri-implant defects had a high potential for healing by regeneration of bone, irrespective of healing protocol and bone augmentation method. Actually, among these studies there were 4 studies showed less mean bone loss in Type 1 group compared with Type 4 group, although no significant difference was found (Lindeboom et al. 2006, Jaffin et al. 2007, Deng et al. 2010, Pal et al. 2011).

(2) It was stated in this study bone thickness decreased significantly more in Type 1 than Type 4 on B_0O_0 and B_1O_1 sections, but less on B_2O_2 section. However, Covani et al. said the pattern of coronal bone remodeling displayed a narrowing of the bucco-lingual width and was clinically similar for Type 1 and Type 4. But, simply comparing the bone change in Type 1 and Type 4 maybe is not fair. It should be emphasized that the Type 4 implantation exhibited smaller bucco-lingual bone width already at the first

time of implant surgery (Covani et al. 2004, Covani et al. 2014). Because there was plenty well-documented resorption of the alveolar ridges after tooth extraction and the greatest amount of bone loss is in the bucco-lingual (horizontal) dimension (Atwood 1957, Lekovic et al. 1997, Lekovic et al. 1998, Schropp et al. 2003b, Botticelli et al. 2004b, Araujo & Lindhe 2005, Araujo et al. 2005, Araujo et al. 2008). A review stated the reduction in width of the alveolar ridges was 3.87 mm (Van der Weijden et al. 2009). Moreover, the horizontal bone resorption of the socket is generally more pronounced at the buccal plate, and the vertical loss is more distinct on the buccal contour of the ridge as well (Pietrokovski & Massler 1967, Araujo & Lindhe 2005). This kind of resorption process results in a narrower and shorter ridge and the resorptive pattern relocates the ridge to a more palatal or lingual position (Pinho et al. 2006). And the width of the alveolar ridge reduced up to 50% during the 12 month after tooth extraction and proximately two thirds of this reduction occurred within the first 3 months (Schropp et al. 2003b). So the Type 1 protocol with bone augmentation procedure might show positive final esthetic outcomes. But more clinical trials still need to be carried out to get more information about the horizontal bone remodeling of Type 1 and Type 4 protocols

(3) In this study, all cases were categorized into mandibular and maxillary cases in order to explore the difference between Type 1 and Type 4 cases excluding the influence of jaw.

On mandible, bone thickness decreased significant more in Type 1 case than Type 4 cases on B_0O_0 section ($p<0.01$); but not on B_1O_1 section ($p=0.081$) and B_2O_2 section ($p=0.095$). And on B_1O_1 and B_2O_2 sections, bone tended to decreases more in Type 4 cases than Type 1 case. On maxillary, bone thickness decreased significant more in Type 1 case than Type 4 cases on

B_0O_0 section (*p<0.05*) and B_2O_2 section (*p<0.05*); but not on B_1O_1 section. It seems no matter on mandible or maxilla the bone tended to absorb more in Type 1 cases on B_0O_0 section. But on B_1O_1 and B_2O_2 sections on mandible, the performance of the bone thickness was on opposition to the results drawn from all cases. This could be explained that, on maxilla, the bone thickness decrease at a much higher level in Type 1 case compared with Type 4 case. It also might be caused by small sample size of maxillary Type 4 cases.

On other hand, the bone height gained more in Type 1 cases than Type 4 cases no matter on maxilla or mandible. This indicated Type 1 with bone augmentation procedure could re-build the vertical bone quantity both on maxilla and mandible to achieve a good esthetic outcome.

3.4.4 The strengths and weaknesses

The selection of CBCT data sets was retrospectively taken from the existing database, rather than randomized patients' recruitment. Therefore, it had less controlled in the uniformity of cases. However, the highly reliable and precise methodology provided the highly reproducible measurements. It avoided subjective judgment of gray shade and influence of metal artifact; carried out the measurement of bone changes based on good registration quality; and was based on the shifted datum within the reference frame. On top of these, few weaknesses were discussed as followings:

First, the SDs were all relatively large, the results of the mean value of bone changes couldn't show the real tendency of bone changes in each group. Additionally, since there were considerable discrepancies among different studies, comparison of the mean of bone changes with other studies may be complicated. Measurement methods, timing of assessment, and the position for measurement etc. were diverse in these related researches.

Second, at $L_0O_0B_0$ and $L_1O_1B_1$ sections, bone thickness was relatively thin. Gonzalez-Martin et al stated that measurement accuracy was significantly influenced by buccal bone thickness, especially if <1 mm, and in presence of peri-implant marginal defects (Gonzalez-Martin et al. 2015). Razavi et al. also emphasized the thin cortical bone adjacent to dental implant may not be accurate with a 0.3 mm resolution CBCT setting, but could be more precise with a 0.125 mm resolution CBCT setting. In this study, all the CBCT data sets were taken with 0.125 mm resolution.

Thirdly, it is widely accepted that the module of bone remodeling around implant is multifactorial. All confounding factors, such as occlusal forces, trauma during the surgical procedure, inflammation, implant bulk device design, loading time, socket expansion during implant placement etc. could have affected the long-term outcomes, not just the timing of implant placement after tooth extraction. The lack of control of the confounding factors limited the potential to draw robust conclusions on bone remodeling between two implant protocols in present study. Furthermore, the bone changes in Type 1 cases in this study were related with the post-extraction trauma, socket expansion during surgery, bone grafting, and bone remodeling. Especially, no related report or reference about socket expansion during surgery was found. It was also related with the original defect of the bone, the more bone defected, the more bone grafting used. However, different individual case has different protocol on whether the bone grafting or flap surgery was needed or what kind of implant system would be used. These factors were regarded as non-splittable parts of Type 1 and Type 4 implant placement protocols.

Regarding the sample size, although two groups in present study were unequal as 44 cases in Type 1 group and 25 cases in Type 4 group. The power calculation of sample size based on meaningful clinical difference of bone changes between two implantation protocols was indicated (page 109) as 0.9 mm. The cases collected in this study were capable for statistical analysis of bone changes in Type 1 and Type 4 groups, and comparisons in lingual and buccal sides. At the same time it indicated that was not enough samples of maxillary cases (13 in Type 1 group and 10 in Type 4 group) to do *t*-test between mandibular and maxillary cases. Furthermore, according to the result in this study, there was significant difference of bone changes between Type 1 and Type 4 cases on four measurements (B_0O_0, B_1O_1, B_2O_2, and H_B). The difference of the mean of bone changes was 0.35 mm, 0.09mm, 0.13mm, and 0.19mm on B_0O_0, B_1O_1, B_2O_2, and H_B respectively, which were all much smaller than 0.9 mm. If using these values to calculate the sample size, it would get a much bigger size. Therefore, it indicated the sample size in this study was still too small to get a solid conclusion. The result of this study was only supposed as cases report.

3.5 Conclusions

Type 1 implant placement protocol was proposed about 40 years ago (Schulte & Heimke 1976). With the advanced development of implant design and surface technology, immediate implant has become a common choice in tooth replacement therapy. And majority of patients are interested in shortening the treatment time between tooth extraction and implant placement. Although, in the literature, it has often been stated that one of the rationales of immediate implant placement is to prevent or at least minimize the loss hard tissue at the extraction socket, there are controversies exist on this issue whether the different timings of implant placement after extraction may lead to various bone remodeling results. According to the results of this study, large diversity of bone remodeling was in the collected cases both in Type 1 and Type 4 group. The most optimistic finding is the obvious bone gain at buccal side with bone augmentation procedure in Type 1 cases. This gave more evidence to support that Type 1 protocol could be considered in patients and sites with a low esthetic risk profile (Martin et al. 2007, Schropp & Isidor 2008).

4. Two Cases with Split Mouth Design

4.1 Introduction

In dental clinical trial, the researchers have the option to randomize treatments over individuals (mouth level) or over sites in mouth (site level). The most common split-mouth design is an example of a randomization scheme on site level where each of two treatments are randomly assigned to either the right or left halves of the dentition (Lesaffre et al. 2009). In 1968, Ramfjord et al. introduced the 'split-mouth' clinical trial when they compared the efficacy of two types of periodontal therapy by randomizing the treatment methods to half of each subject's dentition divided by the mid-sagittal plane between the central incisor teeth (Ramfjord et al. 1968). The advantage of the split-mouth design is that it removes much of the inter-subject variability and may increase the power of the study compared to the whole-mouth design. But, there are several disadvantage of split-mouth design, such as biased treatment efficacy estimates due to carry-across effects; recruitment of patients is hampered because of the need for symmetrical disease patterns; complication of the statistical analysis of a split-mouth design (Hujoel & Loesche 1990, Hujoel & DeRouen 1992, Hujoel 1998). Moreover, it is obviously difficult to obtain cases with Type 1 and Type 4 implantation in spilt-mouth design, which may provide more accurate information of the difference in bone changes around implant.

Among all the cases collected in Chapter 3, there were two paired CBCT data sets in split-mouth design. Although the sample size was small (only 2), it could be a good case report and provided valuable information for clinical treatments. In this Chapter, a comprehensive analysis of these two cases was carried out.

4.2 Materials and Methods

One case was from a 30-year-old male patient who received a Type 1 implantation on the site of maxillary right first premolar (14) and a Type 4 implantation on the site of maxillary left first premolar (24) simultaneously. NobelReplace Tapered Groovy (3.5 mm diameter, 13 mm length) was used in both implantations. On the site of 14, 0.5g Bio-oss and 13*25 mm^2 Bio-Gide was used because the defect of bone wall at buccal side was more than 3 mm. On the site of 24, only 0.25g Bio-oss was used.

The other case was from a 34-year-old male patient who received a Type 1 implantation on the site of mandibular right first molar (46) and a Type 4 implantation on the site of mandibular left first molar (36) simultaneously. NobelReplace Tapered Groovy (5 mm diameter, 13 mm length) was used in both implantations. No bone augmentation surgery was applied to these two implantations, because the site of 46 was only with a very short residual tooth root and the bone quantity was enough in both surgical sites.

Figure 4–1 and Figure 4–2 displayed the CBCT images of these two cases. Since they were 3D CBCT images, it was hard to simultaneously locate symmetrical implantation sites both in the position cross the central of implant. However, the figures still display the situation clearly, in which Type 1 was carried out on right site and Type 4 on left site.

The measurement strategy utilized in Chapter 3 was also applied for the bone changes measurement in these two cases.

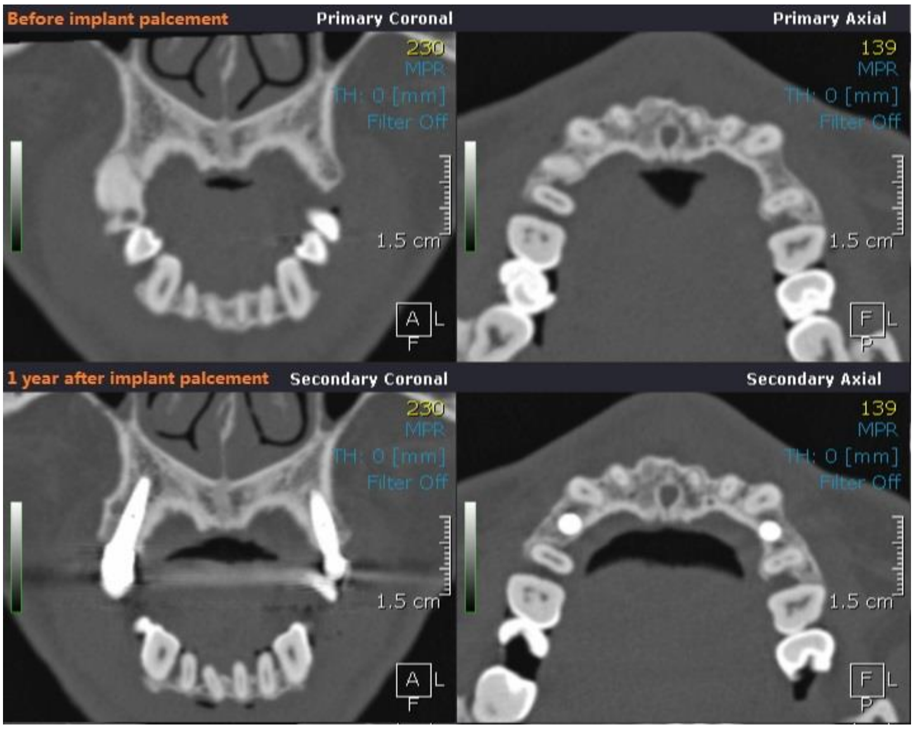


Figure 4–1. The split-mouth design of maxillary first premolar, Type 1 on site of 14 and Type 4 on site of 24.

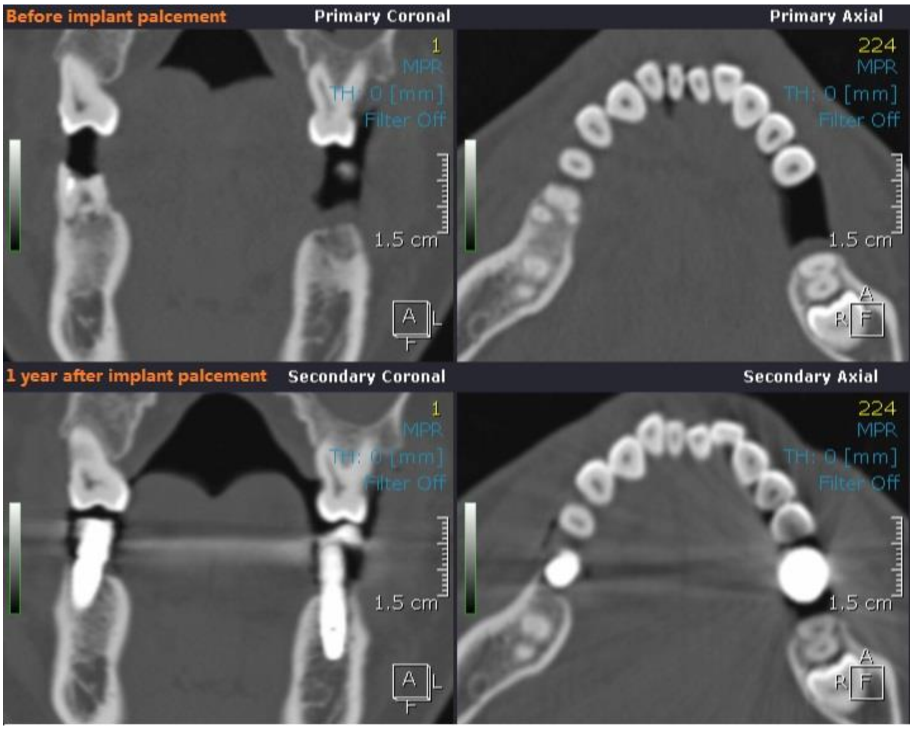


Figure 4–2. The split-mouth design of mandibular first molar, Type 1 on site of 46 and Type 4 on site of 36.

4.3 Results

4.3.1 Maxillary first premolar case

The bone changes on each measurement section of the maxillary right first premolar case in Type 1 protocol were -0.40 mm, -0.60 mm, -0.30 mm, -0.10 mm at ΔL_0O_0, ΔL_1O_1, ΔL_2O_2, ΔL_3O_3 section; were 0.50 mm, 1.00 mm, 1.70 mm, 1.40mm at ΔB_0O_0, ΔB_1O_1, ΔB_2O_2, ΔB_3O_3 section; were -2.30 mm and -1.20 mm at ΔH_L and ΔH_B section. In Type 4 protocol on the site if maxillary left first premolar, they were ‘A’, 0.45 mm, -0.20 mm, 0 at ΔL_0O_0, ΔL_1O_1, ΔL_2O_2, ΔL_3O_3 section, were ‘A’, 1.30 mm, 1.00 mm, 0.20 mm at ΔB_0O_0, ΔB_1O_1, ΔB_2O_2, ΔB_3O_3 section, were 1.90 mm and 1.20 mm at ΔH_L and ΔH_B section. Figure 4–3 and Figure 4–4 showed comparison of the bone changes on each measurement section between Type 1 and Type 4 implantation in this maxillary first premolar spilt-mouth design.

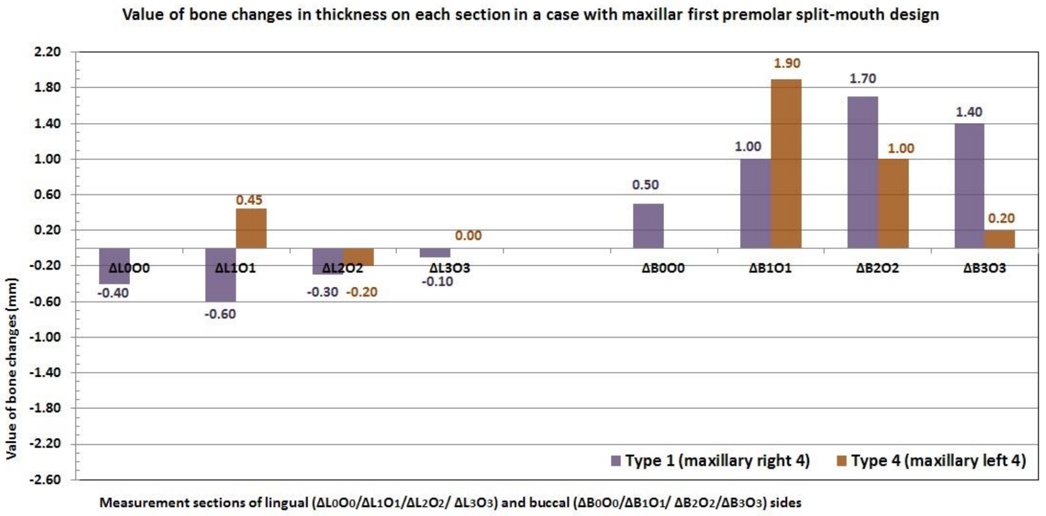


Figure 4–3. Comparing the value of bone changes in thickness one year after placement between Type 1 (maxillary right 4) and Type 4 (maxillary left 4) implant placement with a split-mouth design.

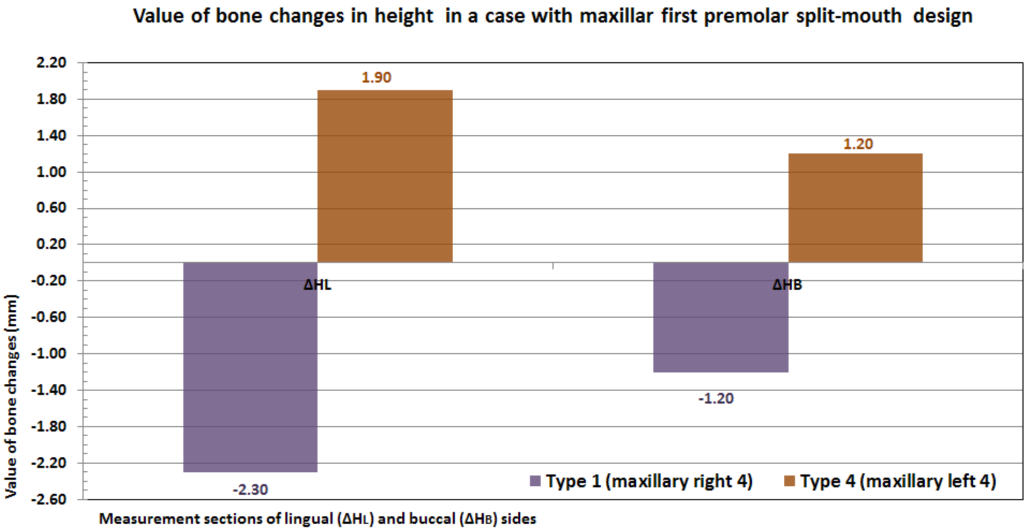


Figure 4–4. Comparing the value of bone changes in height one year after placement between Type 1 (maxillary right 4) and Type 4 (maxillary left 4) implant placement with a split-mouth design.

With the bone augmentation procedure, there was still no bone detected at the level of implant top in Type 4. But in Type 1, the level of bone height kept on the level of implant top. It seemed bone augmentation procedure worked better in Type 1. However, the bone height increased on both lingual and buccal side in Type 4, but decreased in Type 1.

It could be noticed that the bone changes in thickness were less than 0.5 mm on most section of lingual side both in Type 1 and Type 4, which might not be clinically important. Except on the L_1O_1 section of Type 1, the bone thickness decreased 0.60 mm, while that increased 0.45 mm in Type 4. This indicated that on the section 1 mm below the top pf implant was vulnerable to undergo more bone changes compared with other sections at lingual side.

On the other hand, bone thickness increased on all sections of buccal side both in Type 1 and Type 4 with bone augmentation procedure. Except on B_1O_1 section, bone increased more in Type 1 than in Type 4. And all the values of Type 1 were of ≥0.5 mm, with a maximum value of 1.70 mm. In Type 4, the bone thickness also increased with a maximum value of 1.90 mm on B_1O_1 section.

In this case, bone augmentation procedure performed well both in two protocols, no matter in bone thickness or bone height dimension. And bone gained more at buccal side.

4.3.2 Mandibular first molar case

The bone changes on each measurement section of the mandibular right first molar case in Type 1 protocol were -2.50 mm, -0.70 mm, 0, 0 at ΔL_0O_0, ΔL_1O_1, ΔL_2O_2, ΔL_3O_3 section; were -2.60 mm, -0.80 mm, -0.50 mm, -0.1 mm at ΔB_0O_0, ΔB_1O_1, ΔB_2O_2, ΔB_3O_3 section; were -1.00 mm and -1.50 mm at ΔH_L and ΔH_B section. In Type 4 protocol on the site of mandibular left first molar, they were 'A', -0.70 mm, -0.50 mm, and -0.6 mm at ΔL_0O_0, ΔL_1O_1, ΔL_2O_2, ΔL_3O_3 section; were -0.60 mm, 0, -0.30 mm, -0.60 mm at ΔB_0O_0, ΔB_1O_1, ΔB_2O_2, ΔB_3O_3 section, were -0.50 mm and -0.40 mm at ΔH_L and ΔH_B section. Figure 4–5 and Figure 4–6 showed comparison of the bone changes on each measurement section between Type 1 and Type 4 implantation in this mandibular first molar spilt-mouth design.

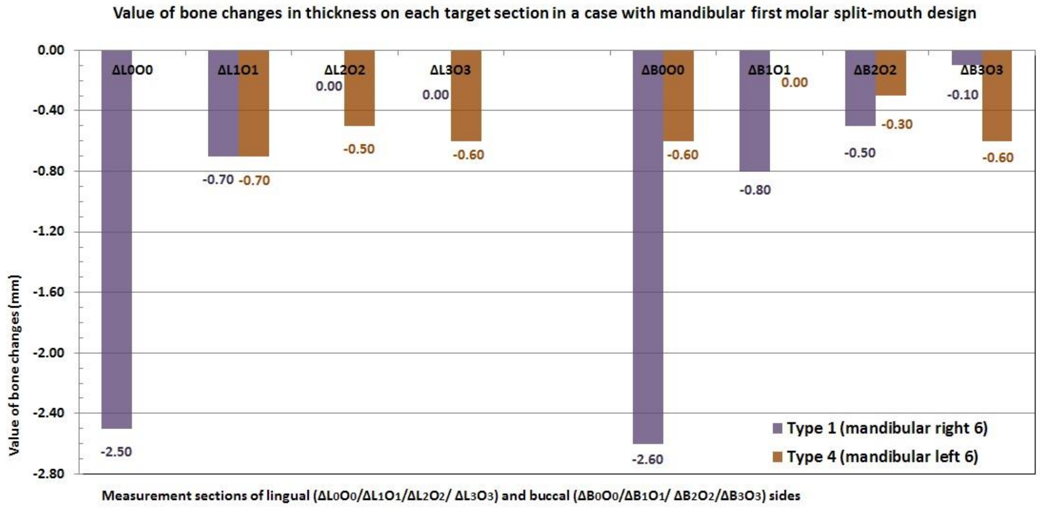


Figure 4–5. Comparing the value of bone changes in thickness one year after implant placement between Type 1 (mandibular right 6) and Type 4 (mandibular left 6) implant placement in a split-mouth design case.

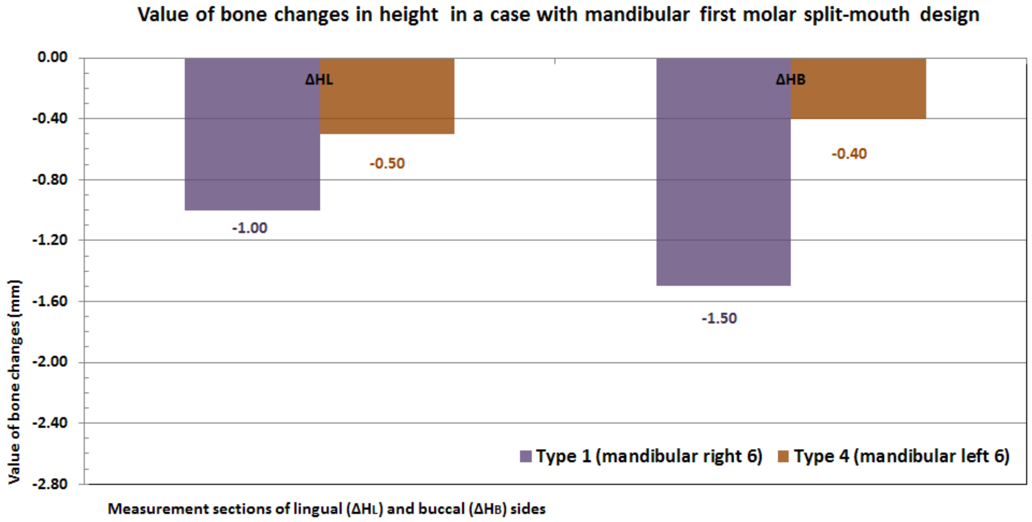


Figure 4–6. Comparing the value of bone changes in height one year after placement between Type 1 (mandibular right 6) and Type 4 (mandibular left 6) implant placement in a split-mouth design case.

In this mandibular first molar case, no bone augmentation surgery was applied and bone decreased on all sections no matter in Type 1 or Type 4. The bone height decreased much more in Type 1 than Type 4. And bone height decreased more at buccal side (1.50 mm) than lingual side (1.00 mm) in Type 1, but only 0.1mm difference in Type 4.

It could be noted that the bone changes in thickness in Type 1 protocol were most pronounced on $L_0O_0B_0$ and $L_1O_1B_1$ sections and no obvious clinical difference was found between lingual and buccal sides. In Type 4, bone changes in thickness were relatively less on $L_0O_0B_0$ and $L_1O_1B_1$ sections compared with Type 1. But, on L_2O_2, L_3O_3, B_3O_3 sections, Type 4 protocol showed more bone thickness decrease compared with Type 1. However, the values of these bone changes were of ≤0.6 mm which might not be clinically important. This further indicated that on the section 1 mm below the top of implant was vulnerable to undergo more bone changes compared with other section no matter at lingual or buccal sides.

4.4 Discussion

Hujoel & Loesche stated patients with symmetric disease distribution are difficult to find, then a whole-mouth design may be more advantageous (Hujoel & Loesche 1990). It is very difficult to find patients who are suitable to receive a Type 1 implantation and a Type 4 implantation on symmetric sites on the dentition. Therefore, these two spilt-mouth design cases provided valuable supplementary information of bone changes around implant in Type 1 and Type 4 protocols, with and without bone augmentation procedure.

There are lots of factors contributing to the marginal bone loss. In the consensus meeting in 2012, most of the scholars agreed, it related to the restoration designing (screw retain vs. cement retain), fundamental diseases (periodontitis, RCT failure, trauma or congenial lost), implant designing (surface treatment, coronal thread, macro thread pitch, connection), patients habit (Smoking or nonsmoking), et al. (Albrektsson et al. 2012, Qian et al. 2012). In these two cases, Type 1 and Type 4 showed difference in bone changes in height and width, although other factors have been controlled, same teeth lost reason (RCT Failure), same surgeon, same implant (NobelReplace Tapered Groovy), and same restoration.

In the maxillary first premolar cases, the results confirmed that bone gain could be achieved by augmentation procedure both in Type 1 and Type 4. This was in line with the result found in Chapter 3 and similar to previous studies (Gher et al. 1994, Chen et al. 2007, Raes et al. 2011, Kinaia et al. 2014, Mazzocco et al. 2016). However, in this case, vertical bone gain was found in Type 4, instead of Type 1. This was different with the conclusion in Chapter 3. Therefore, it further illustrated the value of bone changes in this study related to the post-extraction trauma, bone grafting, original defect of bone, and bone remodelling. In this case, there was more original defect of bone in Type 4.

Bone grafting was successful in the maxillary first premolar case, although it was comprised of buccal bone defect over 3 mm and thin gingival biotype. On the contrast, the mandibular first molar case without bone grafting show bone decrease on all measurement sections, especially buccal bone, even the buccal bone was contacted over 2 mm in width and thick gingival biotype. Additionally, the bone height and bone thickness on $L_0O_0B_0$ and $L_1O_1B_1$ sections decreased more in Type 1 compared with Type 4. And the vertical bone decreased more at buccal side than lingual side in Type 1. This still could be explained that the Type 4 exhibited smaller bucco-lingual bone width already at the first time of implant surgery. Since it has been widely agreed buccal bone absorb more than lingual bone after extraction, one reason for the more bone resorption at buccal sides in Type 1 protocol could be the post-extraction bone resorption (Pietrokovski &

Massler 1967, Schropp et al. 2003b, Araujo & Lindhe 2005, Van der Weijden et al. 2009).

Both of these two spilt-mouth design cases showed pronounced bone changes on the level of implant top and 1 mm below, but slightly on the two lower sections. This was also same to the result in Chapter 3, in which it was stated the value of bone changes below half-length of implant was relatively small and no clinical importance.

5. 1 Year VS 2 Years after Implant Placement

5.1 Introduction

It has been stated that early crestal bone loss is often pronounced in the first year after implantation and minimal bone loss is of ≤0.2 mm annually thereafter (Oh et al. 2002, Wennstrom et al. 2004, 2005, Horwitz et al. 2007, Botticelli et al. 2008, Cochran et al. 2009, Eliasson et al. 2009, Nemli et al. 2016, Voss et al. 2016).

Cochran et al. claimed that clinically significant marginal bone remodelling occurred between the time of implant placement and final prosthesis placement, and after that, bone loss around implant up to 5 years post-loading was minimal (Cochran et al. 2009). They assessed 596 dental implants placed in 192 patients and found the mean marginal bone loss occurred during the first 6 months after implantation was -2.44±1.20 mm with clinically significant. After that, -0.22±0.42 mm of bone loss occurred between the time of prosthesis placement and one year post-loading; and -0.18±0.88 mm between one year post-loading and the last 5-year recall, which was clinically insignificant. 86% of the mean bone loss over 5 years was accounted at the time of prosthesis placement. This conclusion was agreed by Covani et al. who assessed the changes of marginal bone level in 47 patients with Type 1 implantation. The mean values of marginal bone changes at the 1, 3, and 5 years follow-up were -0.68±0.39 mm, -0.94±0.44 mm, and -1.08±0.43 mm. 63% of the total mean bone loss occurred with the first year after implantation (Covani et al. 2014). Nemli et al. also showed a similar tendency in the research with 255 implants placed in 72 patients. The mean marginal loss were -0.35±0.14 mm, -0.47±0.15 mm, and -0.58±0.16 mm at 6, 12, and 24 months after prosthesis placement, respectively (Nemli et al. 2016).

In addition, Botticelli et al. obversed bone changes around implant in 21 Type 1 cases with bone augmentation procedure and claimed an overall bone gain amounted to +0.23±0.43 mm 5 years after implantation, with 6 implants (29%) exhibiting some loss of marginal bone (−0.22±0.22 mm) and the remaining 15 implants (71%) gaining bone (+0.41±0.35 mm). But they stated most bone change occurred during the first year following baseline. Only a few implants exhibited additional minor bone change in the interval between 1 and 5 years. (Botticelli et al. 2008). This is in agreement with the reuslts conculded from a prospective study of 40 Type 4 cases by Wennström et al. (Wennstrom et al. 2004, 2005). They not only reported that most bone change occurred during the first years after loading with only a minor changes took place subsequently but aslo found that 50% of the implants exhibited no bone loss after 5 years and that 28% of implants presented an improved bone height (>0.5 mm).

Among all the cases collected in Chapter 3, three paired CBCT data sets in Type 1 implant placement protocol had extra CBCT data set taken two years after implantation. Bone changes of these cases on each defined measurement sections was assessed 1 and 2 year after implantation and compared with the previous studies. Therefore, this chapter was a cases report of these three 2-year follow-up Type 1 cases.

5.2 Materials and methods

Two cases were from a 49-year-old female patient who received a Type 1 implantation on the site of maxillary left first premolar (24) and maxillary right second premolar (15) simultaneously. NobelReplace Tapered Groovy (4.3 mm diameter, 13 mm length) and 0.25g Bio-oss were used in both implantations.

Another case was from a 46-year-old male patient who received a Type 1 implantation on the site of mandibular left first molar (36). NobelReplace Tapered Groovy (5 mm diameter, 13 mm length) and 0.25g Bio-oss were used in the implantation.

The measurement strategy utilized in Chapter 3 was applied to the measurement of bone changes for these three cases. It should be noted that 3 CBCT data sets of one case were registered with each other and superimposed properly. This step made the target coronal planes for measurement locate on the same position in 3 CBCT data sets taken in different times. And the sagittal, axial, and coronal axes of three CBCT data sets were in the same position and direction as well (Figure 5–1, Figure 5–2, Figure 5–3).

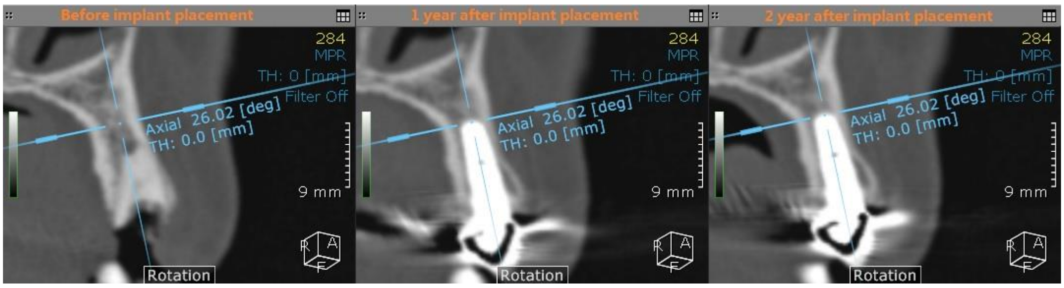


Figure 5–1. Target measurement coronal images of maxillary left first premolar case which were taken before, 1 year and 2 year after implant placement were exactly on the same position. The slice number and the rotation degree were same.

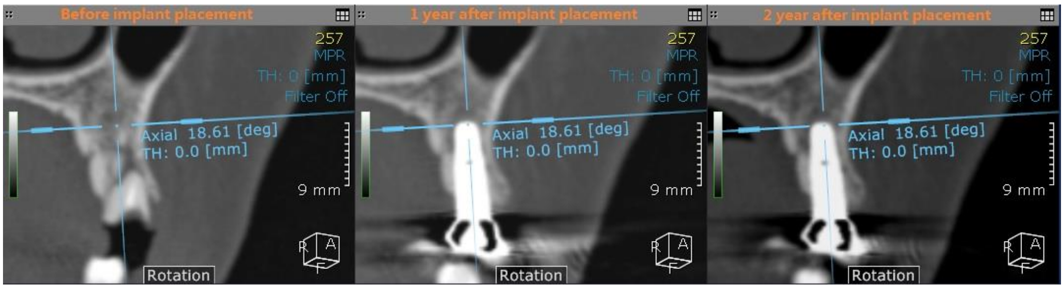


Figure 5–2. Target measurement coronal images of maxillary right second premolar case which were taken before, 1 year and 2 year after implant placement were exactly on the same position. The slice number and the rotation degree were same.

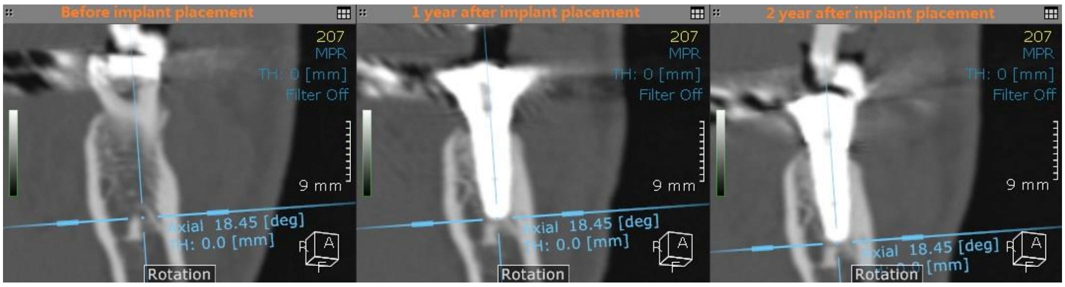


Figure 5–3. Target measurement coronal images of mandibular left first molar case which were taken before, 1 year and 2 year after implant placement were exactly on the same position. The slice number and the rotation degree were same.

5.3 Results

5.3.1 Maxillary left first premolar case

The bone changes on each measurement section of the maxillary left first premolar case one year after implantation were 'A', -0.50 mm, -0.10 mm, -0.10 mm at ΔL_0O_0, ΔL_1O_1, ΔL_2O_2, ΔL_3O_3 section; were -0.80 mm, -0.60 mm, -0.60 mm, -0.80 mm at ΔB_0O_0, ΔB_1O_1, ΔB_2O_2, ΔB_3O_3 section; were -0.50 mm and -0.90 mm at ΔH_L and ΔH_B section. After two years, the bone changes were 'A', -0.60 mm, -0.20 mm, -0.20 mm at ΔL_0O_0, ΔL_1O_1, ΔL_2O_2, ΔL_3O_3 section; were -0.80 mm, -0.60 mm, -0.60 mm, -0.70 mm at ΔB_0O_0, ΔB_1O_1, ΔB_2O_2, ΔB_3O_3 section; were -0.70 mm and -1.00 mm at ΔH_L and ΔH_B section.

Compared with the bone changes one year after implantation, the bone decreased -0.10 mm, -0.10 mm, -0.10 mm at ΔL_1O_1, ΔL_2O_2, ΔL_3O_3 section; 0, 0, 0 at ΔB_0O_0, ΔB_1O_1, ΔB_2O_2 section; -0.2 mm and -0.10 mm at ΔH_L and ΔH_B section during the second year (Figure 5–4, Figure 5–5). But it increased +0.10 mm at ΔB_3O_3 section, which might be caused by measurement error.

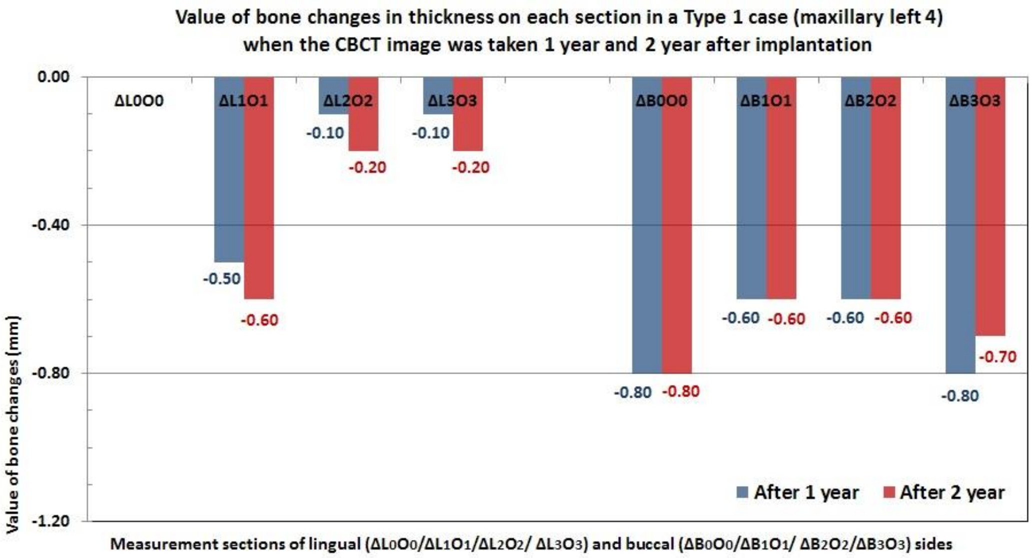


Figure 5–4. Comparing the value of bone changes in thickness on each section between one year after and two year after implantation of a maxillary left first premolar case.

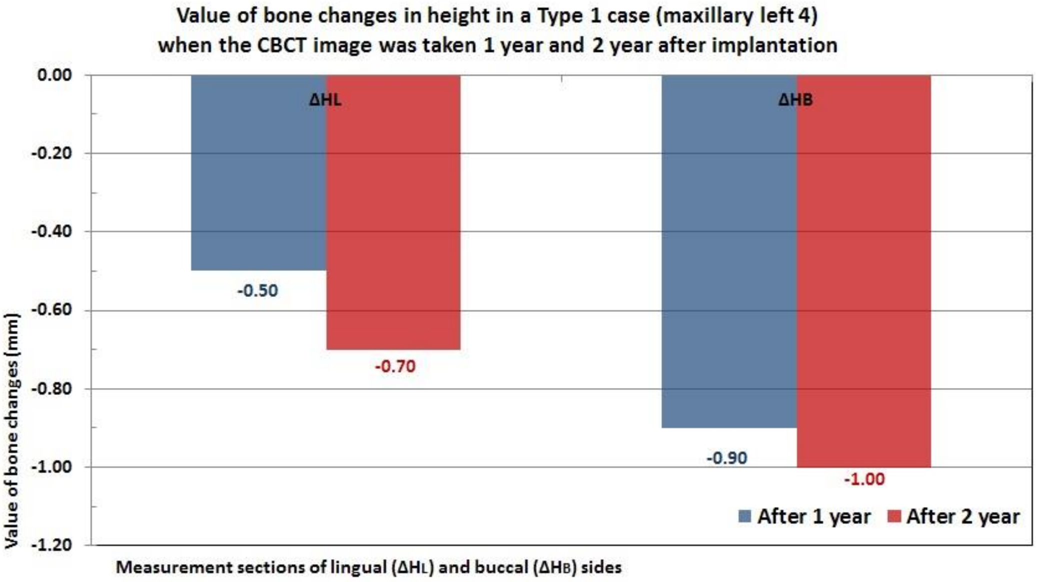


Figure 5–5. Comparing the value of bone changes in height between one year after and two year after implantation of a maxillary left first premolar case.

In this case, the bone grafting didn’t preserve the bone crest properly. Bone height decrease -0.9m at buccal side and -0.50 mm at lingual side in the first year, which was along with bone thickness decrease at the level of implant top. So, there was no lingual bone at the level of implant top and buccal bone thickness loss of -0.80 mm. And bone decreased on all measurement sections. However, bone changes on each section were very slight during the second year, which was of ≤0.20 mm.

5.3.2 Maxillary right second premolar case

The bone changes on each measurement section of the maxillary right second premolar case one year after implantation were 'A', 'A', -0.30 mm, and -0.10 mm at ΔL_0O_0, ΔL_1O_1, ΔL_2O_2, ΔL_3O_3 section; were +2.75 mm, -0.20 mm, 0, -0.40 mm at ΔB_0O_0, ΔB_1O_1, ΔB_2O_2, ΔB_3O_3 section; were -0.40 mm and +0.70 mm at ΔH_L and ΔH_B section. After two years, the bone changes were 'A', 'A', -0.50 mm, and -0.10 mm at ΔL_0O_0, ΔL_1O_1, ΔL_2O_2, ΔL_3O_3 section; were +2.65 mm, -0.30 mm, -0.20 mm, -0.40 mm at ΔB_0O_0, ΔB_1O_1, ΔB_2O_2, ΔB_3O_3 section, were -0.40 mm and +0.70 mm at ΔH_L and ΔH_B section.

Compared with the bone changes one year after implantation, the bone decreased -0.20 mm, 0 at ΔL_2O_2, and ΔL_3O_3 section, -0.1 mm, -0.1 mm, -0.2 mm, 0 at ΔB_0O_0, ΔB_1O_1, ΔB_2O_2, ΔB_3O_3 section, 0 and -0.10 mm at ΔH_L and ΔH_B section during the second year (Figure 5–6, Figure 5–7).

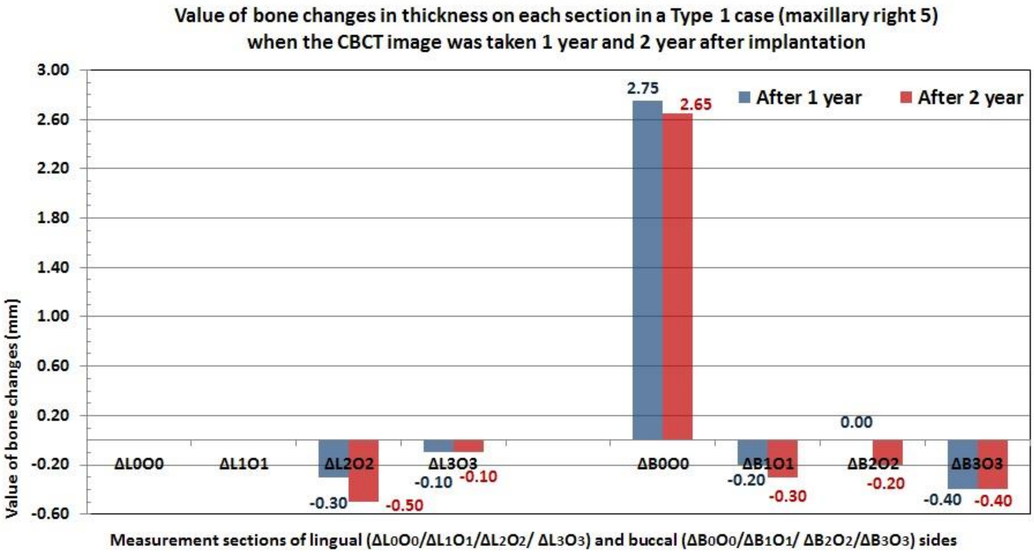


Figure 5–6. Comparing the value of bone changes in thickness on each section between one year after and two year after implantation of a maxillary right second premolar case.

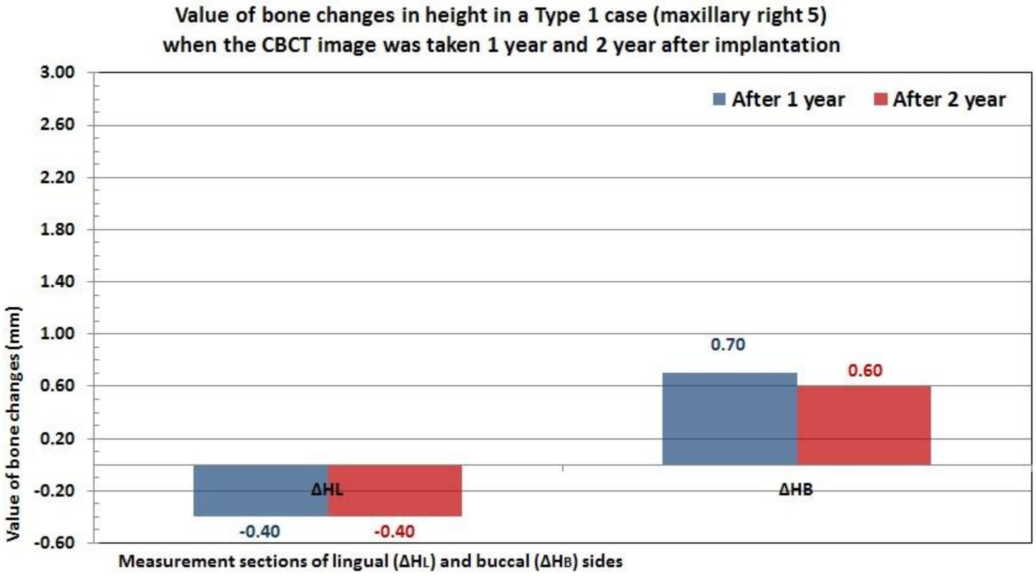


Figure 5–7. Comparing the value of bone changes in height between one year after and two year after implantation of a maxillary right second premolar case.

In this case, pronounced bone gain was detected at buccal side, with +2.75 mm buccal bone thickness increase at level of implant top and +0.70 mm buccal bone height increase. But bone decreased on all other measurement sections.

Especially at lingual side, bone absorbed both horizontally and vertically. No bone was detected even on the level of ΔL_1O_1 section and the lingual bone height decreased -0.40 mm. However, bone changes still happened mostly during the first year and were very slightly during the second year, which was of ≤0.20 mm.

5.3.3 Mandibular left first molar case

The bone changes on each measurement section of the mandibular left first molar case one year after implantation were -1.50 mm, -0.90 mm, -0.40 mm, -0.30 mm at ΔL_0O_0, ΔL_1O_1, ΔL_2O_2, ΔL_3O_3 section; were -1.60 mm, +0.30 mm, +0.80 mm, 0 at ΔB_0O_0, ΔB_1O_1, ΔB_2O_2, ΔB_3O_3 section; were -2.00 mm and -2.30 mm at ΔH_L and ΔH_B section. After two years, the bone changes were -1.50 mm, -0.90 mm, -0.50 mm, -0.40 mm, -0.30 mm at ΔL_0O_0, ΔL_1O_1, ΔL_2O_2, ΔL_3O_3 section; were -1.60 mm, -0.20 mm, +0.60 mm, and -0.20 mm at ΔB_0O_0, ΔB_1O_1, ΔB_2O_2, ΔB_3O_3 section; were -2.00 mm and -3.40 mm at ΔH_L and ΔH_B section.

The bone further decreased of -0.50 mm, -0.20 mm, -0.20 mm, and -1.10 mm at ΔB_1O_1, ΔB_2O_2, ΔB_3O_3, and H_B sections during the second year respectively, compared with the bone changes one year after implantation. And no further bone absorbed on other measurement sections (Figure 5–6, Figure 5–7).

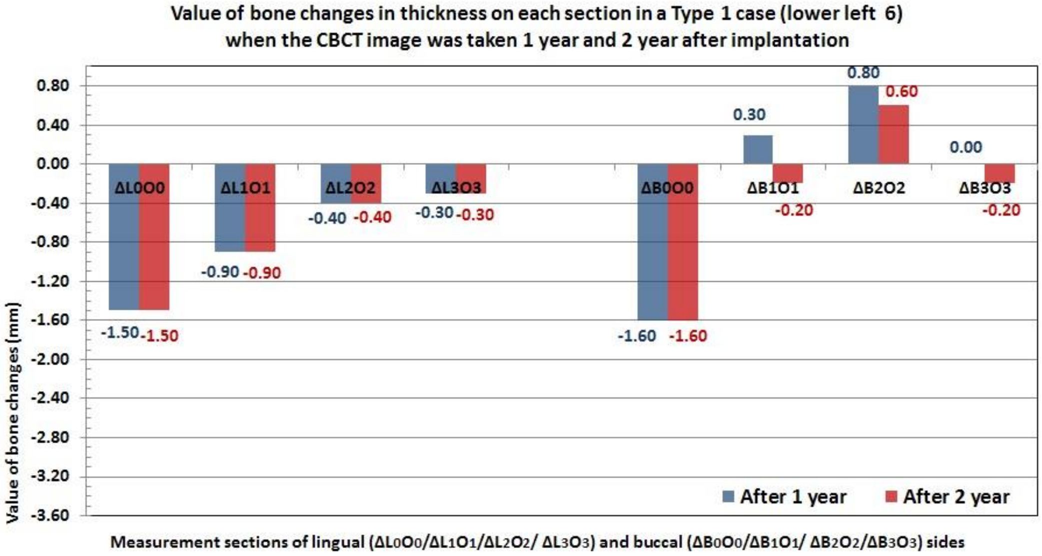


Figure 5–8. Comparing the value of bone changes in thickness on each section between one year after and two year after implantation of a mandibular left first molar case.

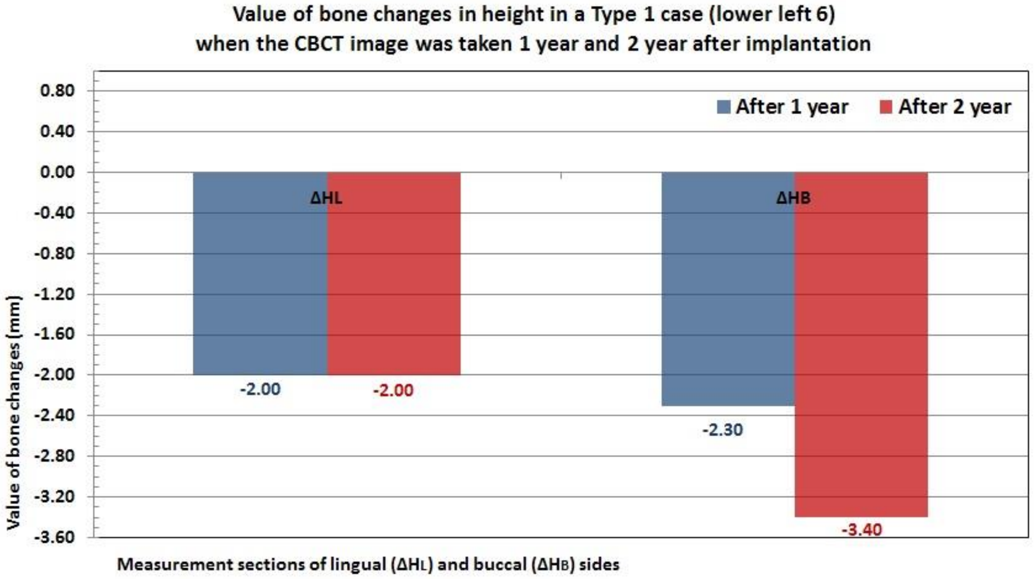


Figure 5–9. Comparing the value of bone changes in height between one year after and two year after implantation of a mandibular left first molar case.

In this case, the bone grafting didn't preserve the bone crest properly as well. Bone height decreased -2.30m at buccal side and -2.00 mm at lingual side in the first year, which was along with pronounced bone thickness decrease at the level of implant top. However, bone thickness increased +0.30 mm and +0.80mm on ΔB_1O_1 and ΔB_2O_2 sections one year after implantation, while bone decreased on all other sections.

It should be noted the buccal bone height further decreased of -1.10 mm in the second year and the bone thickness also continued to decrease of -0.50 mm on ΔB_1O_1 section. And compared with the bone level before implantation, the bone thickness on ΔB_1O_1 section still showed increase of +0.60 mm two year after implantation. However, bone changes on other sections were still very slight during the second year, especially no bone changes at lingual side during the second year.

5.4 Discussion

Firstly, the bone loss was generally higher during the first year in these three cases. Then further decrease happened very slightly during the second year. This was in line with the previous publications (Oh et al. 2002, Wennstrom et al. 2004, 2005, Horwitz et al. 2007, Botticelli et al. 2008, Cochran et al. 2009, Eliasson et al. 2009, Nemli et al. 2016, Voss et al. 2016). Voss et al. and Oh et al. mentioned that early crestal bone loss was often pronounced in the first year after implantation, followed by minimal bone loss of ≤0.2 mm annually thereafter. Cochran et al. confirmed that clinically significant marginal bone remodelling occurred between the time of implantation and final prosthesis placement, and after that, bone loss around implant up to 5 years post-loading was minimal (Cochran et al. 2009). This was also agreed by Covani et al. who also demonstrated the changes in the bone level were minimal at the 5-year point after implantation and a positive final esthetic outcomes could be expected in Type 1 implant placement (Covani et al. 2014).

Secondly, the bone grafting performed differently in these three cases. Only one case showed pronounced buccal bone re-building. This was consistent with the results in Chapter 3, that some cases showed bone increase and others suffered bone decrease. It seemed that outcome of bone grafting was not always positive and it didn't work in some cases.

Thirdly, the buccal bone thickness increase at the level of ΔB_0O_0, ΔB_1O_1 and ΔB_2O_2 sections was observed. It could be explained that buccal bone increased at ΔB_0O_0 and ΔB_1O_1 section was caused by bone grafting. But bone grafting could hardly contribute to the bone increase at ΔB_2O_2 section. This phenomenon was also reported by Block et al. They assessed bone changes in 13 Type 4 cases with bone augmentation and found an average bone gain in width of +0.3±0.7 mm at the position of 10 mm below the bone crest (Block et al. 2015)

At last, there was an issue about measurement error. In the maxillary left first molar case, there was bone loss of -0.80 mm at ΔB_3O_3 section one year after implantation and -0.70 mm two year after implantation. It seemed the bone thickness increased +0.10 mm during the second year. This might be caused by measurement error, not the true bone increase.

6. A 3-year Follow-up Case

6.1 Introduction

In order to ensure implant success, it is essential to select patients who do not possess local or systemic contraindications to treatment protocol. Recent myocardial infarction and cerebrovascular accident, valvular prosthesis surgery, immunosuppression, bleeding issues, active treatment of malignancy, drug abuse, psychiatric illness, and intravenous bisphosphonate use are all absolute contraindications to implant placement (Hwang & Wang 2006). There are some relative contraindications including diabetes (particularly insulin-dependent), angina pectoris, significant consumption of tobacco, certain mental diseases, certain auto-immunes diseases. And there was no enough evidence to describe the relation between these relative contraindication and outcome of dental implantation (Gómez-de Diego et al. 2014).

In this Chapter, a case, from a patient suffering with Systemic Lupus Erythematosus (SLE) which is an auto-immunes disease, was follow up 3 years and the bone changes around the implant was analysed.

6.2 Materials and Methods

A 33-year-old female patient received a dental implant surgery 6 months after the extraction of left mandibular first molar. The patient is a Chinese female and has 5-year medical history of SLE. She received the implant placement surgery two year after the diagnosis of SLE. She took prednisone acetate tablets (one tablet in two days) and vitamin D & Calcium tablets (one tablet per day) in the years after implant placement. ANKYLOS implant (4.5 mm length, 11 mm diameter, taper 5) was placed in the site of left mandibular first molar. The top of implant was at the level of alveolar crest. Before closing the surgery site, the alveolar bone removed during the surgery was replaced back to the top of implant. The crown was loaded 4 months after placement. CBCT (NewTom, 0.125 mm resolution) data sets were taken one week, one year and three years after implantation. These 3 CBCT data sets were registered with each other and superimposed properly. This step made the target coronal plane for measurement locate on the exact same position in 3 CBCT data sets taken in different times. And the sagittal, axial, and coronal axes of three CBCT data sets were in the same position and direction (Figure 6–1).

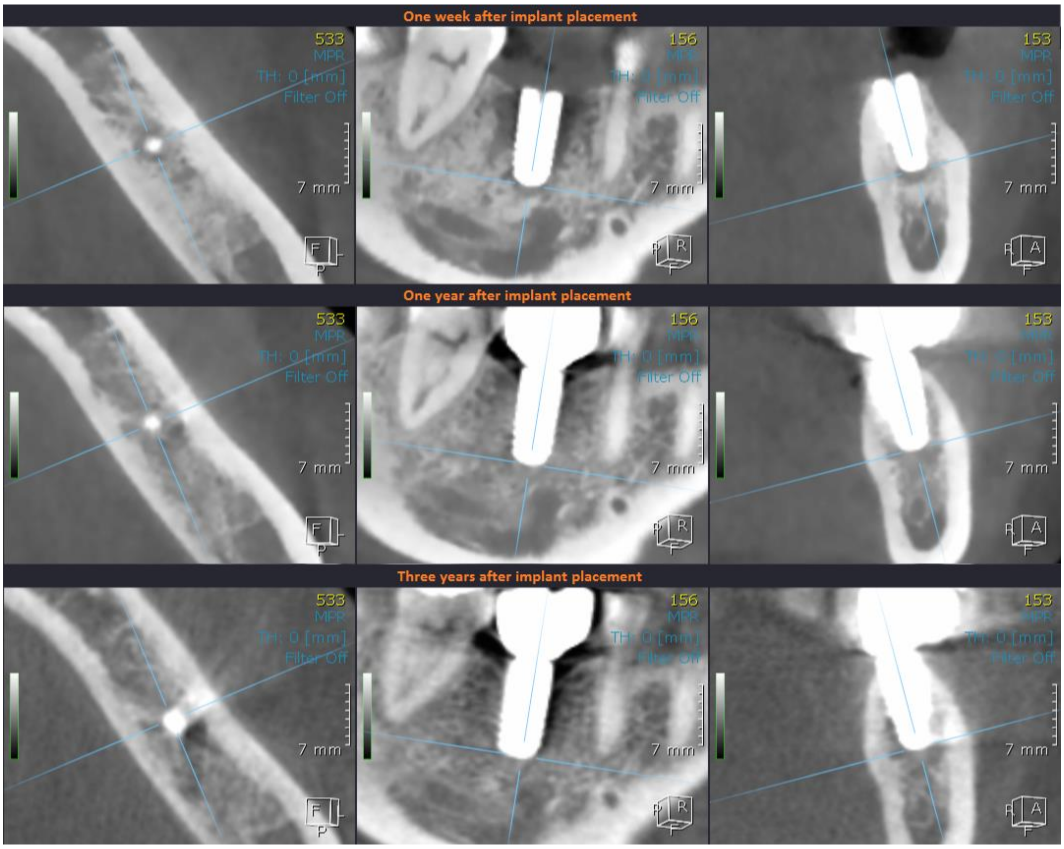


Figure 6–1. Three CBCT images data sets which were one week, one year and three year after implant placement were registered and the target coronal planes for measurement were exactly on the same position in 3 CBCT taken in different times.

The steps of measurement which described in Chapter 3 were applied to this case. Since the length of implant was 11 mm, the intersection points at buccal side were marked as B_0, B_1, B_2, B_3 (11 mm, 10 mm, 7 mm, 4 mm) coronal to the axial axis), while those at lingual side were L_0, L_1, L_2, L_3 and those on sagittal axis were O_0, O_1, O_2, O_3. The intersection points to determine the bone height at lingual and buccal sides was same with those in Chapter 3 (Figure 6–2).

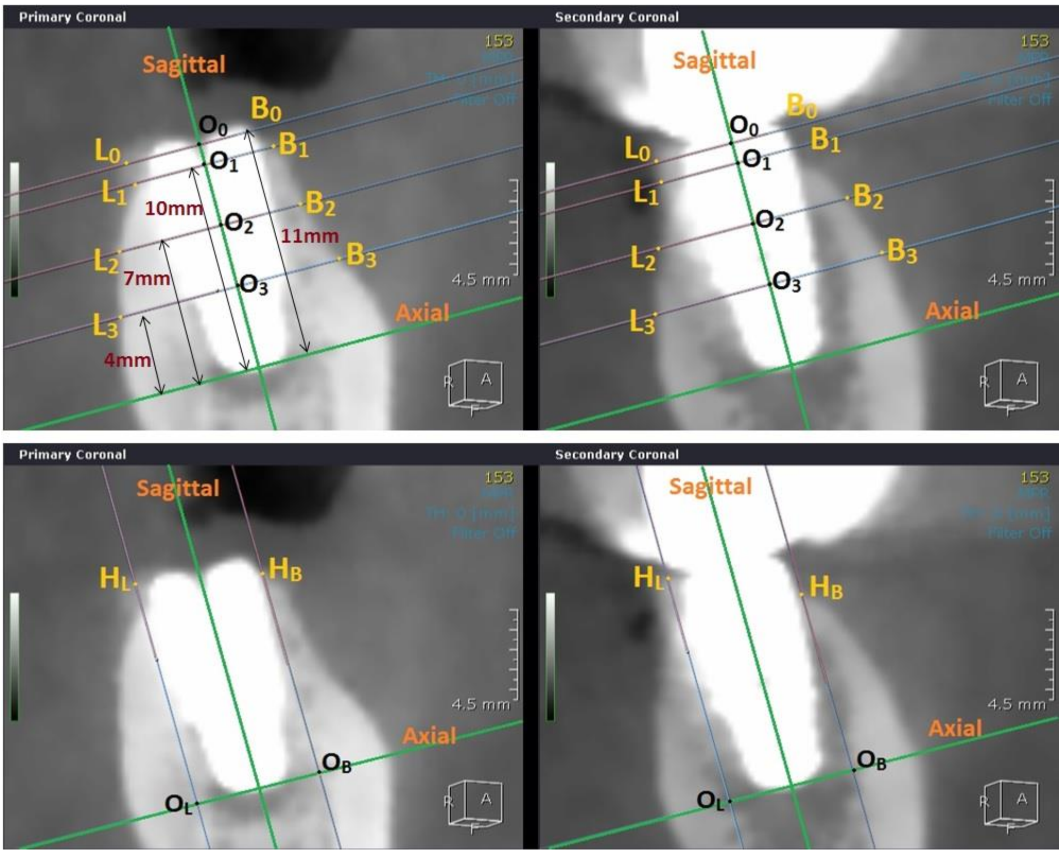


Figure 6–2. Measurement sections of bone thickness and height.

6.3 Results

Compared the image of one week after implantation with that one year after implantation, the bone changes on each measurement section were -0.04 mm, 0, -0.42 mm, -0.18 mm at ΔL_0O_0, ΔL_1O_1, ΔL_2O_2, ΔL_3O_3 section; were 'A', -1.13 mm,

+0.42 mm, +0.64 mm at ΔB_0O_0, ΔB_1O_1, ΔB_2O_2, ΔB_3O_3 section; were -0.02 mm and -1.14 mm at ΔH_L and ΔH_B section.

In Figure 6–3, on the fused coronal image, the white arrow indicated the bone thickness increase at the level of middle part of implant one year after implant placement.

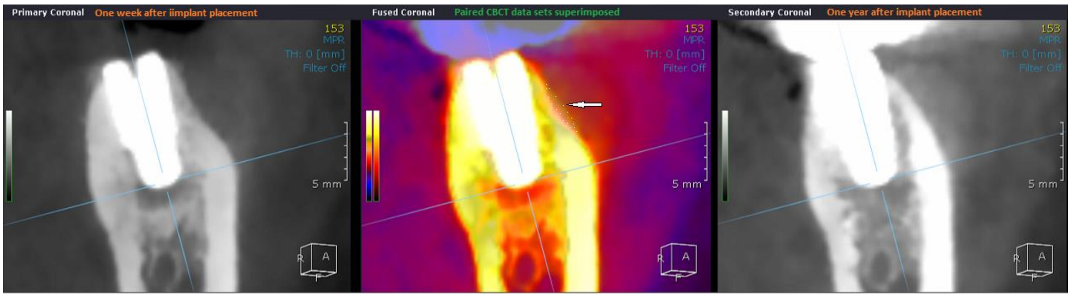


Figure 6–3. The fused image was on the middle, left was image one week after implantation, and right was image one year after implantation. The white arrow indicated the area with bone thickness increase.

Compared the image of one year after implantation with that three years after implantation, the bone changes on each measurement section were -1.34 mm, -1.34 mm, -0.01 mm, -0.02 mm, at ΔL_0O_0, ΔL_1O_1, ΔL_2O_2, ΔL_3O_3 section, were 'A', 0, -0.04 mm, -0.23 mm at ΔB_0O_0, ΔB_1O_1, ΔB_2O_2, ΔB_3O_3 section; were -1.90 mm and -0.01 mm at ΔH_L and ΔH_B section.

Figure 6–4 and Figure 6–5 compared the bone thickness and height changes on each section between one year and three year after implantation. First, no bone was detected on the level of implant top at buccal side on the target coronal image of 3 CBCT data sets. Then, it should be noted that bone thickness increase at ΔB_2O_2 and ΔB_3O_3 sections, not only one year after but also three years after implantation. These bone increase were only slight less on the image of three year after implantation. And on ΔL_2O_2, ΔL_3O_3, ΔB_1O_1, ΔB_2O_2 sections, the bone changes between one year later and three years later were at a very slight level of <0.05 mm.

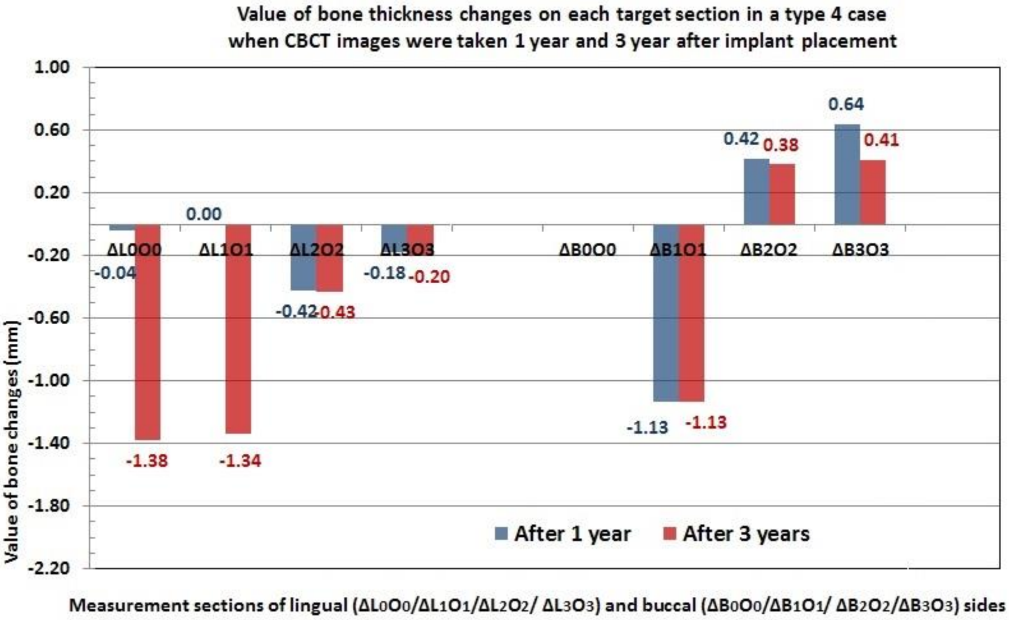


Figure 6–4. Comparison of bone changes in thickness between one year after implantation and three year after implantation.

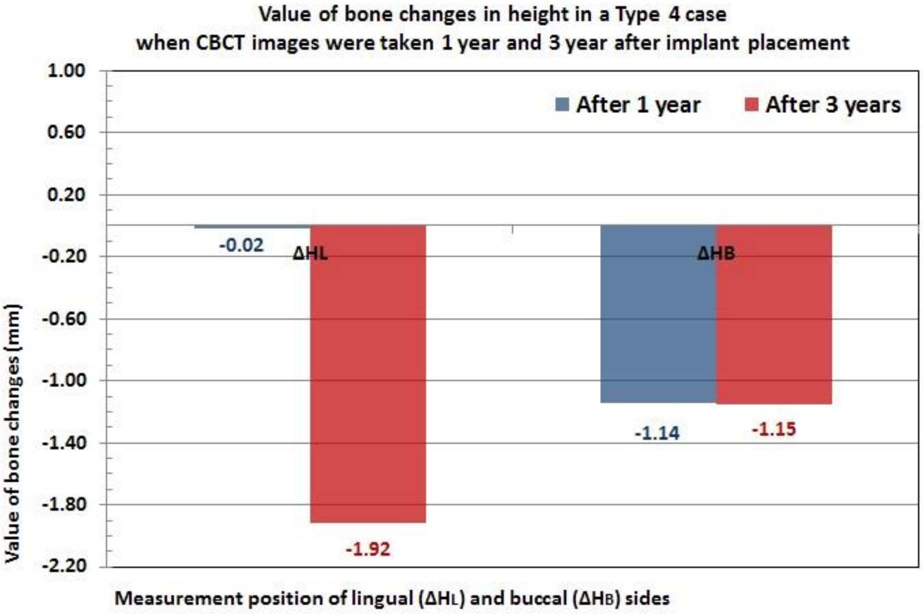


Figure 6–5. Comparison of bone changes in height between one year after implantation and three year after implantation.

The buccal bone height of three years after implantation almost kept at the same level at one year after implantation. Since the buccal bone already decreased -1.14 mm in height during the first year, it happened along with the bone thickness decrease of -1.13 mm on ΔB_1O_1 section.

On the other hand, the lingual bone height didn't decrease obviously during the first year, but decrease -1.92 mm three years later. This leaded to the pronounced bone thickness decrease at the ΔL_0O_0 and ΔL_1O_1 sections.

6.4 Discussion

In this case, the top of implant was place at the level of alveolar crest and autologous bone which was removed during the surgery was put back to the top of implant. But no bone was detected on the level of implant top at buccal side one week later. It indicated the autologous bone absorbed quickly at buccal side and the margin of the buccal alveolar crest also decreased at the first week. After one year, buccal bone height decreased of -1.14 mm which was accompanied by the bone thickness decrease on ΔB_1O_1 section.

The bone changing in buccal and lingual in 3-years was similar with results in Chapter 5 and the previous researches (Oh et al. 2002, Wennstrom et al. 2004, 2005, Horwitz et al. 2007, Botticelli et al. 2008, Cochran et al. 2009, Eliasson et al. 2009, Nemli et al. 2016, Voss et al. 2016). In the first year after implantation, the buccal bone changed rapidly in height and thickness. In the second and third year, the buccal bone kept relatively stable in height and thickness. On the other hand, the lingual bone didn't decrease obviously in height one week and one year later, but significantly in second year and third year. It may indicate the autologous bone survived for one year. However, it decreased at the value of -1.92 mm three years later and along with bone absorption of -1.38 mm at ΔL_0O_0 section and -1.34 mm at ΔL_1O_1. This illustrated autologous bone which was removed during the surgery had a poor performance in bone augmentation. Several studied also stated that autologous bone block grafts didn't prevent the crestal bone loss in Type 4 implant placement (De Santis et al. 2015, Voss et al. 2016).

Another particular finding was buccal bone thickness increased +0.42 mm at ΔB_2O_2 section and +0.64 mm at ΔB_3O_3 section one year after implantation. It could be observed on the fusion images, buccal bone concave was fulfilled with the increase bone. This was similar to the result reported by Block et al. They found +0.3±0.7 mm bone gain at 10 mm below the bone crest in 13 Type 4 cases with bone augmentation procedure. They also stated bone width did not change over time on the section of 5 and 10 mm inferior to the crest (Block et al. 2015). Although the value of this bone thickness increase wasn't clinically important, it was still interesting and the histological mechanism of this bone increases could be further explored. The biological process of the buccal bone increase could be: open flap surgery stimulated the bone reaction; the implant placement and autologous bone graft on the top of the crest provided enough support of concave area; or proper loading was delivered from the restoration to the implant to stimulator the buccal bone re-growth. The similar phenomena also were found in Chapter 3 and Chapter 4. Additionally, whether the patient's medical history and the medicine she took daily would influence the bone remodeling around the implant should be noted in planning a clinical treatment. However, there were no publications shown that the SLE, prednisone acetate, or vitamin D and Calcium tablet contribution to the bone growth.

7. Conclusions

It was conclusive that the measurement stragegy established by this study was reproducible and precise in the quantification of the alveolar bone changes based on consecutive CBCT images, due to the measurement strategy had managed to take the measurement over registered images, avoid the influence of metal artifact by datum shift, and identify the boundary of bone using the combined information of gray value and gray shade. The results showed the error of the measurement strategy was –0.06 mm and the measurement uncertainty was ±0.05 mm. However, it could be better if a standard phantom is avalable and to be used, of which simulate the materials (intensity), shape, size and stucture for the error analysis at each stages from CBCT data capturing, and performance of software and measurement strategy.

Using established measurement strategy, the main results of bone changes from two implant protocols of Type 1 and Type 4 on premolar and molar sites one year after implantation were as follows:

(1) At buccal side, the mean value of bone changes in height was +0.18±1.64 mm in Type 1 cases, which was significantly more than +0.01±0.86 mm in Type 4 cases. It indicated that bone augmentation procedures performed better on re-building the buccal bone height in Type 1 implant placement than Type 4 implant placement.

(2) At buccal side, the bone thickness showed significantly bone loss at two sections (B_0O_0 and B_1O_1) close to the implant shoulder in Type 1 cases (-0.76±1.76 mm and -0.25±1.15 mm) compared with Type 4 cases (-0.41±0.59 mm and -0.16±0.59 mm). It needs to be emphasized that Type 4 cases exhibited smaller bucco-lingual bone width already on the first time of

taking CBCT. This was due to this cohort of patients had bone absorption after tooth extraction, prior to the baseline image taken.

(3) The bone changes in thickness at $L_1O_1B_1$, $L_2O_2B_2$, $L_3O_3B_3$ sections showed significantly more absorption at buccal side (-0.25±1.15 mm, -0.19±0.99 mm, and -0.12±0.57 mm) compared with those at lingual side (-0.13±0.85 mm, -0.16±0.28 mm, and -0.05±0.28 mm) in Type 1 cases; and the bone change in height increased significantly more at buccal side (0.18±1.64 mm) than lingual side (-0.25±0.79 mm) with bone augmentation procedure. However, in Type 4 cases, no significant difference in bone changes could be found. No significant difference in bone changes was found between mandible and maxilla in both Type 1 and Type 4 cases in present study.

(4) The SD in all of the results of bone changes was relatively large. This was due to a large discrepancy of the reactions from each individual patient to the implantation. It is widely accepted that the bone remodelling at the implant crest is multifactorial. Besides the different timing of implantation after tooth extraction, the multiple confounding factors, such as occlusal forces, micro-trauma during the tooth extraction, and surgical procedure, inflammation, etc. affect the bone remodelling process as well.

Overall, the measurement strategy established in this study was reproducible and provided valid quantifiable data of bone changes based on CBCT images. This method could be used for a wide range of clinical trials in future study.

8. Future Work

Despite the valuable findings in this study, a further randomised clinical trial with larger sample size is recommended.

1. To develop a standard phantom, that will reflect the materials (intensity), shape and size of the peri-implant bone and implant, for testing out the accuracy of the measurement strategy and calibrating the measurement strategy in the future.

2. To extend the assessment to intra-examiner measurement in order to analyse the diversity between operators.

3. To extend the measurement of the bone change in height and thickness at distal and mesial sides around implant, in order to obtain more information of bone remodeling. These data could be compared with the measurements from intraoral peri-apical radiography that is more widely used at clinical routines over the world. The measurements from 3D CBCT image and 2D radiographic could also be further compared and evaluated.

4. To analyse the geometrical measurements with the biomarkers that to be collected such as medical and clinical information. This could provide further information to explore the bone changes after implantation.

5. To keep the data collection at follow-up clinic for these cases in order to exam the long-term outcomes. And to carry out a long-term randomized controlled clinical trials with a large sample size and comparison group to verify the conclusions drawn in this preliminary clinical study. More complete

and clear picture could be draw as guidance for dentists to choose proper implant placement protocol for individual patient.

9. References

Adell, R., U. Lekholm, B. Rockler and P. I. Branemark (1981). "A 15-year study of osseointegrated implants in the treatment of the edentulous jaw." Int J Oral Surg 10(6): 387-416.

Al-Ekrish, A. A. and M. Ekram (2011). "A comparative study of the accuracy and reliability of multidetector computed tomography and cone beam computed tomography in the assessment of dental implant site dimensions." Dentomaxillofac Radiol 40(2): 67-75.

Albrektsson, T., D. Buser and L. Sennerby (2012). "Crestal bone loss and oral implants." Clin Implant Dent Relat Res 14(6): 783-791.

Albrektsson, T., G. Zarb, P. Worthington and A. R. Eriksson (1986). "The long-term efficacy of currently used dental implants: a review and proposed criteria of success." Int J Oral Maxillofac Implants 1(1): 11-25.

Albrektsson, T. and G. A. Zarb (1998). "Determinants of correct clinical reporting." Int J Prosthodont 11(5): 517-521.

Alla, R. K., K. Ginjupalli, U. Upadhya, M. Shammas, R. K. Ravi and R. Sekhar (2011). "Surface Roughness of Implants: A Review." Trends Biomater. Artif. Organs 25(3): 112-118.

Anjard, R. (1981). "Mayan dental wonders." J Oral Implantol 9(3): 423-426.

Anneroth, G., K. G. Hedstrom, O. Kjellman, P. A. Kondell and A. Nordenram (1985). "Endosseus titanium implants in extraction sockets. An experimental study in monkeys." Int J Oral Surg 14(1): 50-54.

Annibali, S., I. Bignozzi, L. Iacovazzi, G. La Monaca and M. P. Cristalli (2011). "Immediate, early, and late implant placement in first-molar sites: a retrospective case series." Int J Oral Maxillofac Implants 26(5): 1108-1122.

Annibali, S., I. Bignozzi, G. La Monaca and M. P. Cristalli (2012). "Usefulness of the aesthetic result as a success criterion for implant therapy: a review." Clin Implant Dent Relat Res 14(1): 3-40.

Anusavice, K. J. (2006). Dental Implant. Philips' Science of Dental Materials, Elsevier Sciences: 759-781.

Arai, Y., E. Tammisalo, K. Iwai, K. Hashimoto and K. Shinoda (1999). "Development of a compact computed tomographic apparatus for dental use." Dentomaxillofac Radiol 28(4): 245-248.

Araujo, M., E. Linder, J. Wennstrom and J. Lindhe (2008). "The influence of Bio-Oss Collagen on healing of an extraction socket: an experimental study in the dog." Int J Periodontics Restorative Dent 28(2): 123-135.

Araujo, M. G. and J. Lindhe (2005). "Dimensional ridge alterations following tooth extraction. An experimental study in the dog." J Clin Periodontol 32(2): 212-218.

Araujo, M. G. and J. Lindhe (2009a). "Ridge alterations following tooth extraction with and without flap elevation: an experimental study in the dog." Clin Oral Implants Res 20(6): 545-549.

Araujo, M. G. and J. Lindhe (2009b). "Ridge preservation with the use of Bio-Oss collagen: A 6-month study in the dog." Clin Oral Implants Res 20(5): 433-440.

Araujo, M. G., F. Sukekava, J. L. Wennstrom and J. Lindhe (2005). "Ridge alterations following implant placement in fresh extraction sockets: an experimental study in the dog." J Clin Periodontol 32(6): 645-652.

Araujo, M. G., F. Sukekava, J. L. Wennstrom and J. Lindhe (2006a). "Tissue modeling following implant placement in fresh extraction sockets." Clin Oral Implants Res 17(6): 615-624.

Araujo, M. G., J. L. Wennstrom and J. Lindhe (2006b). "Modeling of the buccal and lingual bone walls of fresh extraction sites following implant installation." Clin Oral Implants Res 17(6): 606-614.

Arvidson, K., H. Bystedt, A. Frykholm, L. von Konow and E. Lothigius (1998). "Five-year prospective follow-up report of the Astra Tech Dental Implant System in the treatment of edentulous mandibles." Clin Oral Implants Res 9(4): 225-234.

Atieh, M. A., H. M. Ibrahim and A. H. Atieh (2010). "Platform switching for marginal bone preservation around dental implants: a systematic review and meta-analysis." J Periodontol 81(10): 1350-1366.

Atwood, D. A. (1957). "A cephalometric study of the clinical rest position of the mandible. Part II. The variability in the rate of bone loss following the removal of occlusal contacts." Journal of Prosthetic Dentistry 7: 544-552.

Atwood, D. A. (1971). "Reduction of residual ridges: a major oral disease entity." J Prosthet Dent 26(3): 266-279.

Barzilay, I., G. N. Graser, B. Iranpour, J. R. Natiella and H. M. Proskin (1996). "Immediate implantation of pure titanium implants into extraction sockets of Macaca fascicularis. Part II: Histologic observations." Int J Oral Maxillofac Implants 11(4): 489-497.

Bechara, B. B., W. S. Moore, C. A. McMahan and M. Noujeim (2012). "Metal artefact reduction with cone beam CT: an in vitro study." Dentomaxillofac Radiol 41(3): 248-253.

Becker, W., B. E. Becker and R. Caffesse (1994a). "A comparison of demineralized freeze-dried bone and autologous bone to induce bone formation in human extraction sockets." J Periodontol 65(12): 1128-1133.

Becker, W., C. Dahlin, B. E. Becker, U. Lekholm, D. van Steenberghe, K. Higuchi and C. Kultje (1994b). "The use of e-PTFE barrier membranes for bone promotion around titanium implants placed into extraction sockets: a prospective multicenter study." Int J Oral Maxillofac Implants 9(1): 31-40.

Becktor, J. P., S. Isaksson and L. Sennerby (2004). "Survival analysis of endosseous implants in grafted and nongrafted edentulous maxillae." Int J Oral Maxillofac Implants 19(1): 107-115.

Benic, G. I., M. Mokti, C. J. Chen, H. P. Weber, C. H. Hammerle and G. O. Gallucci (2012). "Dimensions of buccal bone and mucosa at immediately placed implants after 7 years: a clinical and cone beam computed tomography study." Clin Oral Implants Res 23(5): 560-566.

Benic, G. I., M. Sancho-Puchades, R. E. Jung, H. Deyhle and C. H. Hammerle (2013). "In vitro assessment of artifacts induced by titanium dental implants in cone beam computed tomography." Clin Oral Implants Res 24(4): 378-383.

Benninger, B., A. Peterson and V. Cook (2012). "Assessing validity of actual tooth height and width from cone beam images of cadavers with subsequent dissection to aid oral surgery." J Oral Maxillofac Surg 70(2): 302-306.

Berco, M., P. H. Rigali, Jr., R. M. Miner, S. DeLuca, N. K. Anderson and L. A. Will (2009). "Accuracy and reliability of linear cephalometric measurements from cone-beam computed tomography scans of a dry human skull." Am J Orthod Dentofacial Orthop 136(1): 17 e11-19; discussion 17-18.

Bhat, P. R., S. L. Thakur and S. S. Kulkarni (2015). "The influence of soft tissue biotype on the marginal bone changes around dental implants: A 1-year prospective clinico-radiological study." J Indian Soc Periodontol 19(6): 640-644.

Block, M. S., J. N. Kent and L. Guerra (1997). Implants in Dentistry: Essentials of Endosseous Implants for Maxillofacial Reconstruction, Saunders.

Block, M. S., D. E. Mercante, D. Lirette, W. Mohamed, M. Ryser and P. Castellon (2009). "Prospective evaluation of immediate and delayed provisional single tooth restorations." J Oral Maxillofac Surg 67(11 Suppl): 89-107.

Block, M. S., Z. D. Scoggin and Q. Yu (2015). "Assessment of Bone Width for Implants in the Posterior Mandible." J Oral Maxillofac Surg 73(9): 1715-1722.

Block, M. S. and J. S. Widner (1991). "Method for insuring parallelism of implants placed simultaneously with maxillary sinus bone grafts." J Oral Maxillofac Surg 49(4): 435-437.

Boas, F. E. and D. Fleischmann (2011). "Evaluation of two iterative techniques for reducing metal artifacts in computed tomography." Radiology 259(3): 894-902.

Bobbio, A. (1972). "The first endosseous alloplastic implant in the history of man." Bull Hist Dent 20(1): 1-6.

Bobbio, A. (1973). "Maya, the first authentic alloplastic, endosseous dental implant. A refinement of a priority." Rev Assoc Paul Cir Dent 27(1): 27-36.

Bothe, R. T., L. E. Beaton and H. A. Davenport (1940). "Reaction of bone to multiple metallic implants." Surg Gynecol Obstet 71: 598-602.

Botticelli, D., T. Berglundh, D. Buser and J. Lindhe (2003). "The jumping distance revisited: An experimental study in the dog." Clin Oral Implants Res 14(1): 35-42.

Botticelli, D., T. Berglundh and J. Lindhe (2004a). "Hard-tissue alterations following immediate implant placement in extraction sites." J Clin Periodontol 31(10): 820-828.

Botticelli, D., T. Berglundh and J. Lindhe (2004b). "Resolution of bone defects of varying dimension and configuration in the marginal portion of the peri-implant bone. An experimental study in the dog." J Clin Periodontol 31(4): 309-317.

Botticelli, D., A. Renzi, J. Lindhe and T. Berglundh (2008). "Implants in fresh extraction sockets: a prospective 5-year follow-up clinical study." Clin Oral

Implants Res 19(12): 1226-1232.

Boucher, L. J. (1978). Benefit and Risk of Subperiosteal Implants: A Critique. Dental Implants: Benefit and Risk. An NIH-Harvard Consensus Development Conference. U.S. Dept. of H.H.S., N.I.H.

Brånemark, P. I., B. O. Hansson, R. Adell, U. Breine, J. Lindstrom, O. Hallen and A. Ohman (1977). "Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period." Scand J Plast Reconstr Surg Suppl 16: 1-132.

Brånemark, P. I., G. Zarb and T. Albrektsson (1985). Tissue-integrated prostheses: Osseointegration in clinical dentistry. Chicago, Quintessence Publishing.

Brown, A. A., W. C. Scarfe, J. P. Scheetz, A. M. Silveira and A. G. Farman (2009). "Linear accuracy of cone beam CT derived 3D images." Angle Orthod 79(1): 150-157.

Brownfield, L. A. and R. L. Weltman (2012). "Ridge preservation with or without an osteoinductive allograft: a clinical, radiographic, micro-computed tomography, and histologic study evaluating dimensional changes and new bone formation of the alveolar ridge." J Periodontol 83(5): 581-589.

Buser, D., W. Martin and U. C. Belser (2007). Surgical considerations with regard to single tooth replacement in esthetic zone. Berlin, Quintessenz Verlag.

Buser, D., R. Mericske-Stern, J. P. Bernard, A. Behneke, N. Behneke, H. P. Hirt, U. C. Belser and N. P. Lang (1997). "Long-term evaluation of non-submerged ITI implants. Part 1: 8-year life table analysis of a prospective multi-center study with 2359 implants." Clin Oral Implants Res 8(3): 161-172.

Cangini, F. and R. Cornelini (2005). "A comparison between enamel matrix derivative and a bioabsorbable membrane to enhance healing around transmucosal immediate post-extraction implants." J Periodontol 76(10): 1785-1792.

Cardaropoli, G., M. Araujo and J. Lindhe (2003). "Dynamics of bone tissue formation in tooth extraction sites. An experimental study in dogs." J Clin Periodontol 30(9): 809-818.

Cardaropoli, G., U. Lekholm and J. L. Wennstrom (2006). "Tissue alterations at implant-supported single-tooth replacements: a 1-year prospective clinical study." Clin Oral Implants Res 17(2): 165-171.

Chang, M., P. A. Odman, J. L. Wennstrom and B. Andersson (1999). "Esthetic outcome of implant-supported single-tooth replacements assessed by the patient and by prosthodontists." Int J Prosthodont 12(4): 335-341.

Chen, S. T., J. Beagle, S. S. Jensen, M. Chiapasco and I. Darby (2009). "Consensus statements and recommended clinical procedures regarding surgical techniques." Int J Oral Maxillofac Implants 24 Suppl: 272-278.

Chen, S. T. and D. Buser (2009). "Clinical and esthetic outcomes of implants placed in postextraction sites." Int J Oral Maxillofac Implants 24 Suppl: 186-217.

Chen, S. T., I. B. Darby, G. G. Adams and E. C. Reynolds (2005). "A prospective clinical study of bone augmentation techniques at immediate implants." Clin Oral Implants Res 16(2): 176-184.

Chen, S. T., I. B. Darby and E. C. Reynolds (2007). "A prospective clinical study of non-submerged immediate implants: clinical outcomes and esthetic results." Clin Oral Implants Res 18(5): 552-562.

Chen, S. T., T. G. Wilson, Jr. and C. H. Hammerle (2004). "Immediate or early placement of implants following tooth extraction: review of biologic basis, clinical procedures, and outcomes." Int J Oral Maxillofac Implants 19 Suppl: 12-25.

Cherchieve, R. (1959). "Considerazioni fisiologiche e pratiche su una osservazione originale di un impianto endosseo. ." Inform Dent. 24: 677-680.

Cho, Y. B., S. J. Moon, C. H. Chung and H. J. Kim (2011). "Resorption of labial bone in maxillary anterior implant." J Adv Prosthodont 3(2): 85-89.

Choquet, V., M. Hermans, P. Adriaenssens, P. Daelemans, D. P. Tarnow and C. Malevez (2001). "Clinical and radiographic evaluation of the papilla level adjacent to single-tooth dental implants. A retrospective study in the maxillary anterior region." J Periodontol 72(10): 1364-1371.

Clark M. Stanford (2006). Advancements in Implant Surface Technology for Predictable Long- term Results, US Dentistry. 30: 32.

Cochran, D. L. (1997). "Biologic width around titanium implants. A histometric analysis of the implanto-gingival junction around unloaded and loaded nonsubmerged implants in a canine model." Journal of Periodontology 6: 186-198.

Cochran, D. L., P. V. Nummikoski, J. D. Schoolfield, A. A. Jones and T. W. Oates

(2009). "A prospective multicenter 5-year radiographic evaluation of crestal bone levels over time in 596 dental implants placed in 192 patients." J Periodontol 80(5): 725-733.

Cohnen, M., J. Kemper, O. Mobes, J. Pawelzik and U. Modder (2002). "Radiation dose in dental radiology." Eur Radiol 12(3): 634-637.

Coomes, A. M., B. L. Mealey, G. Huynh-Ba, C. Barboza-Arguello, W. S. Moore and D. L. Cochran (2013). "Buccal Bone Formation After Flapless Extraction: A Randomized Controlled Clinical Trial Comparing Recombinant Human Bone Morphogenetic Protein-2/Absorbable Collagen Carrier and Collagen Sponge Alone." J Periodontol.

Cooper, L. F. (2008). "Objective criteria: guiding and evaluating dental implant esthetics." J Esthet Restor Dent 20(3): 195-205.

Cooper, L. F., F. Raes, G. J. Reside, J. S. Garriga, L. G. Tarrida, J. Wiltfang, M. Kern and H. de Bruyn (2010). "Comparison of radiographic and clinical outcomes following immediate provisionalization of single-tooth dental implants placed in healed alveolar ridges and extraction sockets." Int J Oral Maxillofac Implants 25(6): 1222-1232.

Cordaro, L., F. Torsello, V. Mirisola Di Torresanto and C. Rossini (2006). "Retrospective evaluation of mandibular incisor replacement with narrow neck implants." Clin Oral Implants Res 17(6): 730-735.

Corpas Ldos, S., R. Jacobs, M. Quirynen, Y. Huang, I. Naert and J. Duyck (2011). "Peri-implant bone tissue assessment by comparing the outcome of intra-oral radiograph and cone beam computed tomography analyses to the histological standard." Clin Oral Implants Res 22(5): 492-499.

Covani, U., C. Bortolaia, A. Barone and L. Sbordone (2004). "Bucco-lingual crestal bone changes after immediate and delayed implant placement." J Periodontol 75(12): 1605-1612.

Covani, U., L. Canullo, P. Toti, F. Alfonsi and A. Barone (2014). "Tissue stability of implants placed in fresh extraction sockets: a 5-year prospective single-cohort study." J Periodontol 85(9): e323-332.

Covani, U., R. Cornelini and A. Barone (2003). "Bucco-lingual bone remodeling around implants placed into immediate extraction sockets: a case series." J Periodontol 74(2): 268-273.
Cranin, A. N. (1988). "An introduction to studies of the dental implant interface:

an historic overview." J Oral Implantol 13(4): 567-580.

Cranin, A. N., H. Silverbrand, J. Sher and N. Salter (1982). The requirements and clinical performance of dental implants. Biocompatibility of Dental Materials. D. C. Smith and D. F. Williams. Boca Raton, FL. , CRC Press. 4: 198.

Dahle, E. (1990). "Transplantation to osseointegration. A chronology of dental implants." Bull Hist Dent 38(2): 19-24.

Dahlin, C., L. Andersson and A. Linde (1991). "Bone augmentation at fenestrated implants by an osteopromotive membrane technique. A controlled clinical study." Clin Oral Implants Res 2(4): 159-165.

Danforth, R. A. and D. E. Clark (2000). "Effective dose from radiation absorbed during a panoramic examination with a new generation machine." Oral Surg Oral Med Oral Pathol Oral Radiol Endod 89(2): 236-243.

De Man, B., J. Nuyts, P. Dupont, G. Marchal and P. Suetens (1999). "Metal Streak Artifacts in Xray Computed Tomography: A Simulation Study." IEEE Trans Nucl Sci 46: 691-696.

De Rouck, T., K. Collys and J. Cosyn (2008). "Immediate single-tooth implants in the anterior maxilla: a 1-year case cohort study on hard and soft tissue response." J Clin Periodontol 35(7): 649-657.

De Santis, E., N. P. Lang, G. Favero, M. Beolchini, F. Morelli and D. Botticelli (2015). "Healing at mandibular block-grafted sites. An experimental study in dogs." Clin Oral Implants Res 26(5): 516-522.

Degidi, M., D. Nardi, G. Daprile and A. Piattelli (2012). "Buccal bone plate in the immediately placed and restored maxillary single implant: a 7-year retrospective study using computed tomography." Implant Dent 21(1): 62-66.

Deng, F., H. Zhang, H. Zhang, H. Shao, Q. He and P. Zhang (2010). "A comparison of clinical outcomes for implants placed in fresh extraction sockets versus healed sites in periodontally compromised patients: a 1-year follow-up report." Int J Oral Maxillofac Implants 25(5): 1036-1040.

Denissen, H. W., W. Kalk, H. A. Veldhuis and M. A. van Waas (1993). "Anatomic consideration for preventive implantation." Int J Oral Maxillofac Implants 8(2): 191-196.

Devlin, H., K. Horner and D. Ledgerton (1998). "A comparison of maxillary and mandibular bone mineral densities." J Prosthet Dent 79(3): 323-327.

Draenert, F. G., E. Coppenrath, P. Herzog, S. Muller and U. G. Mueller-Lisse (2007). "Beam hardening artefacts occur in dental implant scans with the NewTom cone beam CT but not with the dental 4-row multidetector CT." Dentomaxillofac Radiol 36(4): 198-203.

Dula, K., R. Mini, P. F. van der Stelt, J. T. Lambrecht, P. Schneeberger and D. Buser (1996). "Hypothetical mortality risk associated with spiral computed tomography of the maxilla and mandible." Eur J Oral Sci 104(5-6): 503-510.

Eliasson, A., F. Blomqvist, A. Wennerberg and A. Johansson (2009). "A retrospective analysis of early and delayed loading of full-arch mandibular prostheses using three different implant systems: clinical results with up to 5 years of loading." Clin Implant Dent Relat Res 11(2): 134-148.

Esposito, M., C. Barausse, R. Pistilli, M. Jacotti, G. Grandi, L. Tuco and P. Felice (2015). "Immediate loading of post-extractive versus delayed placed single implants in the anterior maxilla: outcome of a pragmatic multicenter randomised controlled trial 1-year after loading." Eur J Oral Implantol 8(4): 347-358.

Esposito, M., M. G. Grusovin, I. P. Polyzos, P. Felice and H. V. Worthington (2010). "Interventions for replacing missing teeth: dental implants in fresh extraction sockets (immediate, immediate-delayed and delayed implants)." Cochrane Database Syst Rev(9): Cd005968.

Evans, C. D. and S. T. Chen (2008). "Esthetic outcomes of immediate implant placements." Clin Oral Implants Res 19(1): 73-80.

Farman, A. G. (2009). "Field of view." Oral Surg Oral Med Oral Pathol Oral Radiol Endod 108(4): 477-478.

Farmer, M. and I. Darby (2014). "Ridge dimensional changes following single-tooth extraction in the aesthetic zone." Clin Oral Implants Res 25(2): 272-277.

Fatemitabar, S. A. and A. Nikgoo (2010). "Multichannel computed tomography versus cone-beam computed tomography: linear accuracy of in vitro measurements of the maxilla for implant placement." Int J Oral Maxillofac Implants 25(3): 499-505.

Feldkamp, L. A., L. C. Davis and J. W. Kress (1984). "Practical cone-beam algorithm." J Opt Soc Am 1: 612-619.

Felice, P., R. Pistilli, C. Barausse, A. Trullenque-Eriksson and M. Esposito (2015).

"Immediate non-occlusal loading of immediate post-extractive versus delayed placement of single implants in preserved sockets of the anterior maxilla: 1-year post-loading outcome of a randomised controlled trial." Eur J Oral Implantol 8(4): 361-372.

Ferrara, A., C. Galli, G. Mauro and G. M. Macaluso (2006). "Immediate provisional restoration of postextraction implants for maxillary single-tooth replacement." Int J Periodontics Restorative Dent 26(4): 371-377.

Fugazzotto, P. A. (2005). "Treatment options following single-rooted tooth removal: a literature review and proposed hierarchy of treatment selection." J Periodontol 76(5): 821-831.

Fuhrmann, R. A., A. Bucker and P. R. Diedrich (1995). "Assessment of alveolar bone loss with high resolution computed tomography." J Periodontal Res 30(4): 258-263.

Gómez-de Diego, R., M. Mang-de la Rosa, J. Romero-Pérez Mí, A. Cutando-Soriano and A. López-Valverde-Centeno (2014). "Indications and contraindications of dental implants in." Med Oral Patol Oral Cir Bucal 19(5): e483-489.

Gargiulo, A. W., F. M. Wentz and B. Orban (1961). "Dimensions and relations of the dentogingival junction in humans." Journal of Periodontology 32: 261-267.

Gher, M. E., G. Quintero, D. Assad, E. Monaco and A. C. Richardson (1994). "Bone grafting and guided bone regeneration for immediate dental implants in humans." J Periodontol 65(9): 881-891.

Gibbard, L. L. and G. Zarb (2002). "A 5-year prospective study of implant-supported single-tooth replacements." J Can Dent Assoc 68(2): 110-116.

Gibbs, S. J. (2000). "Effective dose equivalent and effective dose: comparison for common projections in oral and maxillofacial radiology." Oral Surg Oral Med Oral Pathol Oral Radiol Endod 90(4): 538-545.

Gomez-Roman, G. and S. Launer (2016). "Peri-implant bone changes in immediate and non-immediate root-analog stepped implants—a matched comparative prospective study up to 10 years." International Journal of Implant Dentistry 2(1): 1-10.

Gomez-Roman, G., W. Schulte, B. d'Hoedt and D. Axman-Krcmar (1997). "The Frialit-2 implant system: five-year clinical experience in single-tooth and immediately postextraction applications." Int J Oral Maxillofac Implants 12(3): 299-309.

Gonzalez-Martin, O., C. Oteo, R. Ortega, J. Alandez, M. Sanz and M. Veltri (2015). "Evaluation of peri-implant buccal bone by computed tomography: an experimental study." Clin Oral Implants Res.

Gotfredsen, K. (2004). "A 5-year prospective study of single-tooth replacements supported by the Astra Tech implant: a pilot study." Clin Implant Dent Relat Res 6(1): 1-8.

Grandi, T., P. Guazzi, R. Samarani and G. Grandi (2013). "Immediate provisionalisation of single post-extractive implants versus implants placed in healed sites in the anterior maxilla: 1-year results from a multicentre controlled cohort study." Eur J Oral Implantol 6(3): 285-295.

Greenfield, E. J. (1991). "Implantation of artificial crown and bridge abutments. 1913." Int J Oral Implantol 7(2): 63-68.

Grunder, U. (2000). "Stability of the mucosal topography around single-tooth implants and adjacent teeth: 1-year results." Int J Periodontics Restorative Dent 20(1): 11-17.

Hämmerle, C. H., S. T. Chen and T. G. Wilson, Jr. (2004). "Consensus statements and recommended clinical procedures regarding the placement of implants in extraction sockets." Int J Oral Maxillofac Implants 19 Suppl: 26-28.

Hämmerle, C. H. and N. P. Lang (2001). "Single-stage surgery combining transmucosal implant placement with guided bone regeneration and bioresorbable materials." Clin Oral Implants Res 12: 9-18.

Hagiwara, Y. (2010). "Does platform switching really prevent crestal bone loss around implants?" Japanese Dental Science Review 46(2): 122-131.

Hall, J. A., A. G. Payne, D. G. Purton and B. Torr (2006). "A randomized controlled clinical trial of conventional and immediately loaded tapered implants with screw-retained crowns." Int J Prosthodont 19(1): 17-19.

Hamada, Y., T. Kondoh, K. Noguchi, M. Iino, H. Isono, H. Ishii, A. Mishima, K. Kobayashi and K. Seto (2005). "Application of limited cone beam computed tomography to clinical assessment of alveolar bone grafting: a preliminary report." Cleft Palate Craniofac J 42(2): 128-137.

Hammerle, C. H., M. G. Araujo and M. Simion (2012). "Evidence-based knowledge on the biology and treatment of extraction sockets." Clin Oral Implants Res 23 Suppl 5: 80-82.

Hedega°rd, B. (1962). "Some observations on tissue changes with immediate maxillary dentures." Dental Practitioner 13: 70-78.

Heiland, M., D. Schulze, U. Rother and R. Schmelzle (2004). "Postoperative imaging of zygomaticomaxillary complex fractures using digital volume tomography." J Oral Maxillofac Surg 62(11): 1387-1391.

Heinemann, F., R. Biffar, C. Schwahn and T. Mundt (2013). "Bone level changes in dental implants with platform-switched design after immediate and delayed placement in the maxilla." Int J Periodontics Restorative Dent 33(3): 365-372.

Hekmatian, E., N. Jafari-Pozve and L. Khorrami (2014). "The effect of voxel size on the measurement of mandibular thickness in cone-beam computed tomography." Dent Res J (Isfahan) 11(5): 544-548.

Henriksson, K. and T. Jemt (2004). "Measurements of soft tissue volume in association with single-implant restorations: a 1-year comparative study after abutment connection surgery." Clin Implant Dent Relat Res 6(4): 181-189.

Hobkirk, J. A., R. M. Watson and L. J. J. Searson (2003). Implants: An Introduction. Introducing Dental Implants. M. Parkinson. United Kingdom, Elsevier Science: 3-18.

Holberg, C., S. Steinhauser, P. Geis and I. Rudzki-Janson (2005). "Cone-beam computed tomography in orthodontics: benefits and limitations." J Orofac Orthop 66(6): 434-444.

Honda, K., Y. Arai, M. Kashima, Y. Takano, K. Sawada, K. Ejima and K. Iwai (2004). "Evaluation of the usefulness of the limited cone-beam CT (3DX) in the assessment of the thickness of the roof of the glenoid fossa of the temporomandibular joint." Dentomaxillofac Radiol 33(6): 391-395.

Horner, K., R. Jacobs and R. Schulze (2013). "Dental CBCT equipment and performance issues." Radiat Prot Dosimetry 153(2): 212-218.

Horwitz, J., O. Zuabi, M. Peled and E. E. Machtei (2007). "Immediate and delayed restoration of dental implants in periodontally susceptible patients: 1-year results." Int J Oral Maxillofac Implants 22(3): 423-429.

Hounsfield, G. N. (1973). "Computerized transverse axial scanning (tomography).

1. Description of system." Br J Radiol 46(552): 1016-1022.

Hu, H., H. D. He, W. D. Foley and S. H. Fox (2000). "Four multidetector-row helical CT: image quality and volume coverage speed." Radiology 215(1): 55-62.

Hujoel, P. P. (1998). "Design and analysis issues in split mouth clinical trials." Community Dent Oral Epidemiol 26(2): 85-86.

Hujoel, P. P. and T. A. DeRouen (1992). "Validity issues in split-mouth trials." J Clin Periodontol 19(9 Pt 1): 625-627.

Hujoel, P. P. and W. J. Loesche (1990). "Efficiency of split-mouth designs." J Clin Periodontol 17(10): 722-728.

Hwang, D. and H. L. Wang (2006). "Medical contraindications to implant therapy: part I: absolute contraindications." Implant Dent 15(4): 353-360.

Jaffin, R., M. Kolesar, A. Kumar, S. Ishikawa and J. Fiorellini (2007). "The radiographic bone loss pattern adjacent to immediately placed, immediately loaded implants." Int J Oral Maxillofac Implants 22(2): 187-194.

Jahangiri, L., H. Devlin, K. Ting and I. Nishimura (1998). "Current perspectives in residual ridge remodeling and its clinical implications: a review." J Prosthet Dent 80(2): 224-237.

Jemt, T. (1997). "Regeneration of gingival papillae after single-implant treatment." Int J Periodontics Restorative Dent 17(4): 326-333.

Jemt, T., G. Ahlberg, K. Henriksson and O. Bondevik (2006). "Changes of anterior clinical crown height in patients provided with single-implant restorations after more than 15 years of follow-up." Int J Prosthodont 19(5): 455-461.

Jeong, S. M., B. H. Choi, J. Kim, F. Xuan, D. H. Lee, D. Y. Mo and C. U. Lee (2011). "A 1-year prospective clinical study of soft tissue conditions and marginal bone changes around dental implants after flapless implant surgery." Oral Surg Oral Med Oral Pathol Oral Radiol Endod 111(1): 41-46.

Kalender, W. A., R. Hebel and J. Ebersberger (1987). "Reduction of CT artifacts caused by metallic implants." Radiology 164(2): 576-577.

Kamath, S., W. Song, A. Chvetsov, S. Ozawa, H. Lu, S. Samant, C. Liu, J. G. Li and J. R. Palta (2011). "An image quality comparison study between XVI and OBI CBCT systems." J Appl Clin Med Phys 12(2): 3435.

Kamburoğlu, K., C. Kilic, T. Ozen and S. P. Yuksel (2009). "Measurements of mandibular canal region obtained by cone-beam computed tomography: a cadaveric study." Oral Surg Oral Med Oral Pathol Oral Radiol Endod 107(2): e34-42.

Kamburoğlu, K., E. Kolsuz, H. Kurt, C. Kilic, T. Ozen and C. S. Paksoy (2011). "Accuracy of CBCT measurements of a human skull." J Digit Imaging 24(5): 787-793.

Kamburoğlu, K., S. Murat, C. Kilic, S. Yuksel, H. Avsever, A. Farman and W. C. Scarfe (2014). "Accuracy of CBCT images in the assessment of buccal marginal alveolar peri-implant defects: effect of field of view." Dentomaxillofac Radiol 43(4): 20130332.

Kan, J. Y., K. Rungcharassaeng, G. Liddelow, P. Henry and C. J. Goodacre (2007). "Periimplant tissue response following immediate provisional restoration of scalloped implants in the esthetic zone: a one-year pilot prospective multicenter study." J Prosthet Dent 97(6 Suppl): S109-118.

Kan, J. Y., K. Rungcharassaeng, K. Umezu and J. C. Kois (2003). "Dimensions of peri-implant mucosa: an evaluation of maxillary anterior single implants in humans." J Periodontol 74(4): 557-562.

Karabuda, C., P. Sandalli, S. Yalcin, D. E. Steflik and G. R. Parr (1999). "Histologic and histomorphometric comparison of immediately placed hydroxyapatite-coated and titanium plasma-sprayed implants: a pilot study in dogs." Int J Oral Maxillofac Implants 14(4): 510-515.

Kinaia, B. M., M. Shah, A. L. Neely and H. E. Goodis (2014). "Crestal bone level changes around immediately placed implants: a systematic review and meta-analyses with at least 12 months' follow-up after functional loading." J Periodontol 85(11): 1537-1548.

Kobayashi, K., S. Shimoda, Y. Nakagawa and A. Yamamoto (2004). "Accuracy in measurement of distance using limited cone-beam computerized tomography." Int J Oral Maxillofac Implants 19(2): 228-231.

Kois, J. C. (1994). "Altering gingival levels: the restorative connection part I: biologic variables." J Esthet Dent 6: 3-9.

Kois, J. C. (2001). "Predictable single tooth peri-implant esthetics: five diagnostic keys." Compend Contin Educ Dent 22(3): 199-206; quiz 208.

Kovacs, M., P. Fejerdy and N. C. Dobo (2008). "Metal artefact on head and neck cone-beam CT images." Fogorv Sz 101(5): 171-178.

Kuchler, U., V. Chappuis, R. Gruber, N. P. Lang and G. E. Salvi (2016). "Immediate implant placement with simultaneous guided bone regeneration in the esthetic zone: 10-year clinical and radiographic outcomes." Clin Oral Implants Res 27(2): 253-257.

Laney, W. R. (1993). "In recognition of an implant pioneer: Professor Dr. Andre Schroeder." Int J Oral Maxillofac Implants 8(2): 135-136.

Lang, N. P., L. Pun, K. Y. Lau, K. Y. Li and M. C. Wong (2012). "A systematic review on survival and success rates of implants placed immediately into fresh extraction sockets after at least 1 year." Clin Oral Implants Res 23 Suppl 5: 39-66.

Lascala, C. A., J. Panella and M. M. Marques (2004). "Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom)." Dentomaxillofac Radiol 33(5): 291-294.

Lazzara, R. J. (1989). "Use of osseointegrated implants for replacement of single teeth." Compendium 10(10): 550-554.

Lekholm, U., J. Gunne, P. Henry, K. Higuchi, U. Linden, C. Bergstrom and D. van Steenberghe (1999). "Survival of the Branemark implant in partially edentulous jaws: a 10-year prospective multicenter study." Int J Oral Maxillofac Implants 14(5): 639-645.

Lekovic, V., P. M. Camargo, P. R. Klokkevold, M. Weinlaender, E. B. Kenney, B. Dimitrijevic and M. Nedic (1998). "Preservation of alveolar bone in extraction sockets using bioabsorbable membranes." J Periodontol 69(9): 1044-1049.

Lekovic, V., E. B. Kenney, M. Weinlaender, T. Han, P. Klokkevold, M. Nedic and M. Orsini (1997). "A bone regenerative approach to alveolar ridge maintenance following tooth extraction. Report of 10 cases." J Periodontol 68(6): 563-570.

Leonhardt, A., K. Grondahl, C. Bergstrom and U. Lekholm (2002). "Long-term follow-up of osseointegrated titanium implants using clinical, radiographic and microbiological parameters." Clin Oral Implants Res 13(2): 127-132.

Lesaffre, E., B. Philstrom, I. Needleman and H. Worthington (2009). "The design and analysis of split-mouth studies: what statisticians and clinicians should know." Stat Med 28(28): 3470-3482.

Liaje, A., Y. K. Ozkan, Y. Ozkan and B. Vanlioglu (2012). "Stability and marginal bone loss with three types of early loaded implants during the first year after loading." Int J Oral Maxillofac Implants 27(1): 162-172.

Lindeboom, J. A., Y. Tjiook and F. H. Kroon (2006). "Immediate placement of implants in periapical infected sites: a prospective randomized study in 50 patients." Oral Surg Oral Med Oral Pathol Oral Radiol Endod 101(6): 705-710.

Lindquist, L. W., G. E. Carlsson and T. Jemt (1996). "A prospective 15-year follow-up study of mandibular fixed prostheses supported by osseointegrated implants. Clinical results and marginal bone loss." Clin Oral Implants Res 7(4): 329-336.

Linkow, L. (1964). "Intraosseous implants utilized as fixed bridge abutments." J Oral Implant Transplant Surg 10: 17-23.

Linkow, L. I. (1966). "The radiographic role in endosseous implant interventions." Chronicle 29(10): 304-311.

Linkow, L. I. and J. D. Dorfman (1991). "Implantology in dentistry. A brief historical perspective." N Y State Dent J 57(6): 31-35.

Lofthag-Hansen, S., A. Thilander-Klang and K. Grondahl (2011). "Evaluation of subjective image quality in relation to diagnostic task for cone beam computed tomography with different fields of view." Eur J Radiol 80(2): 483-488.

Lops, D., M. Chiapasco, A. Rossi, E. Bressan and E. Romeo (2008). "Incidence of inter-proximal papilla between a tooth and an adjacent immediate implant placed into a fresh extraction socket: 1-year prospective study." Clin Oral Implants Res 19(11): 1135-1140.

Loubele, M., N. Van Assche, K. Carpentier, F. Maes, R. Jacobs, D. van Steenberghe and P. Suetens (2008). "Comparative localized linear accuracy of small-field cone-beam CT and multislice CT for alveolar bone measurements." Oral Surg Oral Med Oral Pathol Oral Radiol Endod 105(4): 512-518.

Ludlow, J. B., L. E. Davies-Ludlow and S. L. Brooks (2003). "Dosimetry of two extraoral direct digital imaging devices: NewTom cone beam CT and Orthophos Plus DS panoramic unit." Dentomaxillofac Radiol 32(4): 229-234.

Ludlow, J. B., L. E. Davies-Ludlow, S. L. Brooks and W. B. Howerton (2006). "Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT." Dentomaxillofac Radiol 35(4): 219-226.

Ludlow, J. B. and M. Ivanovic (2008). "Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology." Oral Surg Oral Med Oral Pathol Oral Radiol Endod 106(1): 106-114.

Mah, J. K., R. A. Danforth, A. Bumann and D. Hatcher (2003). "Radiation absorbed in maxillofacial imaging with a new dental computed tomography device." Oral Surg Oral Med Oral Pathol Oral Radiol Endod 96(4): 508-513.

Mahnken, A. H., R. Raupach, J. E. Wildberger, B. Jung, N. Heussen, T. G. Flohr, R. W. Gunther and S. Schaller (2003). "A new algorithm for metal artifact reduction in computed tomography: in vitro and in vivo evaluation after total hip replacement." Invest Radiol 38(12): 769-775.

Maret, D., N. Telmon, O. A. Peters, B. Lepage, J. Treil, J. M. Inglese, A. Peyre, J. L. Kahn and M. Sixou (2012). "Effect of voxel size on the accuracy of 3D reconstructions with cone beam CT." Dentomaxillofac Radiol 41(8): 649-655.

Marmulla, R., R. Wortche, J. Muhling and S. Hassfeld (2005). "Geometric accuracy of the NewTom 9000 Cone Beam CT." Dentomaxillofac Radiol 34(1): 28-31.

Martin, W. C., D. Morton and D. Buser (2007). Diagnostic factors for esthetic risk assessment. ITI Treatment Guide, vol 1: Implant Therapy in the Esthetic Zone—Single-Tooth Replacements. D. Buser, U. Belser and D. Wismeijer. Berlin, Quintessence: 11-20.

Mayfield, L. J. (1999). Immediate, delayed and late submerged and transmucosal implants. Proceedings of the 3rd European Workshop on Periodontology: Implant Dentistry. L. J. Berlin, Quintessenz: 520-534.

Mazzocco, F., D. Jimenez, L. Barallat, G. Paniz, M. Del Fabbro and J. Nart (2016). "Bone volume changes after immediate implant placement with or without flap elevation." Clin Oral Implants Res 0: 1-7.

McAllister, B. S., J. E. Cherry, M. L. Kolinski, K. D. Parrish, D. W. Pumphrey and R. L. Schroering (2012). "Two-year evaluation of a variable-thread tapered implant in extraction sites with immediate temporization: a multicenter clinical trial." Int J Oral Maxillofac Implants 27(3): 611-618.

McKinney, R. V., D. C. Koth and D. E. Steflik (1984). Clinical standards for dental implants. Clinical Dentistry. J. W. Clark. Harperstown, Harper & Row: 27-41.

Meilinger, M., C. Schmidgunst, O. Schutz and E. W. Lang (2011). "Metal artifact reduction in cone beam computed tomography using forward projected reconstruction information." Z Med Phys 21(3): 174-182.

Mellati, E., S. Chen, H. Davies, W. Fitzgerald and I. Darby (2015). "Healing of Bio-Oss(R) grafted marginal gaps at implants placed into fresh extraction sockets of incisor teeth in dogs: a study on the effect of submerged vs. non-submerged healing." Clin Oral Implants Res 26(5): 553-562.

Mengel, R., B. Kruse and L. Flores-de-Jacoby (2006). "Digital volume tomography in the diagnosis of peri-implant defects: an in vitro study on native pig mandibles." J Periodontol 77(7): 1234-1241.

Miyamoto, Y. and T. Obama (2011). "Dental cone beam computed tomography analyses of postoperative labial bone thickness in maxillary anterior implants: comparing immediate and delayed implant placement." Int J Periodontics Restorative Dent 31(3): 215-225.

Moberg, L. E., P. A. Kondell, L. Kullman, A. Heimdahl and G. W. Gynther (1999). "Evaluation of single-tooth restorations on ITI dental implants. A prospective study of 29 patients." Clin Oral Implants Res 10(1): 45-53.

Moshfeghi, M., M. A. Tavakoli, E. T. Hosseini, A. T. Hosseini and I. T. Hosseini (2012). "Analysis of linear measurement accuracy obtained by cone beam computed tomography (CBCT-NewTom VG)." Dent Res J (Isfahan) 9(Suppl 1): S57-62.

Mozzo, P., C. Procacci, A. Tacconi, P. T. Martini and I. A. Andreis (1998). "A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results." Eur Radiol 8(9): 1558-1564.

Muddugangadhar, B. C., G. S. Amarnath, R. Sonika, P. S. Chheda and A. Garg (2015). "Meta-analysis of Failure and Survival Rate of Implant-supported Single Crowns, Fixed Partial Denture, and Implant Tooth-supported Prostheses." J Int Oral Health 7(9): 11-17.

Nemcovsky, C. E. and Z. Artzi (2002). "Comparative study of buccal dehiscence defects in immediate, delayed, and late maxillary implant placement with collagen membranes: clinical healing between placement and second-stage surgery." J Periodontol 73(7): 754-761.

Nemli, S. K., M. B. Güngör, C. Aydın, H. Yılmaz, B. T. Bal and Y. K. Arıcı (2016). "Clinical and radiographic evaluation of new dental implant system: Results of a 3-year prospective study." Journal of Dental Sciences 11(1): 29-34.

Ngan, D. C., O. P. Kharbanda, J. P. Geenty and M. A. Darendeliler (2003).

"Comparison of radiation levels from computed tomography and conventional dental radiographs." Aust Orthod J 19(2): 67-75.

Nisapakultorn, K., S. Suphanantachat, O. Silkosessak and S. Rattanamongkolgul (2010). "Factors affecting soft tissue level around anterior maxillary single-tooth implants." Clin Oral Implants Res 21(6): 662-670.

Noelken, R., T. Morbach, M. Kunkel and W. Wagner (2007). "Immediate function with NobelPerfect implants in the anterior dental arch." Int J Periodontics Restorative Dent 27: 277-285.

Novaes, A. B., Jr., A. M. Marcaccini, S. L. Souza, M. Taba, Jr. and M. F. Grisi (2003). "Immediate placement of implants into periodontally infected sites in dogs: a histomorphometric study of bone-implant contact." Int J Oral Maxillofac Implants 18(3): 391-398.

Novaes, A. B., Jr., V. Papalexiou, M. F. Grisi, S. S. Souza, M. Taba, Jr. and J. K. Kajiwara (2004). "Influence of implant microstructure on the osseointegration of immediate implants placed in periodontally infected sites. A histomorphometric study in dogs." Clin Oral Implants Res 15(1): 34-43.

Oh, T. J., J. L. Shotwell, E. J. Billy and H. L. Wang (2006). "Effect of flapless implant surgery on soft tissue profile: a randomized controlled clinical trial." J Periodontol 77(5): 874-882.

Oh, T. J., J. Yoon, C. E. Misch and H. L. Wang (2002). "The causes of early implant bone loss: myth or science?" J Periodontol 73(3): 322-333.

Ortega-Martinez, J., T. Perez-Pascual, S. Mareque-Bueno, F. Hernandez-Alfaro and E. Ferres-Padro (2012). "Immediate implants following tooth extraction. A systematic review." Med Oral Patol Oral Cir Bucal 17(2): e251-261.

Pal, U. S., N. K. Dhiman, G. Singh, R. K. Singh, S. Mohammad and L. R. Malkunje (2011). "Evaluation of implants placed immediately or delayed into extraction sites." Natl J Maxillofac Surg 2(1): 54-62.

Palattella, P., F. Torsello and L. Cordaro (2008). "Two-year prospective clinical comparison of immediate replacement vs. immediate restoration of single tooth in the esthetic zone." Clin Oral Implants Res 19(11): 1148-1153.

Palmer, R. M., N. Farkondeh, P. J. Palmer and R. F. Wilson (2007). "Astra Tech single-tooth implants: an audit of patient satisfaction and soft tissue form." J Clin Periodontol 34(7): 633-638.

Paolantonio, M., M. Dolci, A. Scarano, D. d'Archivio, G. di Placido, V. Tumini and A. Piattelli (2001). "Immediate implantation in fresh extraction sockets. A controlled clinical and histological study in man." J Periodontol 72(11): 1560-1571.

Park, H. S., Y. J. Lee, S. H. Jeong and T. G. Kwon (2008). "Density of the alveolar and basal bones of the maxilla and the mandible." Am J Orthod Dentofacial Orthop 133(1): 30-37.

Parsa, A., N. Ibrahim, B. Hassan, K. Syriopoulos and P. van der Stelt (2014). "Assessment of metal artefact reduction around dental titanium implants in cone beam CT." Dentomaxillofac Radiol 43(7): 20140019.

Penarrocha, M., R. Uribe and J. Balaguer (2004). "Immediate implants after extraction. A review of the current situation." Med Oral 9(3): 234-242.

Pietrokovski, J. and M. Massler (1967). "Ridge remodeling after tooth extraction in rats." J Dent Res 46(1): 222-231.

Pinho, M. N., V. L. Roriz, A. B. Novaes, Jr., M. Taba, Jr., M. F. Grisi, S. L. de Souza and D. B. Palioto (2006). "Titanium membranes in prevention of alveolar collapse after tooth extraction." Implant Dent 15(1): 53-61.

Polizzi, G., U. Grunder, R. Goene, N. Hatano, P. Henry, W. J. Jackson, K. Kawamura, F. Renouard, R. Rosenberg, G. Triplett, M. Werbitt and B. Lithner (2000). "Immediate and delayed implant placement into extraction sockets: a 5-year report." Clin Implant Dent Relat Res 2(2): 93-99.

Polyzois, I., S. Renvert, D. D. Bosshardt, N. P. Lang and N. Claffey (2007). "Effect of Bio-Oss on osseointegration of dental implants surrounded by circumferential bone defects of different dimensions: an experimental study in the dog." Clin Oral Implants Res 18(3): 304-310.

Ponder, S. N., E. Benavides, S. Kapila and N. E. Hatch (2013). "Quantification of external root resorption by low- vs high-resolution cone-beam computed tomography and periapical radiography: A volumetric and linear analysis." Am J Orthod Dentofacial Orthop 143(1): 77-91.

Prell, D., Y. Kyriakou, M. Kachelrie and W. A. Kalender (2010). "Reducing metal artifacts in computed tomography caused by hip endoprostheses using a physics-based approach." Invest Radiol 45(11): 747-754.

Prosper, L., S. Redaelli, M. Pasi, F. Zarone, G. Radaelli and E. F. Gherlone (2009).

"A randomized prospective multicenter trial evaluating the platform-switching technique for the prevention of postrestorative crestal bone loss." Int J Oral Maxillofac Implants 24(2): 299-308.

Qian, J., A. Wennerberg and T. Albrektsson (2012). "Reasons for marginal bone loss around oral implants." Clin Implant Dent Relat Res 14(6): 792-807.

Quirynen, M., N. Van Assche, D. Botticelli and T. Berglundh (2007). "How does the timing of implant placement to extraction affect outcome?" Int J Oral Maxillofac Implants 22 Suppl: 203-223.

Röhrig, B., J. B. du Prel, D. Wachtlin, R. Kwiecien and M. Blettner (2010). "Sample Size Calculation in Clinical Trials: Part 13 of a Series on Evaluation of Scientific Publications." Dtsch Arztebl Int 107(31-32): 552-556.

Raes, F., J. Cosyn, E. Crommelinck, P. Coessens and H. De Bruyn (2011). "Immediate and conventional single implant treatment in the anterior maxilla: 1-year results of a case series on hard and soft tissue response and aesthetics." J Clin Periodontol 38(4): 385-394.

Raes, F., J. Cosyn and H. De Bruyn (2013). "Clinical, aesthetic, and patient-related outcome of immediately loaded single implants in the anterior maxilla: a prospective study in extraction sockets, healed ridges, and grafted sites." Clin Implant Dent Relat Res 15(6): 819-835.

Ramfjord, S. P., R. R. Nissle, R. A. Shick and H. Cooper, Jr. (1968). "Subgingival curettage versus surgical elimination of periodontal pockets." J Periodontol 39(3): 167-175.

Razavi, T., R. M. Palmer, J. Davies, R. Wilson and P. J. Palmer (2010). "Accuracy of measuring the cortical bone thickness adjacent to dental implants using cone beam computed tomography." Clin Oral Implants Res 21(7): 718-725.

Ring, M. E. (1985). Dentistry: an illustrated history, Abradale Press.

Ring, M. E. (1995). "A thousand years of dental implants: a definitive history--part 1." Compend Contin Educ Dent 16(10): 1060-1069.

Roe, P., J. Y. Kan, K. Rungcharassaeng, J. M. Caruso, G. Zimmerman and J. Mesquida (2012). "Horizontal and vertical dimensional changes of peri-implant facial bone following immediate placement and provisionalization of maxillary anterior single implants: a 1-year cone beam computed tomography study." Int J Oral Maxillofac Implants 27(2): 393-400.

Rosenquist, B. (1997). "A comparison of various methods of soft tissue management following the immediate placement of implants into extraction sockets." Int J Oral Maxillofac Implants 12(1): 43-51.

Rosenquist, B. and M. Ahmed (2000). "The immediate replacement of teeth by dental implants using homologous bone membranes to seal the sockets: clinical and radiographic findings." Clin Oral Implants Res 11(6): 572-582.

Rosenquist, B. and B. Grenthe (1996). "Immediate placement of implants into extraction sockets: implant survival." Int J Oral Maxillofac Implants 11(2): 205-209.

Ross, S. E., H. W. Crossetti, A. W. Gargiulo and J. S. Ledakis (1989). "The use of the Ross implant in an immediate extraction site." CDS Rev 82(1): 64-68.

Rossi, F., P. Romanelli, E. Ricci, C. Marchetti and D. Botticelli (2013). "A cone beam tomographic evaluation of hard tissue alterations at immediate implants: a clinical prospective study." Int J Periodontics Restorative Dent 33(6): 815-823.

Ryser, M. R., M. S. Block and D. E. Mercante (2005). "Correlation of papilla to crestal bone levels around single tooth implants in immediate or delayed crown protocols." J Oral Maxillofac Surg 63(8): 1184-1195.

Sakpal, T. V. (2010). "Sample Size Estimation in Clinical Trial." Perspect Clin Res 1(2): 67-69.

Sanz, M., D. Cecchinato, J. Ferrus, E. B. Pjetursson, N. P. Lang and J. Lindhe (2010). "A prospective, randomized-controlled clinical trial to evaluate bone preservation using implants with different geometry placed into extraction sockets in the maxilla." Clin Oral Implants Res 21(1): 13-21.

Scaf, G., A. G. Lurie, K. M. Mosier, M. L. Kantor, G. R. Ramsby and M. L. Freedman (1997). "Dosimetry and cost of imaging osseointegrated implants with film-based and computed tomography." Oral Surg Oral Med Oral Pathol Oral Radiol Endod 83(1): 41-48.

Scarfe, W. C. and A. G. Farman (2010). "Interpreting CBCT Images for implant assessment: Part 1--Pitfalls in image interpretation." Australasian Dental Practice Jul/Aug: 106-144.

Scarfe, W. C., A. G. Farman and P. Sukovic (2006). "Clinical applications of cone-beam computed tomography in dental practice." J Can Dent Assoc 72(1): 75-80.

Schincaglia, G. P., S. Rubin, S. Thacker, A. Dhingra, L. Trombelli and E. Ioannidou (2016). "Marginal Bone Response Around Immediate- and Delayed-Loading Implants Supporting a Locator-Retained Mandibular Overdenture: A Randomized Controlled Study." Int J Oral Maxillofac Implants 31(2): 448-458.

Schlegel, A. K. and K. Donath (1998). "BIO-OSS--a resorbable bone substitute?" J Long Term Eff Med Implants 8(3-4): 201-209.

Schnitman, P. A. and L. B. Shulman (1979). "Recommendations of the consensus development conference on dental implants." J Am Dent Assoc 98(3): 373-377.

Schropp, L. and F. Isidor (2008). "Timing of implant placement relative to tooth extraction." J Oral Rehabil 35 Suppl 1: 33-43.

Schropp, L., F. Isidor, L. Kostopoulos and A. Wenzel (2004). "Patient experience of, and satisfaction with, delayed-immediate vs. delayed single-tooth implant placement." Clin Oral Implants Res 15(4): 498-503.

Schropp, L., F. Isidor, L. Kostopoulos and A. Wenzel (2005). "Interproximal papilla levels following early versus delayed placement of single-tooth implants: a controlled clinical trial." Int J Oral Maxillofac Implants 20(5): 753-761.

Schropp, L., L. Kostopoulos and A. Wenzel (2003a). "Bone healing following immediate versus delayed placement of titanium implants into extraction sockets: a prospective clinical study." Int J Oral Maxillofac Implants 18(2): 189-199.

Schropp, L., A. Wenzel, L. Kostopoulos and T. Karring (2003b). "Bone healing and soft tissue contour changes following single-tooth extraction: a clinical and radiographic 12-month prospective study." Int J Periodontics Restorative Dent 23(4): 313-323.

Schulte, W. and G. Heimke (1976). "[The Tubinger immediate implant]." Quintessenz 27(6): 17 - 23.

Schulze, D., M. Heiland, H. Thurmann and G. Adam (2004). "Radiation exposure during midfacial imaging using 4- and 16-slice computed tomography, cone beam computed tomography systems and conventional radiography." Dentomaxillofac Radiol 33(2): 83-86.

Schulze, R., U. Heil, D. Gross, D. D. Bruellmann, E. Dranischnikow, U. Schwanecke and E. Schoemer (2011). "Artefacts in CBCT: a review." Dentomaxillofac Radiol 40(5): 265-273.

Schulze, R. K., D. Berndt and B. d'Hoedt (2010). "On cone-beam computed tomography artifacts induced by titanium implants." Clin Oral Implants Res 21(1): 100-107.

Schwartz-Arad, D. and G. Chaushu (1997). "The ways and wherefores of immediate placement of implants into fresh extraction sites: a literature review." J Periodontol 68(10): 915-923.

Siciliano, V. I., G. E. Salvi, S. Matarasso, C. Cafiero, A. Blasi and N. P. Lang (2009). "Soft tissues healing at immediate transmucosal implants placed into molar extraction sites with buccal self-contained dehiscences. A 12-month controlled clinical trial." Clin Oral Implants Res 20(5): 482-488.

Slagter, K. W., H. J. Meijer, N. A. Bakker, A. Vissink and G. M. Raghoebar (2016). "Immediate Single-Tooth Implant Placement in Bony Defects in the Esthetic Zone: A 1-Year Randomized Controlled Trial." J Periodontol 87(6): 619-629.

Slagter, K. W., G. M. Raghoebar, A. Vissink and H. J. A. Meijer (2015). "Inter- and intraobserver reproducibility of buccal bone measurements at dental implants with cone beam computed tomography in the esthetic region." International Journal of Implant Dentistry 1(1): 1-5.

Small, I. A. and D. Misiek (1986). "A sixteen-year evaluation of the mandibular staple bone plate." J Oral Maxillofac Surg 44(1): 60-66.

Smith, D. E. and G. A. Zarb (1989). "Criteria for success of osseointegrated endosseous implants." J Prosthet Dent 62(5): 567-572.

Smithloff, M. and M. E. Fritz (1976). "The use of blade implants in a selected population of partially edentulous adults. A five-year report." J Periodontol 47(1): 19-24.

Soblonsky, S. (1982). Illustrated dictionary of dentistry. Philadelphia, WB Saunders.

Sonoda, A., N. Nitta, N. Ushio, Y. Nagatani, N. Okumura, H. Otani and K. Murata (2015). "Evaluation of the quality of CT images acquired with the single energy metal artifact reduction (SEMAR) algorithm in patients with hip and dental prostheses and aneurysm embolization coils." Jpn J Radiol 33(11): 710-716.

Spin-Neto, R., E. Gotfredsen and A. Wenzel (2013a). "Impact of voxel size variation on CBCT-based diagnostic outcome in dentistry: a systematic review." J

Digit Imaging 26(4): 813-820.

Spin-Neto, R., A. Stavropoulos, L. A. Dias Pereira, E. Marcantonio, Jr. and A. Wenzel (2013b). "Fate of autologous and fresh-frozen allogeneic block bone grafts used for ridge augmentation. A CBCT-based analysis." Clin Oral Implants Res 24(2): 167-173.

Spray, J. R., C. G. Black, H. F. Morris and S. Ochi (2000). "The influence of bone thickness on facial marginal bone response: stage 1 placement through stage 2 uncovering." Ann Periodontol 5(1): 119-128.

Stratemann, S. A., J. C. Huang, K. Maki, A. J. Miller and D. C. Hatcher (2008). "Comparison of cone beam computed tomography imaging with physical measures." Dentomaxillofac Radiol 37(2): 80-93.

Strock, A. E. (1939). "Experimental work on direct implantation in the alveolus." Am J Orthod Oral Surg 25: 467-472.

Sukovic, P. (2003). "Cone beam computed tomography in craniofacial imaging." Orthod Craniofac Res 6 Suppl 1: 31-36; discussion 179-182.

Suomalainen, A., T. Vehmas, M. Kortesniemi, S. Robinson and J. Peltola (2008). "Accuracy of linear measurements using dental cone beam and conventional multislice computed tomography." Dentomaxillofac Radiol 37(1): 10-17.

Takeshita, F., T. Tokoshima and T. Suetsugu (1997). "A stent for presurgical evaluation of implant placement." J Prosthet Dent 77(1): 36-38.

Takrouri, H. S., M. M. Alnassar, A. Amirabadi, P. S. Babyn, R. Moineddin, N. L. Padfield, G. BenDavid and A. S. Doria (2015). "Metal Artifact Reduction: Added Value of Rapid-Kilovoltage-Switching Dual-Energy CT in Relation to Single-Energy CT in a Piglet Animal Model." AJR Am J Roentgenol 205(3): W352-359.

Tallgren, A. (1972). "The continuing reduction of the residual alveolar ridges in complete denture wearers: a mixed-longitudinal study covering 25 years." J Prosthet Dent 27(2): 120-132.

Tan, W. L., T. L. Wong, M. C. Wong and N. P. Lang (2012). "A systematic review of post-extractional alveolar hard and soft tissue dimensional changes in humans." Clin Oral Implants Res 23 Suppl 5: 1-21.

Tapia, J. L., L. Suresh, M. Plata and A. Aguirre (2002). "Ancient esthetic dentistry in Mesoamerica." Alpha Omegan 95(4): 21-24.

Taylor, T. D. and W. R. Laney (1993). Dental Implants: Are They for Me? . Carol Streams, Ilinois, Quintessence Publishing (IL).

Timock, A. M., V. Cook, T. McDonald, M. C. Leo, J. Crowe, B. L. Benninger and D. A. Covell Jr (2011). "Accuracy and reliability of buccal bone height and thickness measurements from cone-beam computed tomography imaging." American Journal of Orthodontics and Dentofacial Orthopedics 140(5): 734-744.

Torres, M. G., P. S. Campos, N. P. Segundo, M. Navarro and I. Crusoe-Rebello (2012). "Accuracy of linear measurements in cone beam computed tomography with different voxel sizes." Implant Dent 21(2): 150-155.

Tsuda, H., K. Rungcharassaeng, J. Y. Kan, P. Roe, J. L. Lozada and G. Zimmerman (2011). "Peri-implant tissue response following connective tissue and bone grafting in conjunction with immediate single-tooth replacement in the esthetic zone: a case series." Int J Oral Maxillofac Implants 26(2): 427-436.

Van der Weijden, F., F. Dell'Acqua and D. E. Slot (2009). "Alveolar bone dimensional changes of post-extraction sockets in humans: a systematic review." J Clin Periodontol 36(12): 1048-1058.

van Steenberghe, D. (1989). "A retrospective multicenter evaluation of the survival rate of osseointegrated fixtures supporting fixed partial prostheses in the treatment of partial edentulism." J Prosthet Dent 61(2): 217-223.

Vera, C., I. J. De Kok, W. Chen, G. Reside, D. Tyndall and L. F. Cooper (2012). "Evaluation of post-implant buccal bone resorption using cone beam computed tomography: a clinical pilot study." Int J Oral Maxillofac Implants 27(5): 1249-1257.

Vermylen, K., B. Collaert, U. Linden, A. L. Bjorn and H. De Bruyn (2003). "Patient satisfaction and quality of single-tooth restorations." Clin Oral Implants Res 14(1): 119-124.

Veyre-Goulet, S., T. Fortin and A. Thierry (2008). "Accuracy of linear measurement provided by cone beam computed tomography to assess bone quantity in the posterior maxilla: a human cadaver study." Clin Implant Dent Relat Res 10(4): 226-230.

Vignoletti, F., N. Discepoli, A. Muller, M. de Sanctis, F. Munoz and M. Sanz (2012). "Bone modelling at fresh extraction sockets: immediate implant placement versus spontaneous healing: an experimental study in the beagle dog." J Clin

Periodontol 39(1): 91-97.

Voss, J. O., T. Dieke, C. Doll, C. Sachse, K. Nelson, J. D. Raguse and S. Nahles (2016). "Retrospective long-term analysis of bone level changes after horizontal alveolar crest reconstruction with autologous bone grafts harvested from the posterior region of the mandible." J Periodontal Implant Sci 46(2): 72-83.

Wang, Q., L. Li, L. Zhang, Z. Chen and K. Kang (2013). "A novel metal artifact reducing method for cone-beam CT based on three approximately orthogonal projections." Phys Med Biol 58(1): 1-17.

Watzek, G., R. Haider, N. Mensdorff-Pouilly and R. Haas (1995). "Immediate and delayed implantation for complete restoration of the jaw following extraction of all residual teeth: a retrospective study comparing different types of serial immediate implantation." Int J Oral Maxillofac Implants 10(5): 561-567.

Weber, H. P., C. C. Crohin and J. P. Fiorellini (2000). "A 5-year prospective clinical and radiographic study of non-submerged dental implants." Clin Oral Implants Res 11(2): 144-153.

Weiss, C. M. and K. W. Judy (1974). "Intramucosal inserts--solve patients' problems with maxillary dentures. II." Quintessence Int Dent Dig 5(4): 9-15.

Wennstrom, J. L., A. Ekestubbe, K. Grondahl, S. Karlsson and J. Lindhe (2004). "Oral rehabilitation with implant-supported fixed partial dentures in periodontitis-susceptible subjects. A 5-year prospective study." J Clin Periodontol 31(9): 713-724.

Wennstrom, J. L., A. Ekestubbe, K. Grondahl, S. Karlsson and J. Lindhe (2005). "Implant-supported single-tooth restorations: a 5-year prospective study." J Clin Periodontol 32(6): 567-574.

Wheeler, S. L., R. E. Vogel and R. Casellini (2000). "Tissue preservation and maintenance of optimum esthetics: a clinical report." Int J Oral Maxillofac Implants 15(2): 265-271.

White, S. C. (1992). "1992 assessment of radiation risk from dental radiography." Dentomaxillofac Radiol 21(3): 118-126.

White, S. C. and M. J. Pharoah (2013). Cono-beam Computed Tomography: Aquisition. Oral Radiology: Principles and Interpretation, Mosby: 197.

Wilson, T. G., Jr., R. Schenk, D. Buser and D. Cochran (1998). "Implants placed in immediate extraction sites: a report of histologic and histometric analyses of human biopsies." Int J Oral Maxillofac Implants 13(3): 333-341.

Wilson, T. G. and H. P. Weber (1993). "Classification of and therapy for areas of deficient bony housing prior to dental implant placement." Int J Periodontics Restorative Dent 13: 451-459.

Wuest, W., M. S. May, M. Brand, N. Bayerl, A. Krauss, M. Uder and M. Lell (2015). "Improved Image Quality in Head and Neck CT Using a 3D Iterative Approach to Reduce Metal Artifact." AJNR Am J Neuroradiol 36(10): 1988-1993.

Yukna, R. A. (1991). "Porous hydroxyapatite and decalcified freeze-dried bone in human periodontal defects." J Periodontol 62(6): 407.

Zetu, L. and H. L. Wang (2005). "Management of inter-dental/inter-implant papilla." J Clin Periodontol 32(7): 831-839.

Zhang, Y., L. Zhang, X. R. Zhu, A. K. Lee, M. Chambers and L. Dong (2007). "Reducing metal artifacts in cone-beam CT images by preprocessing projection data." Int J Radiat Oncol Biol Phys 67(3): 924-932.

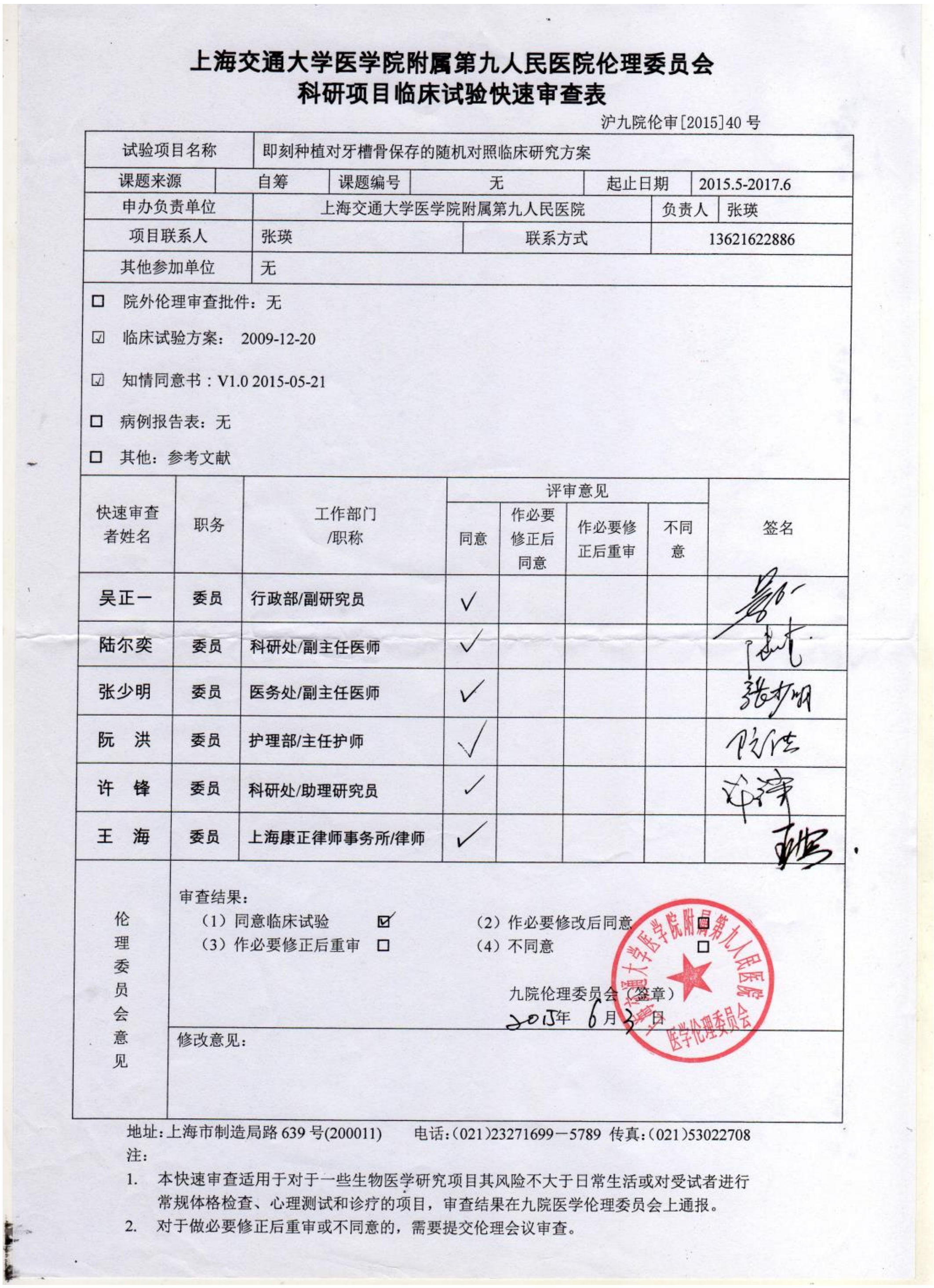
Ziegler, C. M., R. Woertche, J. Brief and S. Hassfeld (2002). "Clinical indications for digital volume tomography in oral and maxillofacial surgery." Dentomaxillofac Radiol 31(2): 126-130.

Zitzmann, N. U., G. Krastl, H. Hecker, C. Walter and R. Weiger (2009). "Endodontics or implants? A review of decisive criteria and guidelines for single tooth restorations and full arch reconstructions." Int Endod J 42(9): 757-774.

Zitzmann, N. U., R. Naef and P. Scharer (1997). "Resorbable versus nonresorbable membranes in combination with Bio-Oss for guided bone regeneration." Int J Oral Maxillofac Implants 12(6): 844-852.

Zitzmann, N. U., P. Scharer and C. P. Marinello (1999). "Factors influencing the success of GBR. Smoking, timing of implant placement, implant location, bone quality and provisional restoration." J Clin Periodontol 26(10): 673-682.

10. Appendix 1: Ethical approval



上海交通大学医学院附属第九人民医院伦理委员会
科研项目临床试验快速审查表

沪九院伦审[2015]40 号

试验项目名称	即刻种植对牙槽骨保存的随机对照临床研究方案				
课题来源	自筹	课题编号	无	起止日期	2015.5-2017.6
申办负责单位	上海交通大学医学院附属第九人民医院			负责人	张瑛
项目联系人	张瑛	联系方式	13621622886		
其他参加单位	无				

□ 院外伦理审查批件：无

☑ 临床试验方案：2009-12-20

☑ 知情同意书：V1.0 2015-05-21

□ 病例报告表：无

□ 其他：参考文献

快速审查者姓名	职务	工作部门/职称	评审意见				签名
			同意	作必要修正后同意	作必要修正后重审	不同意	
吴正一	委员	行政部/副研究员	✓				
陆尔奕	委员	科研处/副主任医师	✓				
张少明	委员	医务处/副主任医师	✓				张少明
阮　洪	委员	护理部/主任护师	✓				
许　锋	委员	科研处/助理研究员	✓				
王　海	委员	上海康正律师事务所/律师	✓				

伦理委员会意见

审查结果：

（1）同意临床试验 ☑　（2）作必要修改后同意 □

（3）作必要修正后重审 □　（4）不同意 □

九院伦理委员会（签章）

2015年 6月 3 日

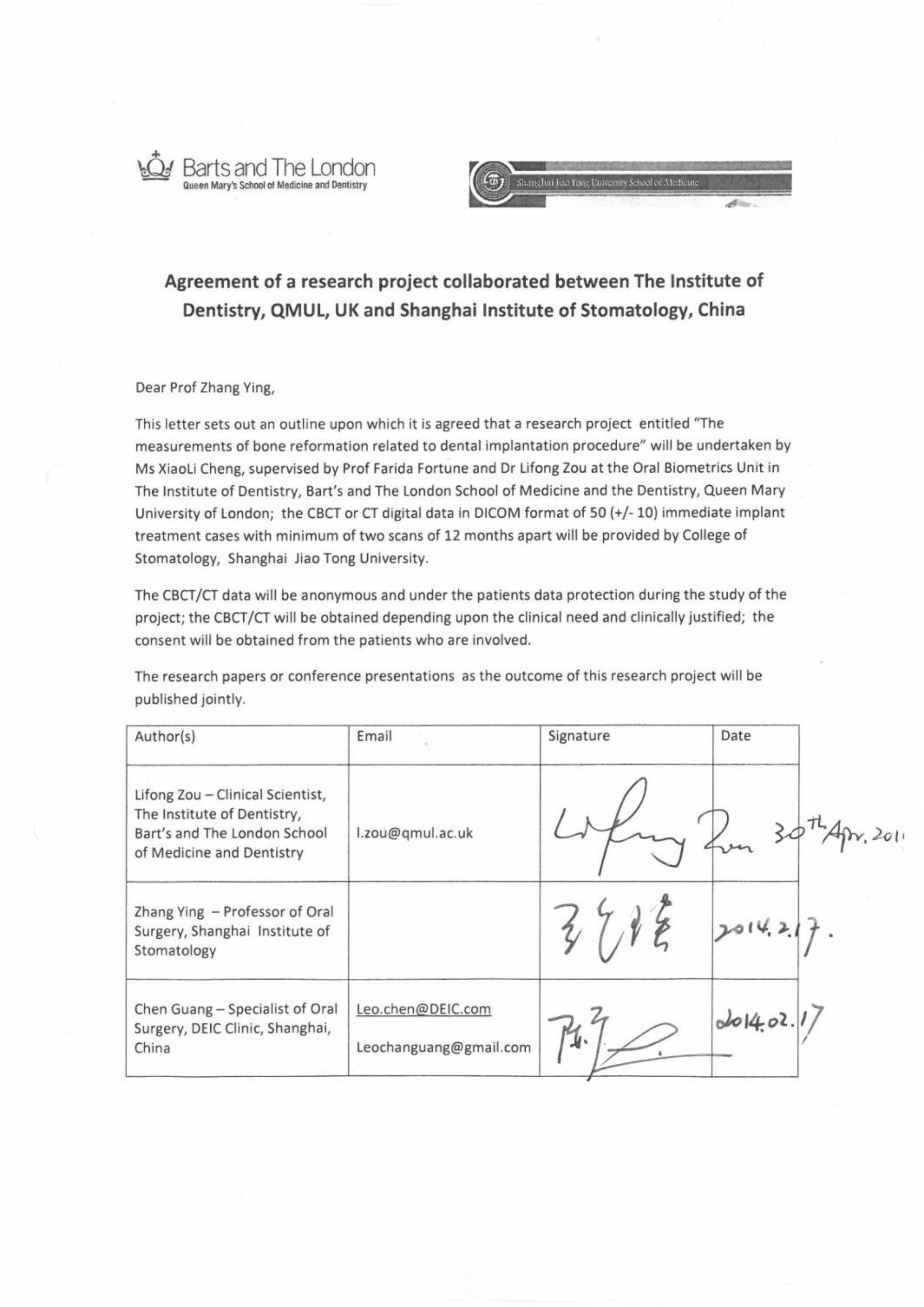
修改意见：

地址：上海市制造局路 639 号(200011)　电话：(021)23271699－5789 传真：(021)53022708

注：

1. 本快速审查适用于对于一些生物医学研究项目其风险不大于日常生活或对受试者进行常规体格检查、心理测试和诊疗的项目，审查结果在九院医学伦理委员会上通报。
2. 对于做必要修正后重审或不同意的，需要提交伦理会议审查。

11. Appendix 2: Agreement of collaboration between The Institute of Dentistry, QMUL and Shanghai Institute of Stomatology, China



Barts and The London
Queen Mary's School of Medicine and Dentistry

Shanghai Jiao Tong University School of Medicine

Agreement of a research project collaborated between The Institute of Dentistry, QMUL, UK and Shanghai Institute of Stomatology, China

Dear Prof Zhang Ying,

This letter sets out an outline upon which it is agreed that a research project entitled "The measurements of bone reformation related to dental implantation procedure" will be undertaken by Ms XiaoLi Cheng, supervised by Prof Farida Fortune and Dr Lifong Zou at the Oral Biometrics Unit in The Institute of Dentistry, Bart's and The London School of Medicine and the Dentistry, Queen Mary University of London; the CBCT or CT digital data in DICOM format of 50 (+/- 10) immediate implant treatment cases with minimum of two scans of 12 months apart will be provided by College of Stomatology, Shanghai Jiao Tong University.

The CBCT/CT data will be anonymous and under the patients data protection during the study of the project; the CBCT/CT will be obtained depending upon the clinical need and clinically justified; the consent will be obtained from the patients who are involved.

The research papers or conference presentations as the outcome of this research project will be published jointly.

Author(s)	Email	Signature	Date
Lifong Zou – Clinical Scientist, The Institute of Dentistry, Bart's and The London School of Medicine and Dentistry	l.zou@qmul.ac.uk	Lifong Zou	30th Apr. 201
Zhang Ying – Professor of Oral Surgery, Shanghai Institute of Stomatology			2014.2.17.
Chen Guang – Specialist of Oral Surgery, DEIC Clinic, Shanghai, China	Leo.chen@DEIC.com Leochanguang@gmail.com		2014.02.17

12. Appendix 3: Clinical information of 69 cases

Information of Patients' No., sex, age, site of implantation, type of implantation, diameter and length of implant, data of CBCT data sets in 69 cases were showed in the table below.

Patients No.	Sex	Age	Site	Group	Diameter(mm)	Length(mm)	Bone grafting	Flapless surgery	Date of CBCT data sets
BLH	F	56	34	Type 1	4.3	13	Applied	Applied	2011/9/27; 2014/3/11
BWJ	M	43	17	Type 1	4.3	10	Applied	Applied	2011/12/19; 2013/5/23
CC	M	20	35	Type 1	5	13	Applied	Applied	2013/1/25; 2014/1/26
CGF	M	32	45	Type 4	4.3	13	Applied	No	2011/12/2; 2012/11/23
CJ	M	33	14	Type 4	4.3	10	No	No	2013/3/15; 2014/3/10
CJY	M	34	36	Type 4	5	13	No	No	2012/5/4; 2013/10/7
			46	Type 1	5	13	No	No	
CLP	M	46	45	Type 4	4.3	10	No	No	2013/7/7; 2014/8/4
CO	M	30	24	Type 4	3.5	13	Applied	No	2011/4/14; 2013/1/11
			14	Type 1	3.5	13	Applied	Applied	
CYB	M	31	46	Type 4	5	10	No	No	2012/9/20; 2013/10/23
CZH	M	38	25	Type 1	4.3	13	Applied	No	2011/9/19; 2013/12/3
FH	F	43	15	Type 1	4.3	13	Applied	No	2013/9/10; 2014/10/1
GH	M	22	36	Type 1	4.3	10	Applied	Applied	2014/2/3; 2015/3/31
GLY	F	43	46	Type 4	4.3	10	Applied	No	2011/4/5; 2013/1/4
			37	Type 1	4.3	10	Applied	Applied	
GM	M	26	36	Type 4	5	10	Applied	No	2013/8/7; 2014/9/5
GQY	F	49	24	Type 1	4.3	13	Applied	No	2011/8/19; 2013/3/14; 2014/3/14

			15	Type 1	4.3	13	Applied	No	
GR	M	29	36	Type 1	5	13	Applied	No	2012/1/13; 2013/3/20
GWL	M	34	35	Type 1	4.3	13	Applied	Applied	2012/7/23; 2013/9/4
GWX	F	32	37	Type 1	5	13	Applied	No	2013/1/25; 2014/4/15
HDQ	F	42	35	Type 1	4.3	13	Applied	Applied	2011/10/10; 2012/11/29
HHW	M	28	46	Type 1	5	13	Applied	Applied	2012/5/24; 2013/12/12
JY	M	34	46	Type 1	5	13	Applied	Applied	2012/10/15; 2014/3/6
LJY	M	35	36	Type 1	4.3	13	Applied	No	2013/10/11; 2015/6/5
LJG	F	19	46	Type 4	5	10	No	No	2013/5/30; 2014/6/2
LYL	M	22	36	Type 1	5	13	Applied	Applied	2011/9/26; 2013/3/28
MBL	M	43	46	Type 1	5	10	Applied	No	2013/6/21; 2014/7/23
MRY	M	38	14	Type 4	4.3	11.5	No	No	2013/1/16; 2014/2/1
MXL	F	38	34	Type 1	4.3	13	Applied	No	2014/1/13; 2015/2/13
QJW	M	60	44	Type 1	4.3	13	Applied	No	2012/5/10; 2013/10/25
RG	M	35	14	Type 1	4.3	10	Applied	No	2013/7/10; 2015/1/5
SJF	M	34	46	Type 1	5	10	Applied	Applied	2013/9/24; 2014/10/25
SLY	F	54	25	Type 4	4.3	10	Applied	No	2011/10/1; 2012/9/27
WF	F	33	24	Type 1	3.5	13	Applied	Applied	2011/11/9; 2013/12/21
WFA	F	33	46	Type 4	5	10	Applied	No	2011/11/7; 2013/8/28
			37	Type 4	5	10	Applied	No	
WHY	F	19	46	Type 1	5	13	Applied	Applied	2012/4/7; 2013/6/21
WKQ	F	53	24	Type 1	3.5	13	Applied	No	2012/9/3; 2013/6/3
WM	F	31	46	Type 1	4.3	13	Applied	No	2013/8/8; 2014/9/11
WW	F	48	37	Type 1	4.3	13	Applied	Applied	2011/11/23; 2013/3/6
WX	F	38	46	Type 1	5	13	Applied	Applied	2013/1/11; 2014/6/15
WXM	M	27	16	Type 4	5	10	Applied	No	2014/9/20; 2015/11/12

WYH	F	25	24	Type 4	4.3	11.5	No	No	2012/8/19; 2013/9/20
XJL	F	24	36	Type 4	4.3	11.5	Applied	No	2012/11/11; 2013/12/10
XJY	F	26	46	Type 1	5	13	Applied	Applied	2013/4/23; 2015/1/21
XL	M	28	46	Type 4	4.3	10	Applied	No	2012/11/1; 2013/10/23
XLM	F	45	36	Type 1	5	13	Applied	No	2013/6/19; 2015/6/17
XM	M	43	35	Type 1	4.3	13	Applied	Applied	2013/6/20; 2014/5/20
XWJ	F	46	17	Type 4	4.3	10	Applied	No	2013/1/20; 2014/1/5
XYA	F	29	46	Type 4	4.3	10	No	No	2012/5/7; 2013/6/23
XYX	M	41	37	Type 4	4.3	10	Applied	No	2012/12/1; 2013/12/16
YHA	F	46	15	Type 4	4.3	10	No	No	2012/7/6; 2013/6/30
YH	M	40	35	Type 4	4.3	13	Applied	No	2013/10/14; 2014/11/1
YSX	F	43	17	Type 4	4.3	10	Applied	No	2013/7/8; 2014/7/3
YYP	M	46	36	Type 1	5	13	Applied	No	2013/6/13; 2014/7/18; 2015/8/20
ZBK	M	34	15	Type 4	4.3	10	No	No	2012/1/5; 2013/12/1
			26	Type 1	4.3	10	Applied	Applied	
ZJJ	M	25	45	Type 1	4.3	13	Applied	No	2012/5/25; 2013/12/2
ZMA	M	42	16	Type 1	4.3	10	Applied	No	2012/4/14; 2013/6/21
ZMJ	F	38	46	Type 1	5	13	Applied	No	2011/12/20; 2013/2/4
ZPL	M	41	37	Type 4	4.3	10	Applied	No	2014/2/14; 2015/3/3
ZPA	F	29	26	Type 1	5	10	Applied	No	2012/4/28; 2013/9/26
ZPB	F	38	17	Type 1	3.5	10	Applied	Applied	2014/4/5; 2015/5/2
ZXN	F	19	35	Type 1	3.5	10	Applied	No	2012/5/25; 2014/3/5
ZXZ	M	57	34	Type 1	4.3	13	Applied	No	2013/9/24; 2014/11/2
ZY	F	36	36	Type 1	4.3	13	Applied	No	2012/11/1; 2014/3/6
ZZW	M	19	35	Type 1	5	13	Applied	No	2013/12/8; 2014/12/3