

**BIOMECHANICAL INVESTIGATION OF
DENTAL IMPLANT USING RESONANCE
FREQUENCY ANALYSIS, 3D BONE
ASSESSMENT AND FINITE ELEMENT
ANALYSIS**

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UNIVERSITI SAINS MALAYSIA

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by

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LIST OF SYMBOL

E Modulus Young

α Volume Fraction

γ Bone Mineral Fraction

I Transmitted photon intensity

I_0 Original intensity of x-ray

μ Linear attenuation coefficient of the material

LIST ABBREVIATIONS

2-D	Two Dimensional
3-D	Three Dimensional
CBCT	Cone Beam Computer Tomography
CT	Computed Tomography
HU	Hounsfield Unit
PDL	Periodontal Ligament
ROI	Region of Interest
RFA	Resonance Frequency Analysis
FEA	Finite Element Analysis
ISQ	Implant Stability Quotient
SD	Standard Deviation
SPSS	Statistical Package for the Social Sciences
MIMICS	Materialise Interactive Medical Image Control System
ANSYS	Analysis System
R	Coefficient correlation
VV	Voxel Value
IRC	Implant-Retained Crown

**PENYIASATAN BIOMEKANIK IMPLAN GIGI MENGGUNAKAN
ANALISIS FREKUENSI RESONANS, PENILAIAN TULANG 3D DAN
ANALISIS UNSUR TERHINGGA**

ABSTRAK

Penilaian bioserasi dan biomekanik selepas pengimplanan gigi adalah satu tugas penting untuk memelihara jangka hayat gigi. Faktor-faktor yang menyokong osseointegrasi tulang, kestabilan gigi dan ciri-ciri baru sistem biomekanik implan gigi perlu difahami supaya sifat dinamik seperti rambatan tekanan dan pergerakan mikro hasil daripada beban yang berbeza termasuk keadaan sebelum dan selepas pemasangan korona boleh dianggarkan. Walau bagaimanapun, dalam teknologi klinikal semasa, tingkah laku biomekanik gigi masih tidak dapat diramalkan kerana ketiadaan instrumen untuk mengukur fenomena tersebut secara klinikal. Satu teknologi pengimejan 3D seperti Cone Beam Computed Tomography (CBCT) dapat menghasilkan imej sistem implan gigi yang lebih baik dan memberikan beberapa kelebihan. Walau bagaimanapun, beberapa isu masih terbenam dalam aplikasi mereka terutama untuk penilaian kepadatan tulang. Objektif kajian ini adalah untuk menilai implan gigi secara biomekanik dalam 3 dimensi, termasuk pemeriksaan ke atas ketepatan dan keterulangan CBCT, pemantauan kestabilan implan menggunakan Analisis Kekerapan Resonans (RFA) dan korelasinya dengan kualiti dan kuantiti tulang serta perubahan ketumpatan semasa rawatan implan gigi. Kajian lanjut akan meliputi kesan bebanan dan pembolehkan ke atas pengagihan tekanan serta pergerakan mikro sistem implan gigi sebelum dan selepas pemasangan korona berdasarkan kajian berangka melalui analisis unsur terhingga (FEA) ke atas model dan data vivo. Kaedah kajian telah ditetapkan untuk mencapai keseluruhan objektif yang melibatkan sepuluh orang pesakit dan seorang doktor bedah mulut di Hospital USM

(HUSM) semasa rawatan implan gigi. Pemantauan implan dijalankan dalam tiga peringkat: seurus selepas pemasangan, 3 bulan selepas pembedahan dan 4 bulan selepas pemasangan implan atau sebulan selepas pemasangan korona. Analisis statistik dilakukan menggunakan perisian SPSS, analisis unsur terhingga (FEA) telah dijalankan dengan menggunakan perisian ANSYS Workbench untuk mensimulasikan agihan tekanan dan pergerakan mikro disebabkan oleh bebanan yang berbeza (menegak, mendatar dan penyingkiran tork bebanan) untuk keadaan sebelum dan selepas pemasangan korona. Penyediaan kajian FEA termasuk pensegmenan dan jaringan dijalankan menggunakan perisian MIMICS dan 3-matic berdasarkan imej CBCT. Hasilnya menunjukkan bahawa ketebalan dan ketinggian kortikal mempunyai pekali korelasi yang lebih tinggi dengan kestabilan implan gigi berbanding ketumpatan dan kelebaran tulang. Penyusutan tulang semasa peringkat penyembuhan telah berlaku 3 bulan selepas pembedahan, manakala osseointegrasi atau pembentukan tulang dan kestabilan implan gigi meningkat dengan ketara 4 bulan selepas pembedahan. Tekanan yang dihasilkan semasa simulasi bebanan adalah rendah untuk pesakit dengan kestabilan implan gigi yang tinggi dan sederhana serta tinggi untuk pesakit dengan kestabilan implan gigi yang rendah. Tekanan tinggi yang terhasil cenderung untuk menghasilkan pergerakan mikro yang lebih tinggi. Tekanan dan pergerakan mikro adalah dua faktor penting yang menentukan kestabilan implan, osseointegrasi dan aktiviti pembentukan semula tulang.

**BIOMECHANICAL INVESTIGATION OF DENTAL IMPLANT USING
RESONANCE FREQUENCY ANALYSIS, 3D BONE ASSESSMENT AND
FINITE ELEMENT ANALYSIS**

ABSTRACT

Biocompatibility and biomechanics assessment after implant placement become an essential task to support longevity of dental implant. Understanding the factors that supporting bony osseointegration, stability of implant and characteristic of new biomechanics system of dental implant are needed. Therefore, the behavior of dynamic properties such as stress propagation and micromotion as responses of different loading including pre and post crown condition can be estimated. However, in current clinical technology, the biomechanical behavior of dental implant is still unpredicted because of unavailability of the instrument to measure those phenomena clinically. A 3D imaging technology such as Cone Beam Computed Tomography (CBCT) able to produce better image of implant dental system and gives some advantages. However, some issues are still embedded in their application especially for bone density assessment. The objective of this research is to assess a dental implant biomechanically in three dimensions (3D), which include the examination on accuracy and repeatability of CBCT, monitoring of implant stability using Resonance Frequency Analysis (RFA) and its correlation with the bone quality and quantity and changes of density during dental implant treatment. Further objectives are to investigate the effect of loading and variables on stress distribution and micro motion of dental implant system in pre and post crown condition based on numerical study through Finite Element Analysis (FEA) on model and in vivo data. Methodology of the research was set to achieve the entire objectives which involved 10 implant patients

and an oral surgeon at Hospital USM (HUSM) during implant treatment. Monitoring of their implant progress were conducted in three stages: immediate after implant placement, 3 months after implant surgery, and 4 months after implant placement or 1 month after crown installation. Statistical analyses were performed in SPSS software, while the Finite Element Analysis (FEA) studies were conducted by using ANSYS Workbench software to simulate the generated stress distribution and micromotion due to different loading (vertical, horizontal and removal torque loading) for pre and post crown condition. The preparation of FEA study including the segmentation and meshing were conducted on MIMICS and 3-Matic software based on CBCT image. The result showed that the cortical thickness and bone height had higher correlation coefficient with implant stability compared to density and width of bone. Bone resorption during healing stage occurred within 3 months after surgery, osseointegration or remodeling occurred 4 months after surgery and implant stability increases significantly 4 months after surgery. The stresses generated during loading simulation was low in the patient with high and moderate implant stability and high for patient with low implant stability. The higher generated stress tends to produce higher micromotion. Stress and micro motion are two crucial factors that determine the implant stability, osseointegration and remodeling activity.

CHAPTER ONE

INTRODUCTION

1.1 Background

A dental implant is defined as a device of biocompatible material(s) placed into mandibular or maxillary bone to replace edentulous tooth. In addition, it is used also to improve appearance, masticatory function and prevent changes in dental arch dimension. Thus dental implant not only improving the convenience of the patient, it is also being able to protect remaining natural teeth, no bone loss and restore facial skeletal structure (Staden *et al.*, 2006).

Statistically it was shown that the use of dental implants to restore missing teeth has become increasingly widespread over the past two decades (Turkyilmaz & Mcglumphy, 2008). The statistic also showed that the success rate of dental implant is over 95% when the implants are designed, manufactured and placed correctly. Staden *et al.* (2006) calculated the survival rate at 15 years is about 90% which is become an advantage in implant treatment as low risk treatment.

While success rate of dental implant treatment is high, but the compatibility of installed implant into jawbone system might generate a problem because the forces conveyed by implant devices differ from those conveyed by natural teeth, thus they require adaptation from the jawbones. Maximum adaptation will be determined by the success of how the implant integrated to the bone as so called as osseointegration process. A biomechanical becomes a most important issue in implant dentistry.

The research about implant dentistry was grown rapidly after Lekholm & Zarb (1985) published his finding a theory of osseointegration. In his theory, the osseointegration is defined as a direct structural and functional connection between living bone and the surface of a loading-bearing implant. Many aspects have been investigated, especially on the aspect related to measure the stability of implant after implant insertion and correlate it with mechanism of internal process of bone to build optimum osseointegration. It still becomes a big challenge to be solved.

Meredith (1998) mentioned that there are some factors affect the success of implant such as the primary implant stability which is comes from mechanical engagement with cortical bone during implant placement, osseointegration, implant placement technique and local bone quality and quantity. Another important determinant for successful implant is a secondary stability. Secondary stability offers biological stability through bone regeneration and remodeling (Atsumi *et al.*, 2007). Continuous monitoring in an objective manner of the status of implant stability will be important to be established to make sure implant success in the future.

Lack of osseointegration during implant dental rehabilitation have been reported. It is because some reasons that might happen during treatment such as infections processes or inadequate load protocols. Incorrect placement technique and also the shape of the implant surface will reduce the coupling between bone and implant surface which can produce the spaces where bacteria could growth. In the other hand, mechanism of daily mastication also may produce large loading that promote a mobility of the implant and holes. However, if generated loading is too small, it is not sufficient to stimulate osteoblast activity, and hence the

osseointegration might be delayed. The mechanism of loading and its effect on progressing the rehabilitation becomes a most important task and the behavior of jaw system during treatment especially the stress distribution due to loading still unclear and still need further investigation.

More questions about stress distribution are still not solved, how bone reacts to the generated stress during loading and its relation between generated stress with a mechanical and hormonal response and remodeling/osseointegration, still unclear. Therefore, it is important to study the stress patterns distribution and correlate it with osseointegration process. However, because of limitation on available clinical instrument that can measure the stress distribution directly, alternative analysis based on numerical computation would be an ultimate method to understand the biomechanical mechanism of implant dental system.

Finite element analysis (FEA) is a numerical method, which has ability to solve the complex mechanical problem into elements, has been well accepted for investigating the behavior of stress in dentistry. Various loading can be examined in different model of in vitro or in vivo situations. This study, a prospective observational study is conducted to integrate the clinical measurements of implant stability using Resonance Frequency Analysis (RFA), site implant measurement using CBCT with numerical studies through FEA to assess biomechanical of dental implant comprehensively in 3D.

1.2 Statement of Problems

Perfect osseointegration between implant and bone that is indicated by high implant stability is a main goal to be achieved during dental implant treatment. Internal and external factors affect the proses to achieve early osseointegration. The external factors such as size of implant, technical and protocol of implant placement, coupling between implant and bone, stress experience during treatment, and internal factors such as the quality and quantity of bone, healthy of mouth environment and internal activity of bone as a response to the external loading are crucial factors that determine the success of dental implant treatment. However, the exact relation between those factors with activity of bone during healing process is still unclear. There is a need to do a comprehensive regular monitoring to measure implant stability which has not been investigated.

CBCT imaging is a recent technology in dentistry especially in Hospital-USM. The accuracy of CBCT in determining the geometry of the jawbone with high resolution image and able to define the geometry of the object up to millimeter scale. However, the accuracy of this method in estimating density is still questionable. More justifications on determining the density using this method still need to be validated and calibrated to make more confidence in interpreting the data especially during.

Clinically, the internal activity of bone or ability of osteoblast in responding to the impact of surgery during implant placement is determined by the intensity of stress received during daily loading from mastication process. However, there is no clinical instrument that can be used to measure directly the effect of those loading including the generated stress around implant site which can be correlated with an

internal bone activity (osseointegration process). It is important to have a method for evaluating the stress distribution due to various external loading in different conditions.

In advance, the developed method should be able to support the clinical measurement, and hence the result of this method can be used as an early warning to maintain the progress of sustainable of dental implant. Combination between numerical analysis and clinical measurement need to be conducted to broaden the use of CBCT data for better understanding the biomechanical evaluation of jaw system and it would be a bridge between laboratory and clinical assessment.

By using 2-D image as tools for evaluating the jawbone can provide only the image for identifying the static parameters such as density and availability of space for the implant site evaluation. However, when the dynamic properties such as the evaluation of stress distribution which usually occurs three dimensionally, this method is not supporting. In other side, CBCT scanning can provide 3D image of jaw. Then the 3D model of jaw can be generated for further study on biomechanical evaluation and simulation by using either in vivo or in vitro data.

The healing process of implant treatment including the pre and post-crown condition. However, the comparative study about biomechanical evaluation of implant system in pre and post-crown condition have not been established yet. Hence the comparison of behavior of dynamic behavior such as stress distribution for both conditions are still not evaluated. This study gave better understanding on mechanism

of stress distribution and able to give a feedback for dentist from engineering perspective.

1.3 Significance of Study

1. This study could offer reliable measurement about bone density based on CBCT during monitoring period.
2. This study also could offer new workflow for biomechanical evaluation that integrated the clinical measurement and numerical study.
3. Special significant for community of cranio facial group study in USM, this study can support the imaging technology and workflow for biomechanical assessment based on imaging data such as CBCT that can be extended with other imaging technology such as CT.
4. Evaluation of the density of mandible using CBCT in 3D gives clinicians a more accurate prediction of bone density difference which facilitates the pre-evaluation of availability of site implant.

1.4 Project Objective

1.3.1 General Objective

The aim of this research is to assess dental implant at mandible biomechanically in three dimensions (3D) for different condition of pre and post crown condition.

1.3.2 Specific Objectives

The specific objectives of this study are:

1. To measure the accuracy and repeatability of CBCT scanning in evaluating the bone quality and quantity of dental implant patient.
2. To analyze the relationship between bone quality and quantity measured from CBCT with implant stability and its classification that are measured by using RFA.
3. To determine bone density changes of jawbone during dental implant treatment.
4. To analyze the effect of cortical thickness and friction coefficient on stress distributions and micro motion of dental implant system during loading in pre and post crown condition.
5. To measure the stress distribution and micro motion due to various loading on pre and post crown condition of in vivo data.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The main goal of this chapter is to provide the background theory of biomechanical of dental implant system the related research and technology of dental implant and numerical study through FEA. The explanation includes a review about the technology related to implant stability which include brief description of molar of mandibular and maxilla, the fundamental mechanism of FEA and RFA and the density estimation and its effect to implant stability. In the end, this chapter also discussed the technology of dental imaging including the explanation of CBCT (Cone Beam Computed Tomography) instrument and its application in dental imaging.

2.2 Bone Formation

Bone is main part of the body that supports the body as a frame work could it is essential for the success in dental implant treatment. The formation of bone consists of main part that are cells and bone matrix. Bone matrix itself consist of inorganic component that cover about 69 % consist of hydroxyapatite and 22% of organic component that consist of collagen as major constituent (Kini & Nandeesh, 2012). In physiological view, bone composed of support cells that are osteoblasts and osteocytes and remodeling cells that are osteoclasts. These components are responsible for the dynamic process that consists of modeling and remodeling process in the bone.

Bone is characterized by its rigidity, hardness and the degree of dynamic process in the bone itself such as modeling and remodeling process. Based on these characteristics, bone can be categorized into two components that are cortical bone and trabecular bone. The cortical bone is dense, solid and surrounds the marrow space while the trabecular bone is honeycomb-like network which is consist of trabecular plates and rods interspersed (Kini & Nandeesh 2012). The slicing of cortical bone and trabecular bone is shown in Figure 2.1.

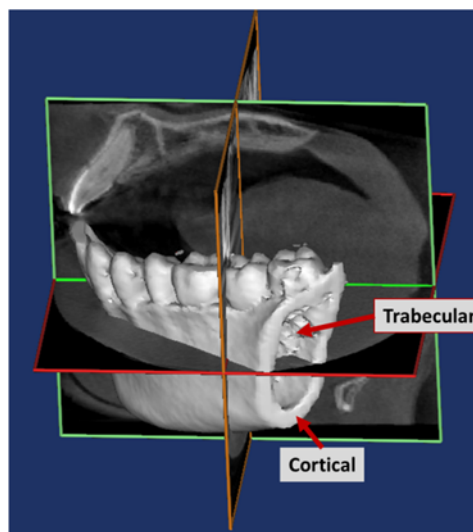


Figure 2.1. Jaw bone structure obtained from CBCT image.

In mandible, cortical bone is identified as a clear white in the CBCT image without trabecular pattern. Meanwhile, trabecular bone is defined as a bone in between two cortical plates. Proportion between trabecular and cortical bone define the quality of bone in implant site. If a proportion of cortical bone is higher than trabecular, bone quality of the implant site is better.

2.3 Bone Quality and Quantity Classification

Bone behavior can be characterized based on bone quality and quantity. It is a vital factor to achieve an osseointegration (Turkyilmaz & McGlumphy, 2008). Turkyilmaz & Mcglumphy (2008b) found that the survival rate of implant in mandible is higher than maxilla. It is because the quality of bone in mandible is higher compared with maxilla especially for posterior maxilla. Bone quality is defined as an ability of bone to withstand a wide range of loading without breaking (Sievänen, Kannus & Järvinen, 2007). In other terms, Lester (2005) defined that bone quality as a sum of total of the bone characteristics that influence the bone's resistance to fracture. Bone quality and quantity affect the survival rate of implant.

Lekholm & Zarb (1985b) have started quality and quantity assessment of bone. In their method, bone quality is scaled between 1 to 4, which is based on radiographic assessment, and the sensation of resistance experienced by the surgeon when preparing the implant site. Based on panoramic radiographs, they classified bone quality as: Type I which has homogenous compact bone, Type II has a thick layer of compact bone surrounding trabecular bone, Type III has a thin layer of cortical surrounding dense trabecular bone and Type IV has a thin layer of cortical surrounding low density trabecular bone. The illustration of those classes is shown in Figure 2.2.

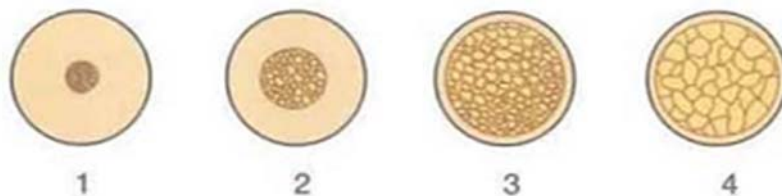


Figure 2.2. Bone quality classification from Lekholm and Zarb; type I, type II, type III and type IV. (Lekholm & Zarb, 1985)

Classification of bone density was introduced by Misch & A.Abbas, (2008). In their classification, bone density was classified based on subjective perception of drilling resistance into four types; D1, D2, D3 and D4. D1 type has a primarily dense cortical bone, D2 type has dense to the porous cortical bone, D3 type has a thin cortical and fine trabecular and D4 has a fine trabecular. The schematic of bone classification based on Misch's theory is presented in Figure 2.3.

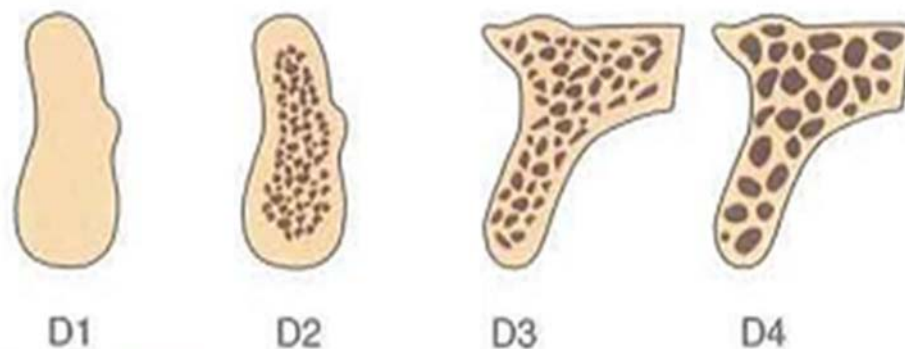


Figure 2.3 Bone classification based on Misch's Theory: D1, D2, D3 and D4 (Misch, 1993).

Other researchers, Linkow *et al.*, (2012) classified bone based on structure into three groups: Class I, Class II and Class III. Class I is identified as bone with spaced trabecular with a small cancellated space. Class II has a larger cancellous and uniformity of osseous pattern is less. Class III is identified as bone with structure large marrow-filled space between trabecular.

Most of the explained technique in determining the bone quality and quantity is based on subjective experience which has difficulties to quantify in general. This classification will depend on person-to-person who do the evaluation. It is interesting if there is an alternative method that can be used to evaluate bone quality and quantity quantitatively. Hence, the evaluation of bone can be done without personal

interference. Because the bone system is a 3D object, it is interesting if the 3D image technology can be optimized as a tool for bone quality and quantity assessment. However, the linearity of available 3D image technology is another issue. Hence, the evaluation of 3D image parameters as density indicator needs to be tested.

The classifications of bone based on subjective parameters have recently been questioned due to poor objectivity and reproducibility (Shapurian *et al.*, 2006; Al-Nakib., 2014). Other technique such as cutting resistance which is performed during surgery; it can be correlated with bone density as assessed by microradiography (Sençimen *et al.*, 2011; Friberg *et al.*, 1995). Direct measurement of insertion torque also showed that there is a strong correlation between insertion torque with density (Bayarchimeg *et al.*, 2013; Khayat *et al.*, 2013).

Micro-computed tomography (Micro CT) is a new method in dental imaging which has very high resolution. This method also can be used to assess jawbone in 3-Dimensionally. The assessment includes bone volume, density, trabecular thickness, trabecular separation, trabecular number and structural model index (Fuller, Fuller & Pereira, 2015). The 3D morphometric data acquired through micro CT also can be correlated with conventional bone assessment methods (Fanuscu & Chang, 2004; Norton *et al.*, 2001; Faot *et al.*, 2015).

Application of CT for bone density assessment on alveolar bone density is questionable because of radiation dosage issue, especially for repetition of scanning which is needed during dental implant treatment. It is rational, if any other technology that can provide lower dosages of exposure but still has high resolution, fast scanning,

noninvasive, and able to estimate precisely the density are preferred for dental system evaluation.

Cone-Beam Computed Tomography (CBCT) with low dosages, fast scanning time, non-destructive and able to produce high resolution is an alternative dental imaging technology in dentistry. Aranyarachkul *et al.* (2005) demonstrated that CBCT could be an alternative diagnostic method for density evaluation, especially since the radiation dosage of CBCT much lower than CT (Computed Tomography). Not only can be correlated with bone density, but also it can be correlated with cutting resistance (CR) values as obtained at the time of implant placement.

Preeti Mahajan Chopra (2010) correlated cone beam computerized tomography (CBCT) bone density values with cutting resistance (CR) as obtained at during implant placement. Also, optimization of CBCT as for density assessment and correlation with direction of tooth movement has been introduced by Chang *et al.* (2012). Other researchers used CBCT as density prediction tools and correlated it with other measured parameter such primary implant stability (Marquezan *et al.*, 2012; Isoda *et al.*, 2012).

CBCT that is offer a high spatial resolution, fast scanning time and low dosage of exposure is an alternative technique in bone quality and quantity assessment technique based on imaging. Previous researchers have introduced correlation between extracted information based on Hounsfield Value of CBCT with other measured parameters related to dental implant. However, the accuracy of this method in defining density in 3-Dimensional still not be tested, the correlation between Hounsfield Value of CBCT

with true density of various object still unclear. Investigation to fulfill this gap is needed to gain the CBCT advantages in dental implant.

2.4 Procedures of Implant Placement

A dental implant that is placed to serves the structural support for dental prosthesis has main components: the implant, the abutment and the prosthesis as shown in Figure 2.4. The technique to install that implants are considered case by case, it might be a two-stage surgical procedure or one-stage technique depend on clinical conditions and situations.

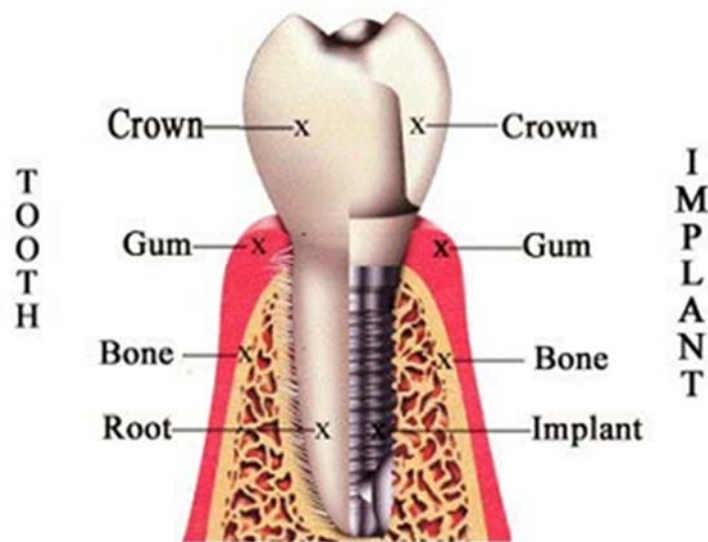


Figure 2.4. An illustration of a dental implant system.(Faegh & Müftü, 2010)

A two-stage surgical procedure is performed to place an implant in the jawbone by considering an adequate bone to support those dental implants. There are two phases surgery in this procedure, in the first phase, the gingival tissue is opened, and implant is placed in the proper site and covered back by gingival tissue. After osseointegration is achieved and implant is fixed, then abutment are connected by

reopened the gingival tissue and artificial tooth is placed on the top of fixture (Natali, 2003).

One-stage technique is performed by placed the implant into jawbone with only one surgical intervention. The abutment is placed directly into implant before implant covered by gingival tissue. The difference technique between two-stage and one-stage technique is described in Figure 2.5.

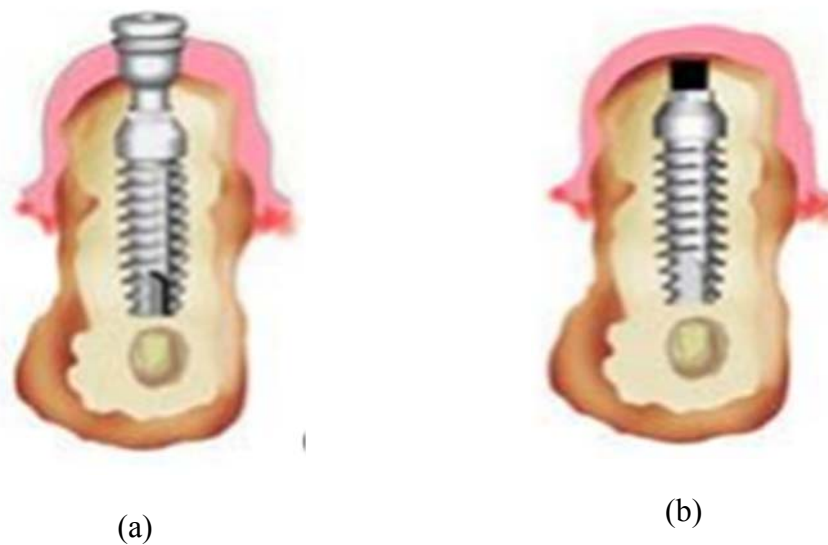


Figure 2.5 (a) Dental implants after the one-stage implantation and (b) After the first phase of a two-stage implantation (Andrade, 2013).

Even the one-stage technique only involving one surgical intervention. However, there are situations in which the two-stage is more favorable (Heijdenrijk, 2000) the reasons are;

- The bone can be protected from the exposure hence the bone regeneration can be achieved rapidly.
- It can avoid undesirable loading that can affect the implant stability during osseointegration period.

- It can protect bone from infection during healing period especially for the patient who does not able to maintain a sufficient level of oral hygiene.
- It is for effectiveness reason for the patients who will receive radiotherapy in the implant region, it will foreseeable.

2.5 Methods of Implant Stability Measurement in Dentistry

Implant stability is an indirect indication of osseointegration, is a measure of the clinical immobility of an implant (Parithimarkalaignan & Padmanabhan, 2013). Implant stability is divided into two types; primary implant stability and secondary implant stability. Primary implant stability is defined as stability during implant insertion meanwhile the secondary implant stability is defined as stability of dental implant after implant insertion.

Implant stability is influenced by internal and external factors, including both material and local tissue dependent variables. External factors that affecting implant stability are: material of implant, the length and diameter of implant, its design, the micro-morphology of implant surface and implant insertion technique. Meanwhile the important determinants as internal factor are the quality and quantity of the bone and osseointegration process. The greatest primary stability of dental implants can be reached with simple drilling. The use of additional thread cutters and bone condensers has been shown to lessen primary stability significantly (Rabel *et al.*, 2007).

Many efforts have been performed to assess dental implant stability biomechanically such as pull out and push out measurement, cutting torque resistance analysis, reverse torque test and percussion test. However these are destructive method

that available for preclinical uses only (Chang & Giannobile, 2012; Swami *et al.*, 2016). The non-destructive methods that give a clinical value are radiographies (CT, CBCT) and RFA method. However the resolution and variability while examination still should be improved (Spin-Neto *et al.*, 2013; Kim, 2014)

2.5.1 Tensional Test Method

Tensional test is used to test the interfacial tensile strength that was originally measured by detaching the implant plate from the supporting bone (Chang *et al.*, 2010; Sachdeva *et al.*, 2016). This technique is a destructive technique that is impossible to be applied for the patient. The schematic of this measurement technique is presented in Figure 2.6 . It is obvious from Figure 2.6a, this test will suffer the osseointegration between supporting bone with body implant. This technique was used only for in vitro study.

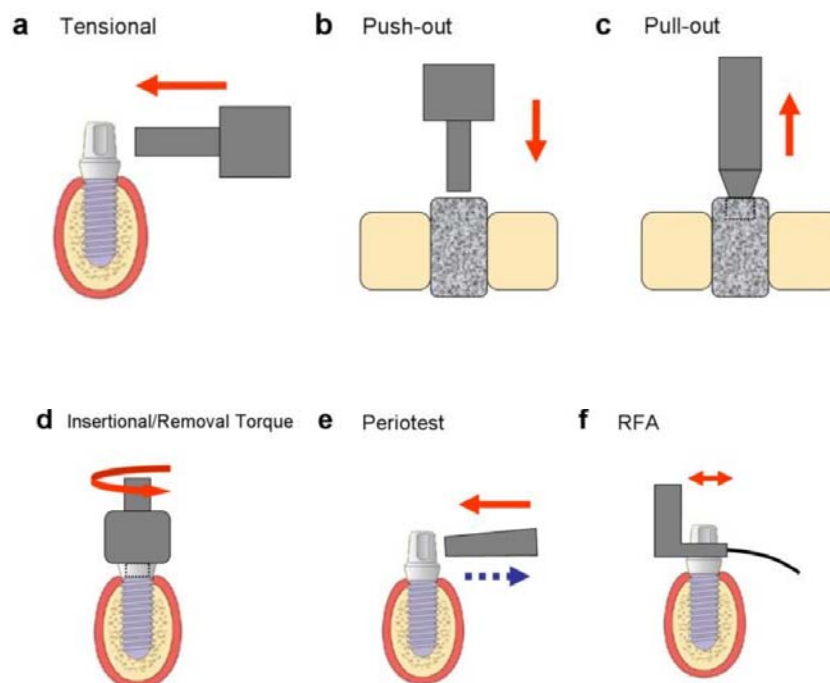


Figure 2.6. Illustration of implant stability assessment technique, a) Tensional, b) Push-out, c). Pull-out, d). Insertion/removal Torque, e). Periotest and f). RFA test (Chang *et al.*, 2010).

2.5.2 Pull-out and Push-out Measurement Method

The pull-out test is the tests that involve a tensile load dislodged a post from post space, while the push-out test use the tensile load is replaced by compressive load (Ahmadian *et al.*, 2013). Illustration of pull out and push out is figured out in Figure 2.6b-c. Those method is used to investigate the healing capabilities within the bone-implant interface (Haïat *et al.*, 2013; Kempen *et al.*, 2009). Based on this mechanism, the push-out and pull-out tests are only applicable for non-threaded cylinder type implants, whereas most of clinically available fixtures are of threaded design (Seong *et al.*, 2013). Both of these method is destructive method, hence it was not practiced in the clinical study.

Pull-out and push-out test were conducted on in vitro model to estimate the implant stability. The result showed that this technique is very sensitive to modifications of technical details; therefore the result of different model cannot be compared directly (Sakoh *et al.*, 2006). In addition, because of this destructive technique, hence finite element method becomes a great method to explain the behavior of the tensile mechanism of dental implant that cannot be achieved by push-out and pull-out test. Chen *et al.*(2013) used the FEA to simulate the push out test on a base model using three parameters: the diameter of the pin, specimen's thickness and elastic modulus of intracanal filter. The resulted stress was analyzed to calculate the bone strength.

2.5.3 Removal Torque Method

The removal torque refers to the torsional force necessary for unscrewing the fixture using a torque manometer calibrated in Newton-centimeters (N-cm) and was first investigated by Johansson *et al.*, (1998). The removal torque test measures the shear

properties of implant–tissue interface. However, this method is categorized as a destructive method.

Koh *et al.* (2009) conducted removal torque by using in vivo studies on the rabbit tibia model, the result showed that at the microscopic level, the fracture after removal torque test occurred at the implant-bone interface. Bardyn *et al.* (2010) applied FEA method to investigate the mechanism of removal torque. In their pilot study on replica of implant that inserted into polyurethane and sheep bone, the simulation result showed that there is a high correlation between estimation by FEA and a direct measurement of removal torque. That simulation was performed by assuming there is a frictional contact between implant and bone.

2.5.4 Cutting Resistance or Insertion Torque Method

The cutting resistance refers to the energy required in cutting of a unit volume of bone while the insertion torque occurs during the fixture tightening procedure (Chang, Lang & Giannobile, 2010). Both of these method can be used to estimate the primary implant stability (Wagner & Ka 2016; Bayarchimeg *et al.*, 2013). However, these methods can be applied limited only during surgery. It is not applicable for monitoring post-surgery.

Dagher *et al.* (2014) measured the insertion torque of ex vivo study on sheep model. They showed that the insertion torque could be used as indication of primary implant stability. This measurement has been cross checked with Resonance Frequency Analysis and the result showed that there is significant positive correlation between insertion torque with RFA result.

Numerical study by using FEA to investigate the influence of insertion torque on the stress distribution around an immediately oral implant has been conducted by Atieh *et al.* (2012). Their results showed that the use of insertion torque during placement of dental implant increases the stress on crestal bone and it was correlated with the bone quality of site implant.

2.5.5 Resonance Frequency Analysis (RFA) Method

Resonance Frequency Analysis (RFA) is a non-invasive and non-destructive method that measure the implant stability objectively and reliable for any stage of the treatment or at follow-up examinations (Konstantinović *et al.*, 2015). This method was introduced by Meredith *et al.* (1997) by developing the device that called as Ostell®. The implant stability measurement by this method is based on the micro-movement of an implant in its site that is reflected by a frequency resonance.

In the RFA device, a sinusoidal wave with certain frequency ranges (5 - 15 kHz) are generated and passed into transducer that attached into a small cantilever beam and it attached into the implant or abutment. Received signal will be received by a piezo ceramics element receives and it will be transferred into frequency analyzer (Digholkar *et al.*, 2014). The peak of amplitude defines the excitation which is showing a resonance frequency. A schematic of RFA measurement is shown in Figure 2.7.

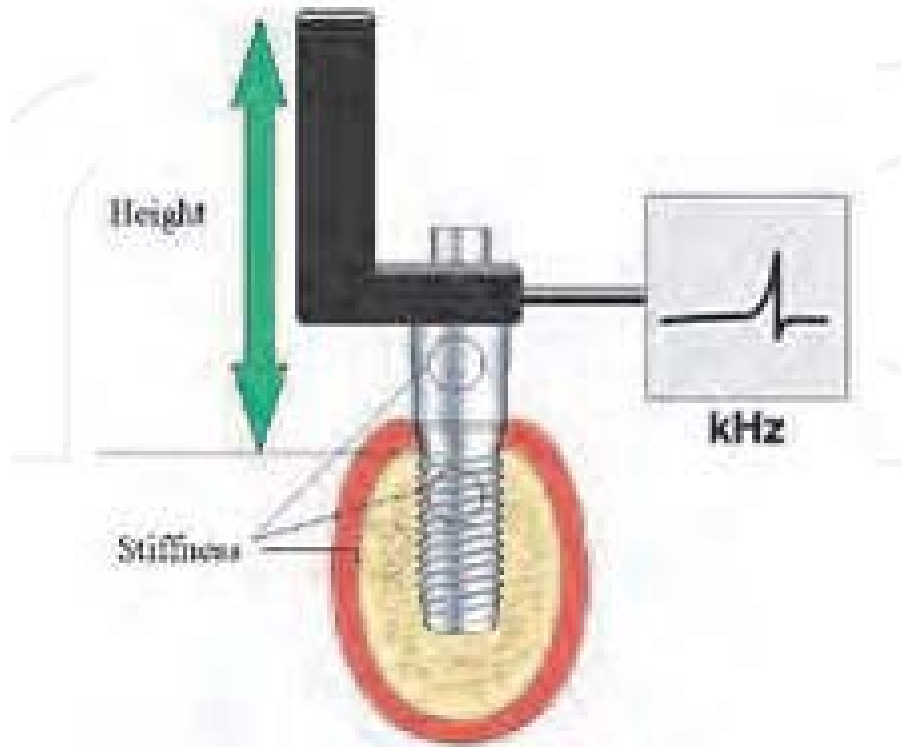


Figure 2.7 A schematic showing the principle of electronic resonance frequency analyzer. (Chang et al. 2010).

In this instrument, the measured resonance frequency is converted into a scale ranges from 0 to 100. This scale is called as Implant Stability Quotient (ISQ) which is representing the degree of implant stability. The higher implant stability is indicated with higher ISQ. The most recent version of RFA is Osstell Mentor™ and Osstell ISQ™ which are supported with wireless smart peg™ as a tuning fork, the illustration of these devices is presented in Figure 2.8.



(a)



(b)

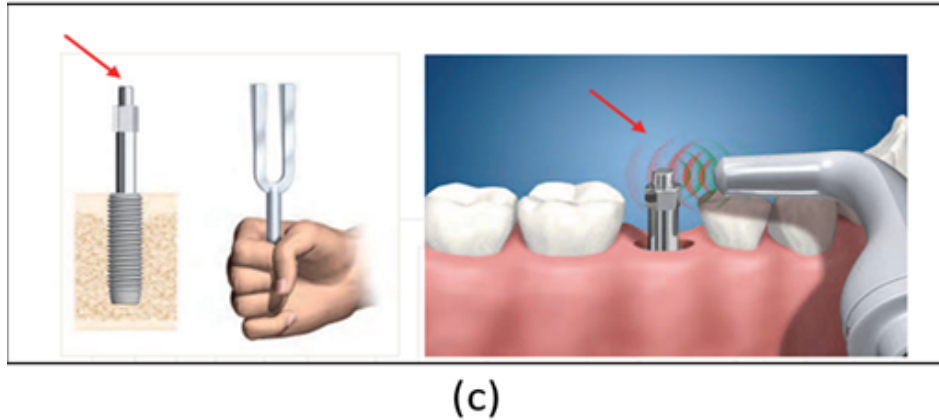
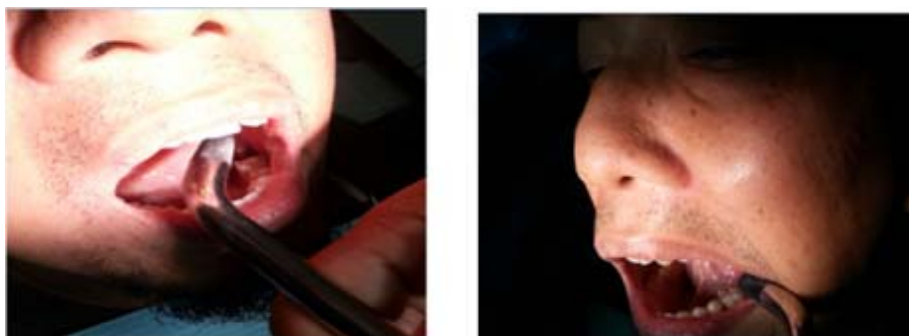


Figure 2.8 RFA device and its schematic of implant stability measurement, a) Osstell Mentor™, (b) Osstell ISQ™, and c) Illustration of Osstell measurement, both device measure ISQs by the magnetic technology.(Meredith, Science & Maudlin, 1997)

There are some important factors during measurement using RFA system; transducer design, contact between implant with surrounding bone, and the effective length above the marginal bone level (Sennerby & Meredith, 2008). To have an optimal measurement result and avoid the effect of soft tissue, the Smart-peg™ of RFA device need to be located at least 1-3 mm from marginal bone level or 3 mm above the soft tissue. The direction of that smart peg should perpendicular to the object. An example of the application of RFA for implant stability assessment on immediate implant patient is shown in Figure 2.9.



(a)



(b)

Figure 2.9 (a) Measurement of implant stability on the immediate dental implant in Hospital USM, and (b) Illustration of smart peg™ position (Sennerby & Meredith, 2008).

Measurement of implant stability by using RFA method has some advantages such as the consistency of measurement as object oriented and measurement can be performed any time on any condition such as for immediate implant or delayed implant placement. Studies showed that implant stability (both primary and secondary implant stability) could be associated with osseointegration (Kunnekel *et al.*, 2011; Shokri & Daraeighadikolaie, 2013).

Breakthrough on implant stability measurement using RFA explored more detail on determinant of dental implant. Implant stability measured by RFA can be related with other parameters such as insertion torque, bone density and cortical thickness (Má *et al.*, 2011; Trisi *et al.*, 2011; Wada *et al.*, 2015). However, the relation between dynamic properties of implant such as stress distribution, which is generated during loading of implant with different grade implant stability still not investigated yet. It might be possible that the mechanism of osseointegration can be related also with behavior of stress distribution that needs to be investigated further.

2.6 Dental Imaging Technology

Radiography is an important aspect of dental treatment, because it provides the image in detail of the site implant that is important for evaluation purposes. Site implant evaluation includes the dimension and availability of site implant and bone quality and quantity. Some imaging technology such as CT-scan, OPG scan, CBCT scan and DEXA have been used in dentistry. However, the frequent problem in radiographic imaging is a bargaining between resolution and doses of X-ray exposure or radiation. Higher resolution of images usually need higher doses of x-ray that is contradictive with the health issue.

Some of dental imaging technologies that are used in this research and commonly used in Hospital USM will be explained in the following subchapter.

2.6.1 Computerized Tomography (CT) Scan

Computerized Tomography (CT) is an imaging technique that shows human anatomy in cross section and provides a three-dimensional dataset that can be used for image reconstruction and analysis in several planes or three-dimensional settings. As well as another x-ray technique, a detector records the x-ray beam that passing through the patient's body. The computer then processes this information to create the CT image. CT technology provide 3D image that can be used as diagnostic tool and treatment planning including evaluation of quality and quantity of site implant (Karatas & Toy, 2014).

CT technology can provide high quality image by reducing the superimposition of images of structures outside the area of interest and high contrast between different