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College of Dentistry

EVALUATION OF BONE QUALITY AND DENSITY IN HUMAN JAW BONE AND THEIR EFFECTS ON THE STABILITY OF DENTAL IMPLANT: CLINICAL, RADIOLOGICAL AND HISTOMORPHOMETRIC STUDY

A thesis submitted to the council of the College of Dentistry/ University of Baghdad in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Oral and Maxillofacial Surgery

by

Ali Tareef Noaman

B.D.S., M.Sc.

Supervised by

Prof. Dr. Salwan Y. Bede

B.D.S., F.I.B.M.S.

2022 A.D. **1443 A.H.**

SUPERVISOR CERTIFICATION

This is to certify that this thesis was organized and prepared by the graduate student **Ali Tareef Noaman** under my supervision in the Department of Oral and Maxillofacial Surgery, College of Dentistry/ University of Baghdad, as partial fulfillment of the requirements for the degree of Doctor of Philosophy in Oral and Maxillofacial Surgery.

Signature

Professor

Dr. Salwan Y. Bede

B.D.S., F.I.B.M.S.

LINGUISTIC CERTIFICATION

This is to certify that the thesis entitled: "**Evaluation of Bone Quality and Density in Human Jaw Bone and Their Effects on the Stability of Dental Implant: Clinical, Radiological and Histomorphometric Study**" was reviewed to meet the academic style of English writing.

Signature:

Assist. Prof. Dr. Dhea Mizhir Krebt

M.Sc.,Ph.D.

Linguistic Reviewer

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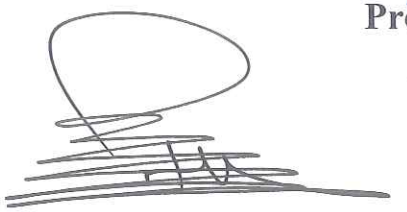
(Maxillofacial Surgery)



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B.D.S, M.Sc., Ph.D. (UK) (Conservative Dentistry)
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I declare that this thesis was prepared, written, and entirely the result of my own work and I have faithfully and properly cited all sources used in the dissertation.

Signature

Ali Tareef Noaman

B.D.S., M.Sc.

DEDICATION

I would like to dedicate this work to,

-The memory of my father and my mother, who I miss them a lot and pray for them every day,

-My brother and my sister for their great help and support during my Ph.D. study,

-My dear wife for her patience and encouragement for me throughout the study,

-My lovely little daughter **Haya**, who I hope to be proud of her father in the future.

Ali

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ABSTRACT

Background: The quality of alveolar bone at a dental implant site has been demonstrated to have a considerable influence on the implant's osseointegrative final outcome, with the risk of implant failure being relatively high when the bone is of low quality.

This study aimed to assess the stability of the dental implants (primary and secondary stability) in different bone types i.e. bone quality and density.

Materials and methods: This study included 24 patients who received 42 dental implants (DI). Thirty one bone specimens were available for histomorphometric analysis belonged to 15 patients. The bone density of the planned implant site was preoperatively measured using cone beam computed tomography (CBCT). Bone specimen was harvested using trephine bur (3.2mm outer diameter and 2.5mm inner diameter). The implant stability was measured using Osstell® ISQ. The implant stability quotient (ISQ) values were recorded immediately post-operatively (primary stability) and after 16 weeks (secondary stability). The insertion torque (IT) value was categorized as 35 Ncm or > 35 Ncm. Bone specimens were fixed, decalcified, longitudinally sectioned into 5 micrometers slices, and stained with hematoxylin/eosin techniques. Measurements were performed using the ImageJ software. Trabecular bone morphometric parameters measured included bone volume density, bone surface fraction, bone surface density, trabecular thickness, Trabecular number, and Trabecular separation.

Results: The mean (standard deviation, SD) primary stability was 79.58 (5.27) ISQ which was significantly higher than the secondary stability 74.31 (6.34) ISQ ($p < 0.0001$). There was a significant moderate positive

correlation of bone density with primary stability (r=0.4, p= 0.0099) and no correlation with secondary stability (r=0.003, p=0.9867). The bone density of DI with 35 Ncm IT was significantly lower than with > 35 Ncm IT (p=0.0390). Better stability was recorded with wider implants, whereas the length of the DI showed a non-significant correlation with (primary and secondary stability) p = 0.7633 and 0.4670 respectively, and with IT.

Regarding trabecular bone morphometric parameters, recipient jaw significantly correlated with bone surface density, and trabecular thickness. Bone density measured by CBCT correlated significantly with bone volume density, bone surface density, trabecular thickness, and Trabecular separation. IT correlated significantly with trabecular thickness. Primary ISQ values significantly correlated with bone surface density and trabecular thickness. No significant correlation regarding the secondary stability was detected.

Conclusion: The CBCT may be considered as a useful method to assess bone density of the proposed implant site. The combination of trabecular bone density and structure can be considered as important predictors for implant stability.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation	Representative Words
%	Percentage
2D	Two dimensions
3D	Three dimensions
AB	Bone area
ANOVA	Analysis of variance
AT	Total section area
Bap	Biological apatite
BMD	Bone mineral density
BS	Bone surface
BV	Bone volume
CBCT	Cone beam computed tomography
cc	Cubic centimeter
Co.	Company
CT	Computed tomography
DI	Dental implant
ECM	Extracellular matrix
FOV	Field of view
HA	Hydroxyapatite
HR-pQCT	High resolution peripheral quantitative computed tomography
HU	Hounsfield unit

ISQ	Implant stability quotient
IT	Insertion torque
Kv	Kilovolt
mA	Milliampere
MDCT	Multidetector computed tomography
mg	Milligram
mm	Millimeter
MRI	Magnetic resonance imaging
MSC	Mesenchymal stem cell
N.	Number
Ncm	Newton per centimeter
NIH	National Institutes of Health
NS	Non-significant
Ø	Diameter
OPG	Orthopantomography
P	Probability
PA	Periapical
PB	bone perimeter
R	Correlation
®	Trade mark
RFA	Resonance frequency analysis
ROI	Region of interest
Rpm	Revolution per minute
S	Significant
SD	Standard deviation

Tb.N	Trabecular number
Tb.Sp	Trabecular separation
Tb.Th	Trabecular thickness
TNF	Tumor necrosis factor
TV	Tissue volume
USA	United States of America
µm	Micrometer
VV	Voxel values

INTRODUCTION

INTRODUCTION

The dental implant successful outcome is determined by a sequence of patient-related and procedure dependent elements, including "general health conditions, biocompatibility of the implant material, the implant surface features, the surgical procedure, and the local bone quality and quantity" (**Turkyilmaz *et al.*, 2007**).

According to a systematic review and meta-analysis, placing implants in lower quality of bone and inadequate bone volume significantly influence the rates of implant failure (**Chrcanovic *et al.*, 2017**).

A number of methods have been used to estimate bone quality, these can be broadly classified into two groups; destructive methods which include histomorphologic analysis, tensional test, push- out/pull-out test and removal torque test. These methods are invasive and are not suitable for the clinical assessment. The other group is the non-destructive methods which include percussion test, cutting torque test, periotest and resonance frequency analysis. These methods can be used in clinical assessment (**O'Sullivan *et al.*, 2004**; **Atsumi et al., 2007**; **Sennerby L., 2008**).

These measures, however, cannot be used for preoperative surgical planning because they are only available during or after implant insertion. Prior to implant placement in a specific site, a preoperative radiologic evaluation of bone quality can help predict primary implant stability and guide loading protocol selection(**Hakim *et al.*, 2019**). In recent years, cone-beam computed tomography (CBCT) has become more popular in dentistry. Compared to standard computed tomography (CT), CBCT

provides the advantages of economic effectiveness, superior resolution, and lower radiation exposure (**Yim *et al.*, 2011**).

According to some studies, the CBCT voxel gray value does not correspond to the calibrated voxel gray value represented in Hounsfield units (**Hua *et al.*, 2009**), other investigations found that the Hounsfield unit obtained from CBCT voxel values had a significant association with actual parameters of bone density derived from Micro-CT and multi-slice CT, implying that the CBCT may be used to quantify bone density (**Naitoh *et al.*, 2009**; **Cassetta *et al.*, 2014**; **Parsa *et al.*, 2015**).

The trabecular bone is one of the main components that influences bone quality (**Licata**, **2009**). The trabecula is considered as the fundamental anatomical and functional unit of the trabecular bone. Although cortical bone aids in initial implant stability, cancellous bone also plays an important role. This is due to the fact that cancellous bone has a greater rate of bone turnover than in cortical bone (**Sakka and Coulthard**, **2009**), and is in direct interaction with the majority of the implant's surface (**Fanuscu and Chang**, **2004**). As a result, it has an impact on the healing and osseointegration process at the bone-implant surface (**Minkin and Marinho**, **1999**).

Trabecular density and microstructure should be integrated to improve bone strength prediction (**Müller**, **2003**). This is because these measurements do not always correspond to one another. High bone density, for example, does not always imply high "trabecular parameters" like trabecular thickness (Tb.Th) or trabecular number (Tb.N) (**Gomes de Oliveira *et al.*, 2012**). As a result, relying solely on trabecular density to predict implant success is no longer recommended (**Wirth *et al.*, 2011**).

There appears to be a few clinical studies that addressed the relationship of histomorphometric analysis of the trabecular bone and

dental implants stability, therefore, this study aimed to investigate the trabecular bone microstructure and bone density values in Hounsfield units (HU) measured by CBCT and their effect on implant stability.

AIMS OF THE STUDY

- ❖ Assess the stability of the dental implants (primary and secondary stability) in different bone types i.e. bone quality and density.

Objectives:

1. Evaluation of the bone quality in human jaw bone using histomorphometric assessment of trabecular bone microarchitecture.
2. Assessment of the implant stability (primary and secondary).
3. Evaluation of the bone density at the planned implants sites using cone beam computed tomography (CBCT).

CHAPTER 1

REVIEW OF LITERATURE

REVIEW OF LITERATURE

1.1 Dental implant

Dental implants have proven to be a reliable method of replacing missing teeth. The goal of implant-supported tooth replacement is to restore acceptable function and aesthetics without compromising neighboring hard and soft tissue components. Since clinical trials using dental implant treatment have shown favorable outcomes, dental implants are increasingly being used in oral rehabilitation **(Turkyilmaz and McGlumphy, 2008a).**

The dental implant successful outcome is determined by a sequence of patient-related and procedure dependent elements, including "general health conditions, biocompatibility of the implant material, the implant surface features, the surgical procedure, and the local bone quality and quantity" **(Turkyilmaz *et al*., 2007).**

The clinician's task is made more difficult by the fact that these many elements must be managed practically simultaneously if a predictable effective outcome is to be expected (**Parithimarkalaignan and Padmanabhan**, **2013**).

The successful placement of dental implants in patients who have lost their teeth and, in many cases, their surrounding bone is dependent on the thorough collection of clinical and radiological data, interdisciplinary communication, and meticulous planning. Proper treatment planning is one of the most critical aspects in implant success. Implant diagnosis and treatment plans are solely determined in the past by periapical radiographs and panoramic imaging. Computed tomography (CT) and cone-beam computed tomography (CBCT) are becoming increasingly important for

appropriate placement of implant , particularly in complicated reconstructions, thanks to advancements in radiography technology **(Chan *et al*., 2010).**

1.1.1 Present indications and treatment planning of dental implants

Previously, only those who are completely edentulous individuals with excellent dimensions of jaw bone (width and height) were thought to be candidates for implant therapy; however, practically each edentulous space is now regarded to be eligible for implant installation. When there is inadequate bone for implant treatment, bone augmentation methods are frequently addressed. Benic & Hammerle, indicated that such procedures are very predictable provided suitable recommendations are followed and adequate healing time for bone regeneration is permitted (**Benic and Hämmerle**, **2014**). In the posterior maxilla when bone height is restricted, a sinus lift operation is advised. In addition to the traditional lateral window procedure, a less invasive transalveolar technique has been developed by (**Pjetursson and Lang**, **2014**).

Various studies have indicated satisfactory outcomes using short implants in both the mandible and the maxilla as an alternative to surgical bone regeneration (**Nisand and Renouard**, **2014**).

The current changes regarding the present indication and treatment planning are summarized in **(Table 1.1)**.

Table 1.1: Changes to the original 'standard' implant protocol regarding the indication and planning of dental implant (**Quirynen *et al.*, 2014**).

Original' protocol	**Present' protocol**
Indication/ planning	
Primarily fully edentulous patients	All type of indications
Strict inclusion/ exclusion criteria	Rare exclusion criteria
Minimal jaw bone width of 7–8 mm	Guided bone regeneration for horizontal augmentation
Minimal jaw bone height of 10 mm Planning	Guided bone regeneration for vertical augmentation
Planning based on two-dimensional radiographs	Three-dimensional cone beam computed tomography and virtual planning
Anterior to the maxillary sinus	Sinus augmentation techniques

1.1.2 Present implant treatment strategies

The early strategy of implant placement involved inserting dental implants in healed ridges (at least 6 months following tooth extraction) and allowing for a prolonged healing time (of 3–6 months) to achieve optimum osseointegration. The introduction of implants with a fairly rough surface has accelerated osseointegration and reduced the needed healing time (**Wennerberg and Albrektsson**, **2010**).

Similarly, placing dental implants at the moment of tooth extraction has greatly decreased treatment duration and morbidity in patients. This surgical technique, however, may be linked with esthetic difficulties as a

result of hard/soft tissue remodeling following tooth extraction (**Chen and Buser**, **2009**; **Hämmerle *et al.***, **2012**).

The current changes regarding the present implant treatment strategies are summarized in **(Table 1.2)**.

Table 1.2: Changes to the original 'standard' implant protocol regarding implant treatment strategies (**Quirynen *et al.***, **2014**).

Original' protocol	**Present' protocol**
Timing	
Six months of healing after tooth extraction	Immediate placement
Two-stage surgery	One-stage surgery
Submerged healing (3–6 months)	Non-submerged healing
No denture immediately after implant insertion	Immediate loading

1.2 Bone

Bone is a specialized connective tissue consisting of cells, fibers, and ground substance. Unlike other connective tissues, its extracellular components are mineralized giving it substantial strength and rigidity (**Weatherholt *et al.***, **2012**).

The extracellular matrix (ECM) is composed of around 60% inorganic components and 30% organic matrix, lipids, and water (**Clarke**, **2008**).

The mineralized ingredient of bone, hydroxyapatite (HA), is an inorganic component composed of calcium and phosphorus that contributes to the ECM's high mechanical stability (**Wiesmann *et al.***, **2005**), The

organic matrix, on the other hand, gives elasticity and flexibility. Collagen I is the most abundant component of the organic matrix, accounting for 85–90% of entire bone protein (**Ricard-Blum**, **2011**).

1.2.1 Structure of bone

Macroscopically, bones come in two types.: cortical bones (compact), which comprise 80 percent of the skeleton and may be present in the shafts of long bones like the femur, tibia, and radius, as well as the exterior surfaces of flat bones like the skull, mandible, and scapula; and trabecular bones (cancellous), which are primarily located at the ends of long bones and the interior regions of flat bones (**Brandi**, **2009a**), **Figure (1.1).**

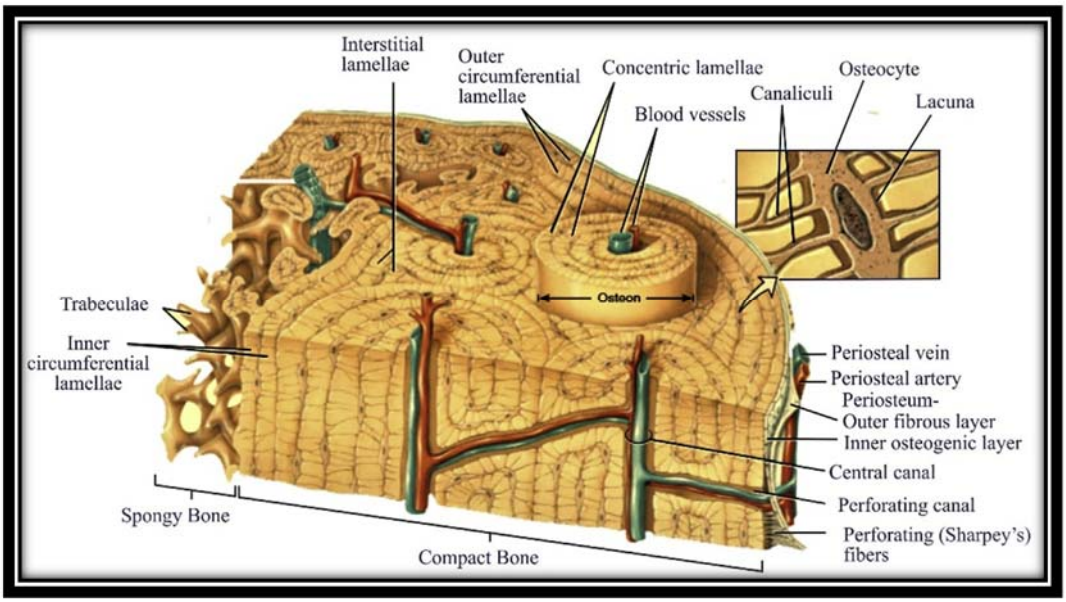


Figure 1.1: Structure of cortical and cancellous bone (**Black and Tadros**, **2020**).

Despite being formed of the same constituents, namely hydroxyapatite, collagen, and water, trabecular bone is less mineralized than cortical bone because it has lower calcium content and higher water

content, resulting in lower tissue density and mineral content (**Oftadeh *et al.***, **2015**).

Microscopically, human bone has two structural types: woven and lamellar. Woven bone is a type of transitional bone presented in healthy individuals during development or fracture repair. It is also present in pathological bone, where it is a component of malignancies, Pagetic bone, and osteogenesis imperfecta. In compared to lamellar bone, it is rapidly laid down and comparatively cell rich. It is made up of mineralized collagen fibril bundles with no obvious orientation. Woven bone is an ideal solution when a scaffold is required for the later development of more structured lamellar bone (**Reznikov *et al.***, **2014**).

Lamellar bone is comprised of lamella. Lamellae are microscopically thin layered sheets of collagen matrix laid out by osteoblasts. This matrix self-assembles to form collagen fibrils, which then self-assemble to form collagen fibril bundles (a collagen fiber). Mineralization of these collagen fibrils results in the formation of sheets of parallel-arranged collagen fibers aligned along stress lines, resulting in the fundamental structure of each lamella (**Ramachandran**, **2018**).

1.2.2 Bone cells

Osteocytes, osteoblasts, and osteoclasts are three cell types that play important roles in bone (**Florencio-Silva *et al.***, **2015**; **Ramachandran**, **2018**).

- Osteocytes: Osteocytes are the most prevalent type of cell in mature bone, accounting for 90% of the skeleton's cells. These cells are produced from osteoprogenitors via osteoblast differentiation. Osteocytes are thought to act as mechano-sensing which convert mechanical stimulus to biological signals, and also play a role in controlling calcium and phosphorus metabolism, **(Figure 1.2).**

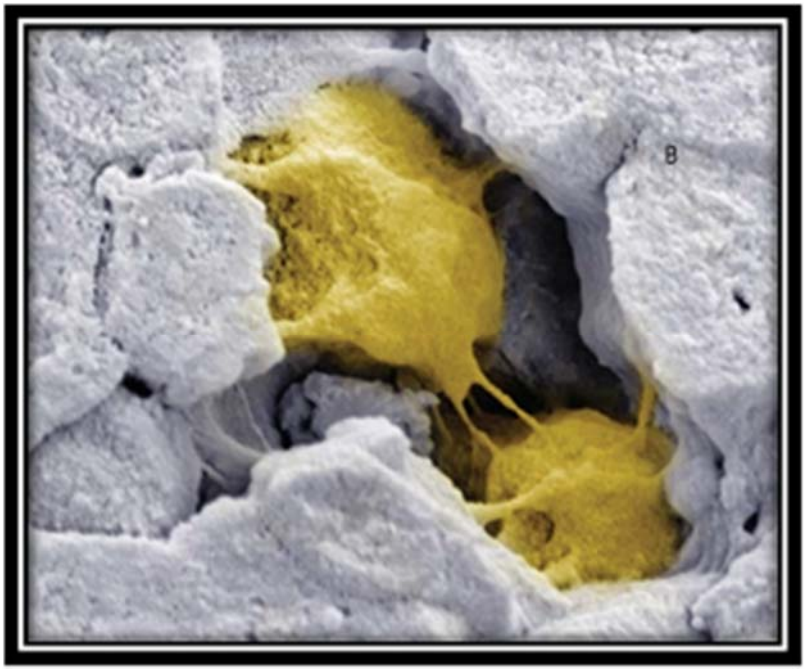


Figure 1.2: Osteocytes surrounded by bone matrix (**Florencio-Silva *et al.***, **2015**).

- Osteoblast: account for 4-6 percent of total bone cells and are well-known for their bone-building activity. Osteoblasts develop from a pluripotent mesenchymal stem cell (MSC) through the expression of certain genes.
- Osteoclast: are multinucleated terminally developed cells derived from the haematopoietic macrophage and monocyte stem cell lineages. The primary function of osteoclasts is bone resorption, which can occur through pits known as Howship's lacunae or through cutting cones in direct bone repair. Recent research reveals that they can also be a source of cytokines that regulate the activity of other cells.

1.2.3 Bone remodeling

Bone remodeling is a highly complex process by which old bone is replaced by new bone, in a cycle comprised of three phases (**Sims and Gooi**, **2008**):

(1) Osteoclasts initiate bone resorption,
(2) The transition (or reversal stage) from resorption to new bone synthesis,
(3) Osteoblasts initiate bone synthesis.

Normal bone remodeling is required for fracture healing, mechanical skeleton adaptability, and calcium homeostasis (**Dallas *et al.*, 2013**).

An imbalance of bone resorption and synthesis, on the other hand, leads in a variety of bone disorders. Excessive resorption by osteoclasts, for example, without a proportional quantity of new bone formation by osteoblasts, contributes to bone loss and osteoporosis (**Khosla *et al.*, 2012**). In contrast, the opposite may result in osteopetrosis (**Sobacchi *et al.*, 2013**). Thus, a balance between bone synthesis and resorption is required, and it is influenced by a variety of local and systemic variables such as hormones, cytokines, chemokines, and biomechanical stimulation (**Crockett *et al.*, 2011**).

1.2. 4 Bone quality, quantity and bone mineral density

Bone quantity and bone quality are two frequently discussed parameters that influence surgical technique, healing time, and progressive loading during prosthodontic rehabilitation. The term bone quantity is most often understood as "the amount of bone (e.g., height and width of the alveolar crest) available for implant installation" **(Lindh *et al.*, 2004)**, whereas bone quality is "a collective term referring to the mechanical properties, architecture, degree of mineralization of the bone matrix, chemistry and structure of the bone mineral crystals as well as the remodeling properties of bone" (**de Oliveira *et al.*, 2008**)**.**

Until the year 2000, bone strength and bone mineral density (BMD) were thought to be synonymous. However, a new clinical parameter, “bone quality,” was proposed by the National Institutes of Health (NIH) in 2000. Bone quality, that is defined as "the sum of all characteristics of bone that

influence the bone's resistance to fracture" is fully independent of BMD as a result, not only BMD but also bone quality must be assessed in order to estimate bone strength. The NIH defines bone quality as "comprising bone architecture, bone turnover, bone mineralization, and micro- damage accumulation" (**NIH**, **2000**).

The trabecular bone is one of the main components that influences bone quality (**Licata**, **2009**). The trabecula is considered as the fundamental anatomical and functional unit of the trabecular bone. Although cortical bone aids in initial implant stability, cancellous bone also plays an important role. This is due to the fact that cancellous bone has a greater rate of bone turnover than cortical bone (**Sakka and Coulthard**, **2009**), and is in direct interaction with the majority of the implant's surface (**Fanuscu and Chang**, **2004**). As a result, it has an impact on the healing and osseointegration process at the bone-implant surface (**Minkin and Marinho**, **1999**).

Trabecular density and microstructure should be integrated to improve bone strength prediction (**Müller**, **2003**). This is because these measurements do not always correspond to one another. High bone density, for example, does not always imply high "trabecular parameters" like trabecular thickness (Tb.Th) or trabecular number (Tb.N) **(de Oliveira *et al.*, 2012)**. As a result, relying solely on trabecular density to predict implant success is no longer recommended (**Wirth *et al.***, **2011**).

(**Kuroshima *et al.***, **2017**) shown that "osteocytes, biological apatite (Bap), and collagen fibers" may be used as new clinical parameters to assess bone quality in implant dentistry, implying that a better understanding of bone quality is clinically relevant.

The term "bone quality" has already been used in dentistry, which contributes to some of the misunderstanding. Despite the fact that bone

quality is independent of BMD, bone quality has been widely associated with BMD in dentistry based on radiographic and clinical assessments (**Misch**, **1999**). Although, the hypothesis of bone quality has evolved from BMD-based assessments to microstructural evaluations of bone, BMD-based diagnosis is still the gold standard in dentistry. Therefore, recognizing and understanding the present conception of bone quality is essential (**Kuroshima *et al.***, **2017**)**, (Figure 1.3).**

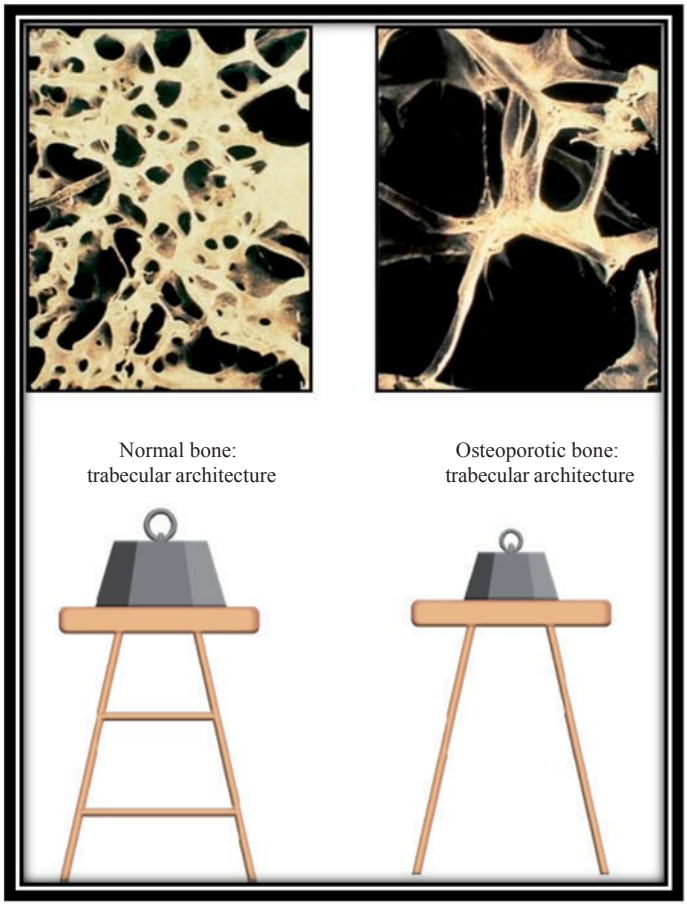


Figure 1.3: The importance of bone microarchitecture (**Brandi**, **2009b**).

The BMD is "the amount of bone tissue in certain volume of bone". The evaluation of jaw BMD may be beneficial in implant planning (**Gulsahi *et al.***, **2010**)**.**

Previously, the amount and structure of compact and trabecular bone tissue (based on its radiographic appearance and drilling resistance), was

used to classify bone quality into four categories (**Ribeiro-Rotta *et al.*, 2011**). (Bone Quality Index) **(Figure 1.4):**

• Type Ⅰ: cortical bone that is homogenous.

• Type Ⅱ: thick cortical bone with a marrow cavity.

• Type Ⅲ: cortical bone is thin, whereas trabecular bone is dense with good strength.

• Type Ⅳ: cortical bone that is extremely thin, whereas trabecular bone is poor in density and with minimal strength.

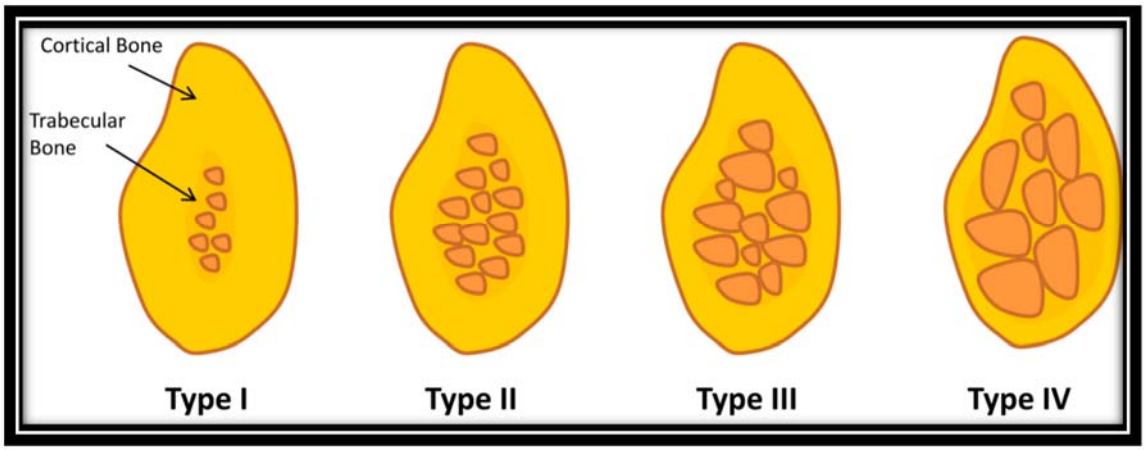


Figure 1.4: Bone quality index **(Lekholm and Zarb, 1985).**

Misch (2008) used computed tomography to determine 4 bone density groups (D1–D4) in all zones of the jaws that differ in both macroscopic cortical and trabecular bone types "D1 bone, >1250 Hounsfield unit (HU); D2 bone, 750–1250 HU; D3 bone, 375–750 HU; D4 bone, <375 HU".

Bone density is recognized to have an effect on implant success, with lower bone density, the likelihood of failure is increased **(Martinez, 2001; Holahan *et al.*, 2011).** Implant surgical failure varied from 3.2% to 5% in high bone quality and 1.9% to 20% in low bone quality with most studies suggesting a higher failure rate (up to 65%) in soft bone **(Misch, 2008)**.

According to a systematic review and meta-analysis, placing implants in lower quality of bone and inadequate bone volume significantly influences the rates of implant failure **(Chrcanovic *et al*., 2017).**

1.2.4.1 Trabecular bone microarchitecture

The conception of bone quality has lately shifted from a density-based approach to a structural one, As it has been revealed that trabecular bone microarchitecture influences implant stability (**Wirth *et al.***, **2011**). The Preoperative trabecular structure analysis might thus predict patient prognosis and be used to choose the optimal implant placements (**Panmekiate *et al.***, **2015**).

The most often used histomorphometric variables for describing trabecular bone microarchitecture are bone volume density (BV/TV), which is regarded as the most essential factor for evaluating bone quantity since it shows the amount of mineralized bone tissue. The ratio of bone surface to volume (BS/BV) and bone surface fraction (BS/TV) are useful measures for assessing the complexity of bone structures. These parameters are complementary, A homogeneous piece of bone, for example, will have a high bone volume but a low bone surface value because only the external surface contributes to the bone surface, whereas a network of trabecular bone will have a substantially greater bone surface value for a given bone volume (**Pauwels *et al.***, **2015**), **(Figure 1.5)**.

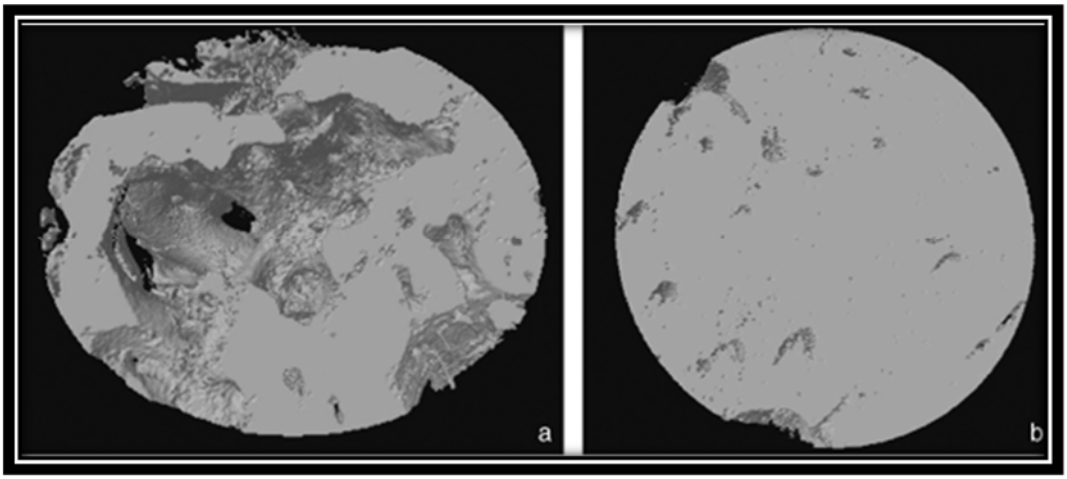


Figure 1.5: 3D axial images of bone cores. Despite the sample (a) being less dense than sample (b), possibly it has a rod/sphere-like pattern of the trabeculae, higher surface area and therefore, a greater BS/BV(**Gomes de Oliveira *et al.***, **2012**).

Trabecular thickness (Tb.Th),Trabecular separation (Tb.Sp), and trabecular number (Tb.N) are all parameters that offer information on the spatial distribution of the bone, allowing the contribution of microstructure to bone strength to be evaluated (**Klintström *et al.***, **2018**).

These variables may be examined with microscopes fitted with oculars containing specified reticules or image analyzers, and are obtained from a combination of measurements from trabecular surfaces and perimeters (**Parfitt**, **1987**).

1.2.4.2 Alterations of trabecular microarchitecture

- **During aging**

The trabecular network is abundant and plexiform in the young. Because of a continuous osteoblastic depression, bone trabeculae thin with age. Osteoblasts, like any connective cell, have a decreased ability for matrix formation (collagen and non-collagenic proteins decrease with time), causing the trabecular plates to gradually convert into rods (**Chappard *et al.***, **2008**).

- **In female**

Estrogen deficit during menopause causes an increase in numerous cytokines "Interlukein-6, Interlukein-7, and tumor necrosis factor (TNF)", which stimulates osteoclastic activity (**Cohen-Solal *et al.***, **1998**). As a result, the number of trabecular perforations increases, disrupting the 3D microarchitecture. Some researchers have used the phrase "killer osteoclasts" to describe the process that causes an acceleration of bone remodeling with bone loss of up to 2% each year after menopause, resulting in a 20 to 30% decrease in original bone mass (**Chappard *et al.***, **2008**).

- **In male**

The etiologic factors that cause bone loss in men are numerous and complicated, and the diagnosis is sometimes more difficult than in women. The evolution of bone trabecular microarchitecture with age appears to be dissimilar in normal men, as demonstrated by histomorphometric techniques. Males have fewer perforations in bone trabeculae, allowing connections to be preserved (**Chappard *et al.***, **2008**).

The alterations of trabecular microarchitecture regarding the age and gender are shown in **(Figure 1.6).**

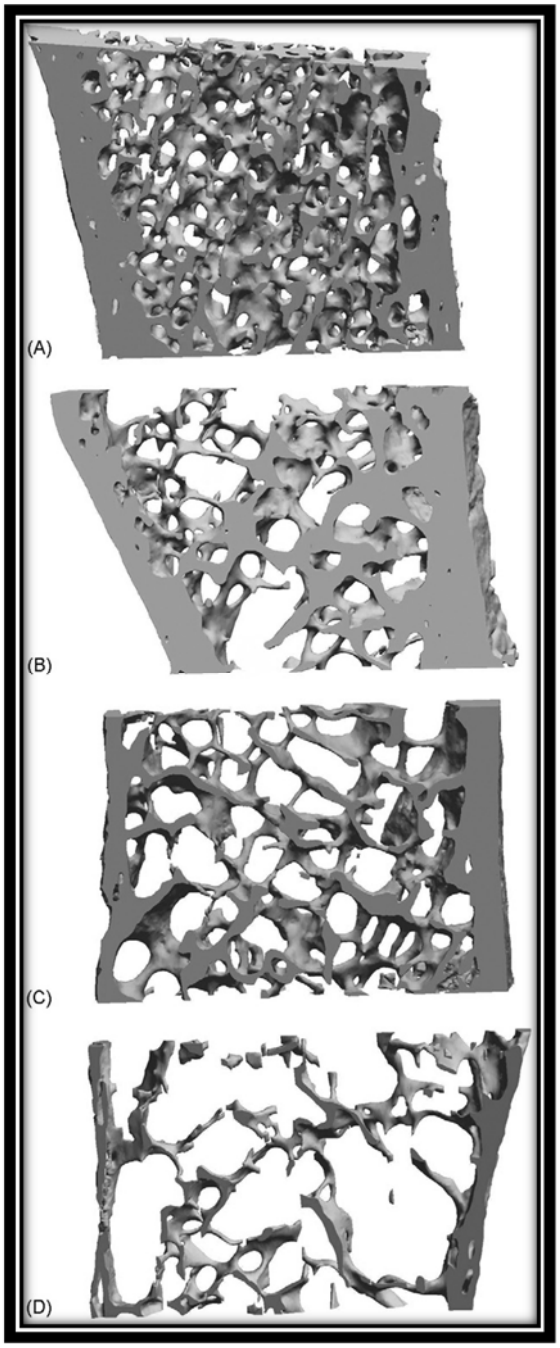


Figure 1.6: MicroCT imaging of iliac bone. (**A)** In a young subject: the cortices are thick, the trabecular network is dense. **(B)** In a postmenopausal osteoporosis, note the holes inside the network corresponding to areas of loss of connectivity. (**C**) In a male with idiopathic osteoporosis, note the conversion of plates into rods, although the connectivity is rather well even if trabeculae are thin. **(D)** In a male with osteoporosis due to multiple risk factors (alcoholism and glucocorticoid treatment). Note the thinning of the cortices, the considerable disorganization of the trabecular network with area without trabeculae, (**Chappard *et al.***, **2008**).

1.2.4.3 Techniques of bone quality assessments

1- Bone histomorphometry

For bone microarchitecture analysis, histomorphometry has long been regarded the gold standard (**Chappard *et al.*, 2005**). This method allows for two-dimensional (2D) evaluation and produces a high-spatial resolution, high-contrast image, but it is time-consuming (**Müller *et al.*, 1998**).

Only on the basis of stereology can a third dimension be added (**Parfitt *et al.*, 1983**).

Histomorphometry also has the drawback of being destructive and not allowing for further measurements of a sample **(Carbonare *et al.*, 2005).**

2- Dental radiographs

In dentistry, the first-choice diagnostic clinical tools are periapical (PA) and panoramic radiographs. The volume and pattern of trabecular bone structure can be evaluated with the help of PA radiographs with greater resolution and clarity **(Whaite, 2013)**.

Several classification systems are applied to examine bone quality in PA images. The first of the three categorization systems, Lekholm and Zarb, Trisi and Rao, and Misch, is widely used in oral implant research on trabecular bone evaluation **(Aalam *et al.*, 2005; Jonasson *et al.* , 2007; Ribeiro-Rotta *et al.*, 2011)**. In 1996, a visual index was suggested to help in trabecular categorization on PA radiographs (**Lindh *et al.*, 1996**). This index assigns trabecular patterns a classification based on "the intertrabecular spaces (small or large) and the degree of trabeculation (sparse or dense)" **(Lindh *et al.*, 2008; Pham *et al.*, 2010).** However, these

subjective methods are yet only partially validated (**Ribeiro-Rotta *et al.***, **2011**)**.**

Panoramic radiographs, on the other hand, have been utilized in the assessment of trabecular structure. However, the lower resolution of panoramic images limits their capacity to detect fine trabeculae (**Bollen *et al.***, **2001**). As a result, they are less useful in trabecular evaluations than PA radiographs **(Pham *et al.*, 2010).**

Dental radiographs are undeniably a quick, generally safe, and practical approach to analyze trabecular microstructure in the jaws. Despite the fact that the 2D image's nature prevented it from providing information in the buccolingual direction **(Lofthag-hansen *et al.*, 2009)**. Dental radiographs are still widely used for pre-implant evaluation because of their availability and low cost (**Sakakura *et al.***, **2003**)**.**

3- Magnetic resonance imaging (MRI)

The MRI is a non-invasive, non-ionizing technology that uses strong magnetic fields, transmission of radiofrequency waves and detection of radiofrequency signals from excited hydrogen protons. The bone marrow of trabecular bone contains free protons and emits a high magnetic resonance signal (**Lespessailles *et al.***, **2006**). Fat and water protons in bone marrow tissue are often seen as negative images. As the trabecular structure cannot be observed directly, this approach employs image processing to reverse the negative image (**Licata**, **2009**)**.**

However, MRI machines are still not widely available or accessible to dental practitioners.

4- Multidetector computed tomography (MDCT)

With the newest generations, the resolution of multidetector CT (MDCT) devices has been enhanced to 150–300 μm in plane and 300–500

μm in slice thickness **(Burghardt *et al.*, 2011).** The MDCT was used to quantify trabecular microstructure parameters like trabecular number, trabecular thickness, and trabecular separation, which were compared to high resolution peripheral quantitative CT (HR-pQCT) (**Issever *et al.***, **2010**). The results from both approaches were strongly consistent, despite the resolution being exceeding trabecular sizes (50– 200 μm). The trabecular microstructure parameters of MDCT and micro-CT, as well as micro-CT finite element modeling, were compared in a human cadaver. The researchers found that assessing trabecular bone structure with MDCT is feasible in general; however its spatial resolution remains a limitation (**Issever *et al.***, **2009**). As a result, while MDCT is commonly used in oral implant research, its application is limited to bone density measures (**Araki and Okano**, **2013**)**.**

5- High-resolution peripheral quantitative CT

This machine is utilized for trabecular microstructural imaging and has a spatial resolution of 82 μm. Microstructural parameter measurements are said to be comparable to micro-CT (voxel size of 25 μm) (**Liu *et al.***, **2010**)**.**

The method offers a greater spatial resolution than MDCT, however scanning locations are confined to the peripheral skeletal region (e.g., wrist and tibia), and currently the accessibility is restricted **(Burghardt *et al*, 2011).** Microstructural examination with high-resolution CT, unlike MRI, allows for direct viewing of trabecular bone. The latter procedure, on the other hand, implicates a rather high radiation dosage that exceeds the clinically acceptable limit. As a result, its use in oral implant imaging studies is limited (**Ito**, **2011**)**.**

6- Micro-CT

This non-invasive high-resolution (about 10 μm) technology illustrates the trabecular network in various grey levels based on its mineral composition. Trabecular characteristics measured by micro-CT have been found to be comparable to traditional 2D histomorphometric values (**Lespessailles *et al.*, 2006**). In oral implant research, however, only small-sized jaw specimens have been used to evaluate trabecular microstructure **(de Oliveira *et al.*, 2012; González-García and Monje, 2013).**

7- Cone beam computed tomography (CBCT)

In the 1990s, CBCT systems were invented. The CBCT was established as a 3D imaging technique in 2001. Since that day, It has been mostly superseded both single and multislice CT in oral implant diagnostic imaging (**Hatcher**, **2010**). The demand for CBCT imaging prior to implant placement has expanded tremendously due to the general availability of the devices, rapid scan and processing times, high-resolution images, and comparatively low scan radiation dose and costs **(Corpas *et al.*, 2011)**.

Although many researches have been done on CBCT, there is a lack of literature on its usefulness for evaluating trabecular bone microstructural features at oral implant sites. This could be related to previous generations of CBCT systems' inability to represent bone microstructure due to their low resolution (**Araki and Okano**, **2013**).

The CBCT, on the other hand, was described as a potential technique for analyzing trabecular bone in a study on bone microstructure **(Corpas *et al.*, 2011).** The mandibular condyle's bone parameters (trabecular thickness, trabecular number, and trabecular separation) were successfully assessed using CBCT with a resolution of 125 μm and image processing **(Liu *et al.*, 2007).**

Because the need to examine intended implant sites prior to surgical implantation has grown significantly, CBCT should be verified as a non-invasive technique for examining bone microstructure (**Ibrahim *et al.***, **2013**)**.**

1.3 Dental implant stability

Dental implant stability may be defined as "the capacity of implant to withstand loading in axial, lateral and rotational direction" (**Mesa *et al.***, **2008**)**.**

Dental implant stability can be divided into primary and secondary components. Primary stability refers to "the mechanical bracing of the implant in bone and absence of any micromovement", while secondary stability refers to "successful osseointegration of the implant with the surrounding" **(Sennerby and Meredith, 2008).**

1.3.1 Primary stability of dental implant

At the time of implant insertion, primary stability is crucial. The most important factor for successful osseointegration is a solid anchoring of the implant within the host bone, free of micro-motions. Micro-motions may develop if an implant is not sufficiently stable at the time of implant placement, disrupting the normal healing process and forming a fibrous tissue capsule, resulting in clinical mobility and eventual implant failure (**Meyer *et al.***, **2004**).

However, in recent years, there has been debate about the importance of achieving good primary stability during implant insertion to ensure osseointegration. Some studies have shown that primary stability is not required for osseointegration, providing clinical evidence that osseointegration can occur in implants with low primary stability and, conversely, that implants placed with a relatively high insertion torque do

not always achieve adequate integration **(Degidi *et al.*, 2012; Strub *et al.*, 2012; Trisi *et al.*, 2015).**

Primary stability arises from bone compression which is linked to the mechanical engagement of implant with the surrounding bone **(Figure 1.7)**.

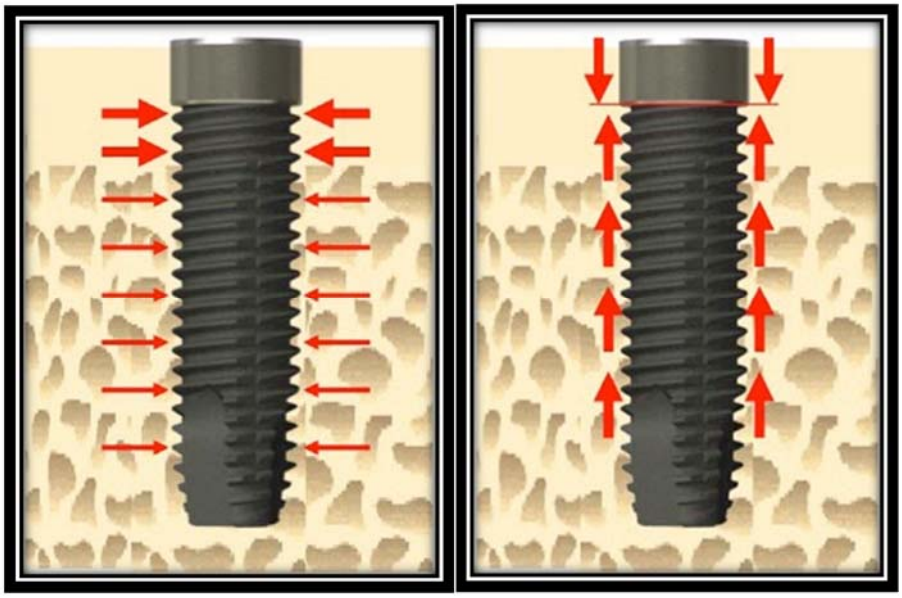


Figure 1.7: Illustrations of primary implant stability achieved by axial and lateral compression of bone during insertion (**Sennerby**, **2015**).

Many factors influence primary stability, including "local bone quantity and quality, implant-related factors such as dimensions, form, and surface characterization, and the surgical procedure used, such as drill size in relation to implant size, pre-tapped or self-tapping implants" **(Strub *et al.*, 2012)**.

1.3.2 Secondary stability of dental implant

Secondary stability refers to the changes in implant stability that occurs after insertion as a result of bone growth and remodeling at the implant-tissue interface. Secondary stability has been found to rise 4 weeks after implant placement, with the lowest stability is expected up to this point, i.e. around 2-3 weeks following the placement **(Atieh *et al.*, 2012).**

Secondary stability is a "biological stability". It depends upon primary stability, bone formation and remodeling. At the moment of implant insertion, there is a sparse bone to implant contact. Newly generated bone will eventually fill in the gaps in the inter-surface zone and grow into the imperfections on the implant surface. Complete bone-implant contact is uncommon, with clinically observable osseointegration accounting for around 80% of bone contact. Though, for implant stability, more than 60% bone-implant contact is considered acceptable (**Simunek *et al.***, **2010**). The implant surface microtopography is primarily responsible for this process (**Davies**, **2003**). When compared to turned surfaces, implants with micro-rough surfaces had higher survival rates, and they seemed to induce rapid and greater bone apposition around the fixture (**Wennerberg and Albrektsson**, **2009**).

Nanostructured surfaces have lately been interpreted as an attempt to enhance implant-bone interaction on a cellular level by producing bioactive surfaces that can interact with binding proteins and osteoblasts (**Mendonça *et al.***, **2008**). Such surfaces revealed greater bone-to-implant contact as compared to micro-rough surfaces (**Lee *et al.***, **2012**).

1.3.3 Methods used to assess implant stability

Several authors have published numerous techniques that may be divided into two categories **(Meredith, 1998; O'Sullivan *et al.*, 2004; Atsumi *et al.*, 2007; Sennerby and Meredith, 2008):**

1- **Destructive methods:** include "histomorphologic research, Tensional test, Push- out/pull-out test and removal torque test". These are invasive techniques that are unsuitable for clinical evaluation.

2- Non-destructive methods: include "Percussion test, radiography, cutting torque test, periotest and resonance frequency analysis". These

techniques are non-invasive and can be employed in clinical evaluations.

1.3.3.1 Insertion torque (IT)

"The force used to insert a dental implant is called insertion torque (IT)" (**Cehreli *et al.***, **2009**). It is the torque necessary to drive the implant into the prepared osteotomy, given in Newton centimetres (Ncm). The amount of energy needed for implant insertion is related to the thread placement force applied by instrument's tip and the friction created when the implant enters bone (**Ilser Turkyilmaz and McGlumphy**, **2008**).

Aside from indicating bone quality, it is a significant factor in determining the loading strategy and the implant's primary stability at the site, both of which are crucial for implant longevity. Higher insertion torque leads to greater primary stability (**Meredith**, **2008**), while failures have been linked to lower ranges. Various studies demonstrated insertion torques in the 35 Ncm range to be satisfactory (**Ottoni *et al.***, **2005**; **Ilser Turkyilmaz and McGlumphy**, **2008**).

However, inducing over-compression may jeopardize the healing process. Angiogenesis is disrupted under extreme stress, which affects the development of new blood vessels. This causes hypoxia in the periimplant tissues, which inhibits bone growth and has a negative impact on stability (**Checa and Prendergast**, **2010**).

The bone tubule network is filled with interstitial fluid, which supplies the bone cells. It is capable of transmitting external pressures to bone cells via "Mechano-transduction." Mechanical energy from external stressors is transformed into bioelectric and biochemical signals that influence bone cell metabolism. When the mechanical energy is too great, osteocytes are induced to death, which is followed by the appearance of

osteoclasts and bone breakdown occurs. This might have an impact on the osseointegration process (**Burger and Klein-Nulend**, **1999**).

The insertion torque is affected by "bone density and hardness, the use of under-dimensioned drills, and the tapered implant design". Torque is proportionate to bone density. It will be the highest in a D-1 type bone, while it will be the lowest in D-4 type bone if compression procedures are not used. Insertion torque in low quality bone might be enhanced by using compression methods to provide more stability (**Goswami *et al.***, **2015**).

The use of undersized drills and an implant design with tapered geometry will result in local compression and therefore high stability (**Meredith**, **2008**).

1.3.3.2 Resonance frequency analysis (RFA)

In an animal research, Meredith (1996) proposed a non-invasive technique of evaluating periimplant bone by attaching an L-shaped transducer to an implant. The transducer generates a high-frequency mechanical vibration and records the incoming signal's frequency and amplitude. The resonance frequency was thus established as "the peak of frequency- amplitude plot" which was then translated to a number reflecting the stiffness of the bone implant interface **(Meredith *et al*, 1996).**

The resonance frequency analysis system that was tested was commercialized as Osstell® (Osstell AB, Gothenburg, Sweden). The implant stability quotient (ISQ) of Osstell® is measured on a scale of 1 to 100, with 100 indicating the best implant stability. Later versions of Osstell® included Osstell® Mentor and Osstell® ISQ. Generally, ISQ readings for successful implantation have been reported to range from 57 to 82 ISQ. The Osstell device's wired transducer, **(Figure 1.8)** was changed with a wireless aluminum rod with magnets (smartpeg) during product

development, allowing non-contact measurements. Magnetic pulses are used to activate the magnet linked to the smartpeg **(Sennerby and Meredith, 2008), (Figure 1.9).**

Figure 1.8: The first commercial RFA instrument (Osstell) with a wired transducer (**Sennerby**, **2015**).

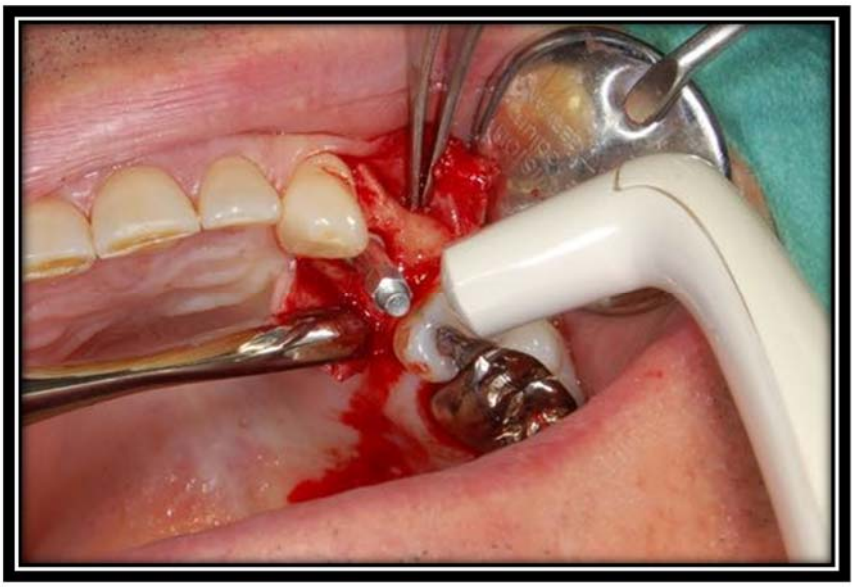


Figure 1.9: The use of wireless RFA technique (SmartPeg and Osstell Mentor) (**Sennerby**, **2015**).

1.3.3.3 Factors determining Osstell® measurements

A- Primary implant stability

1- Factors related to bone

The density of the bones is a key factor in Osstell measuring. ISQ units have a favorable association with bone density, insertion torque measures, and quantitative CT **(Turkyilmaz *et al.*, 2006)**.

Osstell measurements may be influenced by the characteristics of the marginal bone; studies have found a favorable association between cortical bone thickness and ISQ readings. In the same way, research has found a link between the height of the crestal cortical bone and ISQ values **(Nkenke *et al.*, 2003; Tözüm *et al.*, 2010).**

2- Factors related to dental implant

The effect of implant length and diameter on Osstell measures is unclear, and results appear to differ between various studies. Despite this, most studies have found little evidence that implant surfaces affect ISQ readings (**Sennerby *et al.*, 2005**)**.** However, Rompen et al. found that surfaced-modified implants retained stability during the early healing phase, whereas machined implants exhibited a reduction in stability (**Rompen *et al.*, 2000**).

3- Factors related to surgical technique

Using a strategy to improve lateral compression during insertion appears to result in increased stability. This might be due to undersize drilling prior to implant placement, larger implants, or the use of "tapered implants" (**O'Sullivan *et al.*, 2004**)**.**

B- Secondary stability

1- Time dependence

The resonance frequency rises throughout time as the stiffness of the bone increases due to new bone production and remodelling. However, if

the implant's primary stability is extremely high, little variations in stiffness may be undetectable (**Rompen *et al.***, **2000**; **Sennerby *et al.***, **2005**).

Friberg et al. reported that, regardless of primary stability, all implants installed in the edentulous maxilla tended to attain a comparable level of stability at the time of abutment attachment (6– 8 months later) and after 1 year in function (**Friberg *et al.***, **1999**) . This is in line with a clinical study (**Sennerby *et al.***, **2005**), who demonstrated that in comparison to implants inserted in dense bone, implants in soft bone with low primary stability demonstrated a significant improvement in stability. The findings suggest that the healing and remodelling of soft trabecular bone causes the peri-implant bone to become stiffer.

2- Marginal bone resorption and presence of defects

According to Sennerby et al., radiographic bone loss and ISQ values have a negative association (**Sennerby *et al.***, **2005**). Another study found a link between significant marginal bone loss around mandibular implants and poorer implant stability in the first six months after implantation. There was no such link between the 6 and 12 month study periods. The authors hypothesized that bone loss was offset by enhanced interfacial stiffness caused by bone growth and remodelling over the course of 6 to 12 months **(Turkyilmaz *et al.*, 2006)**.

1.3.3.4 Interpretation of clinical ISQ measurements

The ISQ measurements have been shown throughout studies to offer clinicians with useful information regarding the current condition of the bone-implant interface. It appears that the method, when combined with clinical/radiographic outcomes, can be utilized to aid decision-making during implant placement and follow-up in terms of healing periods, loading procedure, and identifying implants at risk of failure **(Sachdeva *et al.*, 2016).**

1.4 Cone beam computed tomography in dental implantology

The use of CBCT in dental clinics and hospitals has improved the way dental implant surgery is practiced. Three-dimensional (3D) knowledge is required for the implantologists concerning bone volume and topography before the placement of an implant to increase the overall success and perhaps reduce surgical and postoperative implant concerns (**Tyndall *et al.*, 2012**). The amount of bone volume accessible, bone density, and closeness to anatomical structures may all be accurately assessed prior to surgery using imaging techniques at the implant site. CBCT is the preferred approach for implant dentistry as compared to two-dimensional (2D) imaging because it gives higher measurement precision while using fewer radiation doses (**Dreiseidler *et al.*, 2009**), **(Figure 1.10).**

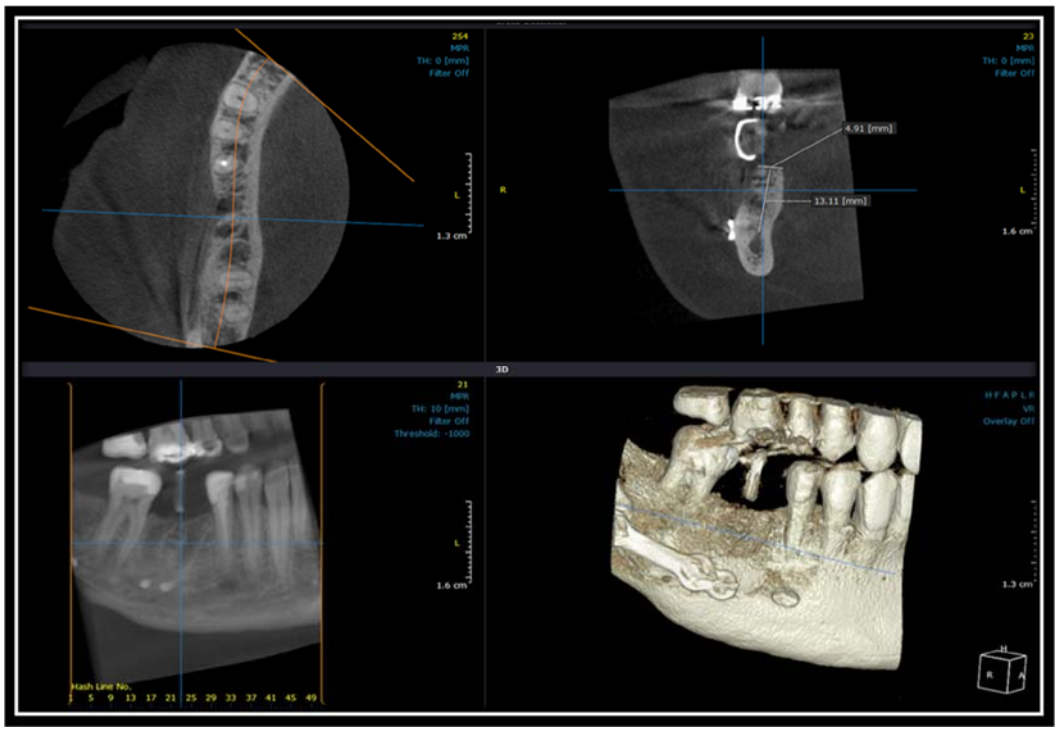


Figure 1.10: Implant treatment planning with CBCT: Linear measurements in region #30. Axial image (upper left), cross sectional view (upper right), panoramic view (lower left) and 3D image (lower right) (**Kiljunen *et al.*, 2015**).

1.4.1 Recommendations for role of CBCT in dental implantology

The recommendations for the role of CBCT in dental implantology (**Tyndall *et al.***, **2012**) :

1- The CBCT should not be used as the first diagnostic imaging evaluation.
2- To facilitate preoperative cross-sectional screening of prospective implant regions, CBCT should be considered the preferred imaging modality.
3- Before placing dental implants, CBCT should be used when clinical circumstances suggest the necessity for augmentation treatments or site development: a) sinus augmentation; b) block or particle bone grafting; c) ramus or symphysis grafting; d) examination of impacted teeth in the region of interest; and e) review of previous traumatic damage.
4- If bone reconstructive and augmentation operations (such as ridge preservation or bone grafting) have been undertaken to correct bone volume deficits prior to implant implantation, CBCT imaging should be addressed.
5- Use cross-sectional imaging (preferably CBCT) right after surgery if the patient complains of mobility of the dental implant or altered sensation, particularly if the fixture is in the posterior mandible.
6- The CBCT imaging should not be used to follow on clinically asymptomatic implants.
7- If implant retrieval is expected, CBCT should be performed.

1.4.2 The CBCT-guided implant surgery

Before undergoing surgery, the type and size of the intended implant, as well as its positioning inside the bone, correlation to the planned restoration and contiguous teeth and/or implants, and closeness to vital

structures, may all be established. The use of CBCT scans in conjunction with computer-aided design/computer-aided manufacturing technologies makes this possible. The virtual treatment plan can be used to construct computer-generated surgical guidance. The implantologist uses these surgical guides to set the intended implants in the patient's mouth in the same positioning as in the virtual treatment plan, resulting in more precise and predictable implant placement as well as lower patient morbidity (**Orentlicher and Abboud**, **2011**).

1.4.3 Cone beam computed tomography and bone density

The CBCT has been widely utilized in the oral and maxillofacial field for preoperative evaluation and planning rather than medical computed tomography CT), because of its small size and low radiation dosage. Despite the fact that previous studies have shown that CBCT has good geometric accuracy for linear measurements (**Lagravère *et al.***, **2008**)**,** the accuracy and reliability of bone quality estimation are still up for debate.

According to Hua et al. , the voxel gray value obtained from CBCT does not correspond to the calibrated voxel gray value expressed in Hounsfield units (**Hua *et al.***, **2009**). Additionally, Livada measured bone density at 23 implant sites using four different methods of measures (clinical, CBCT, histology, and micro-CT). There was no correlation between clinical, radiological, histological, and micro-CT data on bone density, according to the findings (**Livada**, **2009**). Another study concluded that CBCT gray values have limited validity and have no association with histomorphometric bone parameters assessed by micro-CT and histology analyses (**Suttapreyasri *et al.***, **2018**). The authors stated that the inaccuracy of CBCT gray values can be impacted by the machine and

scanning settings, and they are extremely sensitive to movement because of its high spatial resolution.

On the other hand, Gonzalez-Garcia and Monje investigated the validity of CBCT in determining bone density of the dental implant site in the maxillary bone and found a substantial positive association between bone density measured by CBCT and micro-CT (**González-García and Monje**, **2013**).

Moreover, other investigations found that the Hounsfield unit obtained from CBCT voxel values had a significant association with actual bone density parameters from Micro-CT and multi-slice CT, implying that the CBCT may be used to quantify bone density (**Cassetta *et al.***, **2014**; **Parsa *et al.***, **2015).**

However, technology-specific artifacts and excess scattering exhibit by CBCT might be considered as the perpetrator for the unreliable BMD measurements (**Schulze *et al.***, **2011**; **Araki and Okano**, **2013**).

1.4.4 Cone beam computed tomography (CBCT) artifacts

An image artifact may be defined as "a visualized structure in the reconstructed data that is not present in the object under investigation"**,** CBCT imaging exhibits the same image artifacts as conventional CT systems (**Schulze *et al.***, **2011**).

1- The CBCT artifacts from machine factors

A- Noise

This artifact shows as gray values that are inconsistent and have significant standard deviations. This is due to a low signal to noise ratio of intensity, which must be maintained to keep the radiation dosage minimal.

By raising the excitation potential and current, the noise level can be decreased, **(Figure 1.11)**

Figure 1.11: Noise (**Nagarajappa *et al.*, 2015**).

B- Scatter artifacts

The main intensity can be enhanced by adding scattered X-ray photons from the original course, resulting in an underestimate of attenuation value. Larger detectors have a higher probability of detecting scattered X-ray photons, resulting in streak artifacts during the CBCT image reconstruction process.

C- Beam hardening

Since the energy levels of polychromatic X-ray beams utilized in CBCT are not equal, lower energy photons can readily be absorbed near the margins of the scanned target, leading in X-ray beam hardening and

resulting in lower gray values near the subject's center "cupping artifact" even though the subject's density is homogeneous.

D_ Ring artifacts

Ring artifacts with concentric rings in the CBCT picture can be caused by detector defects or un-calibrated components. Inconsistent gray values in the ring voxels might increase overall errors in bone density measurement.

E- Partial volume effects

The irregular forms of scanned individuals are not entirely delineated by cubic or rectangular voxels. As a result, the gray value of voxels along the boundary between various density materials comprises averaged attenuations. The number of erroneous partial volume gray values grows as the voxel size of the CBCT image increases.

2- CBCT artifacts from patient factors

A- Streak artifact

When scanning dense metallic objects, the gray values can surpass the software's maximum level of operation, resulting in severe streaking artifacts. This artifact restricts examination of local gray values surrounding patients' dental restorations and metal implants. Other causes of streak artifact include "beam hardening, noise, and photon starvation", which occur when not enough photons reach the detector, as shown in **(Figure 1.12)**.

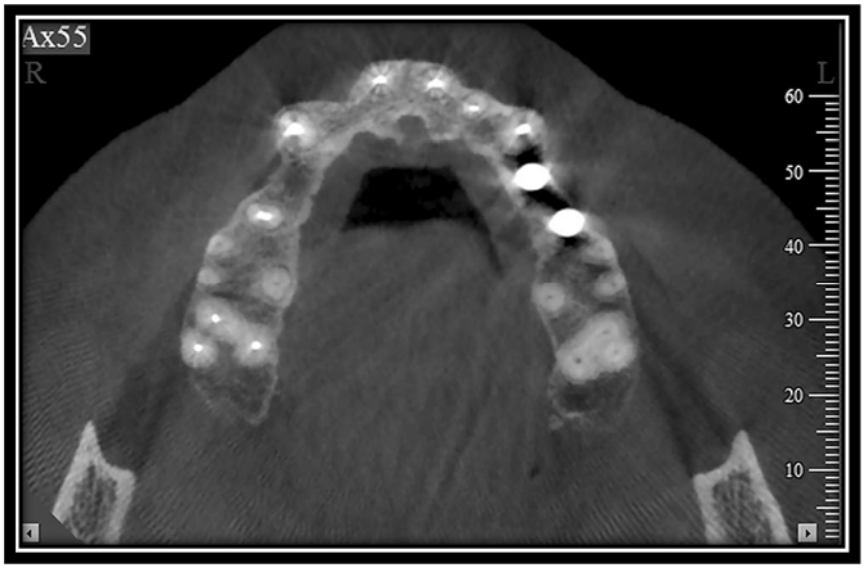


Figure 1.12: Metal artifact. Note the hypodense streak that connects titanium implants in the upper left premolar area and that goes on mesially and distally (**Nardi *et al.*, 2015).**

B- Patient Motion

When gray values are erroneously registered owing to patient motion during CBCT scanning, shading or streaking may be detected. This artifact is frequently visible as duplicate contours in the CBCT image, **(Figure 1.13)**.

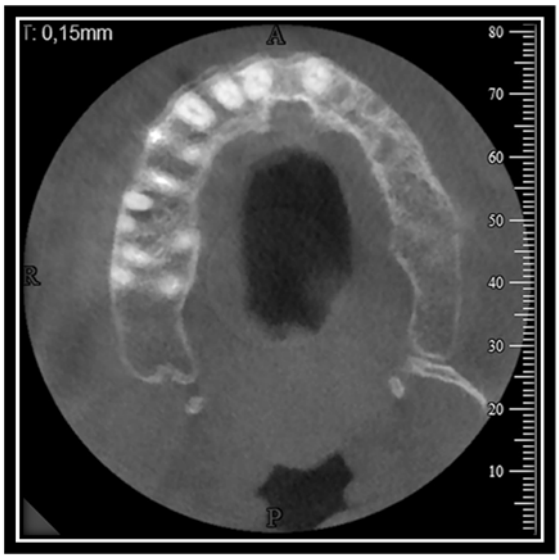


Figure 1.13: Motion artifacts. Upper jaw CBCT, Double edge effect, mainly evident in the anterior region of the right jaw (**Nardi *et al.*, 2015**).

1.5 Osseointegration

While researching the healing processes of bone tissue in 1952, Professor Per-Ingvar Branemark inadvertently found that when pure titanium comes into intimate contact with the living bone tissue, the two actually grow together to form a permanent biological adhesion. Osseointegration was his term for the phenomena (**Khan *et al.*, 2012**)

Originally, osseointegration was defined as "direct bone deposition on the implant surfaces", a fact also called "functional ankylosis" (**Schenk and Buser**, **1998**).

Albrektsson et al defined osseointegration as a "phenomenon where intimate contact between bone and biomaterials occurs at the optical microscopy level, enabling surgical implants to replace load bearing organs restoring their form and function" (**Khan *et al.*, 2012**)

Currently, an implant is regarded osseointegrated if there is no ongoing relative movement between it and the bone with which it makes direct contact. In essence, osseointegration is an anchoring mechanism that allows non-vital components to be stably integrated into living bone under all conventional circumstances of loading (**Dimitriou and Babis**, **2007**).

1.5.1 Prerequisites for osseointegration

1- Material and surface properties

Osseointegration necessitates the use of a bio-inert or bioactive substance as well as surface geometries that encourage bone growth. Titanium, whether commercially pure or in specific alloys, is widely acknowledged as bio-inert, and it is widely utilized in oral and orthopedic surgery. A bioactive substance is considered to produce a positive tissue reaction by forming chemical interactions with tissue components

(hydroxyapatite) or by stimulating cellular processes involved in the development of the bone matrix (**Khan *et al.***, **2012**)

Cooper showed that the quantity of bone produced at the bone-implant contact might be influenced by surface topography (macro and micro roughness), (**Cooper**, **2000**).

The success rates for rough-surface implants in the maxillary arch were found to be significantly higher than the success rates in the mandible in a meta-analysis by Cochran, suggesting that differences in success rates due to implant surface characteristics are more likely to be found in lower bone densities (**Cochran**, **1999**).

2-Primary stability and adequate load

Primary implant stability is thought to be crucial to osseointegration success (**Vidyasagar *et al.***, **2004**). According to a review, Primary implant stability has been shown to be impacted by bone quality and quantity, implant design, and site preparation method (**Sennerby and Roos**, **1998**).

1.5.2 Stages of osseointegration

Osseointegration follows a common, biologically determined program that is subdivided into 3 stages (**Khan *et al.***, **2012**; **Parithimarkalaignan and Padmanabhan**, **2013**):

a) Incorporation through the development of woven bone;

The earliest type of bone tissue to develop is woven bone. It is sometimes regarded as a primitive type of bone tissue, distinguished by a random, felt-like orientation of its collagen fibrils, a large number of irregularly shaped osteocytes, and, intially, a low mineral density. Woven bone formation clearly dominates the picture over the first 4-6 weeks following surgery.

b) Bone mass adaptation to load (lamellar and parallel fibered bone deposition);

Begin in the second month, the microscopic structure of newly generated bone shifts, either towards the well-known lamellar bone or towards an equally essential but less well-known variation known as parallel-fibered bone.

c) Bone structure adaption to load (bone remodeling).

The last stage of osseointegration is characterized by bone remodeling. It begins in the third month and, after a few weeks of increasing activity, slow down again, but continues for the rest of life. Remodeling starts with osteoclastic resorption, followed by lamellar bone deposition. Resorption and formation are coupled in space and time.

1.5.3 The advancements in dental implant technology designed to improve osseointegration

1. Advanced computer assisted design/computer aided manufacturing software is used for computer aided radiography treatment planning and surgical guide construction.

2. Hydrophilic implant surfaces encourage new bone formation through osteoconduction.

3. Recombinant human growth factors are used on the implant surface or as part of the implant installation procedure.

4. Modifications of implants surface chemistry to promote bone formation (fluoride modified titanium oxide surface).

(**Parithimarkalaignan and Padmanabhan**, **2013**)

1.6 Histomorphometry

Histomorphometric bone analysis can range from simple assessments of bone structure to more comprehensive examinations of cell counts and function. Static measures are those that "take bone structure without taking into account rates of change or dynamic bone remodeling processes like resorption or generation". Measurements that quantify trabecular bone structure (trabecular thickness, number, and separation, for example) or that describe the amount of tissue are examples of these (bone volume, cortical area, and porosity). They reflect the outcome of all of the growth, modeling, and remodeling processes that have undertaken without regard for the time span or rates at which those structures were created. Static measurements include also parameters such as osteoblast, osteoid, and osteoclast surface, which offer a clear image of the tissue at the moment it is seen. Fluorochrome labels are used in dynamic measurements to quantify the rates and magnitudes of change in bone tissue, either at the moment the tissue was obtained or at different periods in the past, depending on when the fluorochrome labels were applied. Thus, dynamic measures may be used to" analyze the long-term impacts of a single therapy or intervention and, as a result, can be used to interpret the particular effects of that intervention" (**Allen and Burr**, **2014**).

CHAPTER 2

MATERIALS AND METHODS

MATERIALS AND METHODS

2.1 Materials

This clinical prospective observational study was conducted from September 2019 to June 2021 at the Department of Oral and Maxillofacial surgery/ College of Dentistry \ University of Baghdad.

The Research Ethics Committee at the College of Dentistry / University of Baghdad approved the protocol of this study (protocol reference number 036118) as seen in **(Appendix I)**, and each patient signed an informed consent form to take part in this study regarding the steps of the treatment and the free use of patient's data for the scientific or academic research purposes, as seen in **(Appendix II).**

2.1.1 Study Sample

The sample included 24 patients with an age range of 25-75 year, presented with missing teeth who were restored with implant supported fixed prostheses. Patients, who met the eligibility criteria, were enrolled in this study. They received 42 dental implants.

2.1.1.1 Inclusion criteria

1. Patients ≥ 18 year of age with good general health.
2. Patients with partially edentulous maxilla or mandible indicated for delayed implant placement protocol with a minimum of 6 months after teeth extraction.

3. Patients with sufficient alveolar bone ridge dimensions with a minimum of 6 mm width and 10 mm height.

2.1.1.2 Exclusion criteria

1. Any systemic conditions that may impair normal healing such as uncontrolled diabetes mellitus, patients with a history of head and neck irradiation or chemotherapy during the last 5 years, patients treated with oral or intravenous bisphosphonates.
2. Local conditions included the existence of acute or chronic infection, as well as local pathological abnormalities in the planned implant zone, insufficient interocclusal space, active periodontitis and poor oral hygiene.
3. Clinical evidence of parafunctional habits (bruxism or clenching).

2.1.1.3 Data collecting sheet

All necessary information required in the study such as personal details, medical and previous dental history were collected from each patient utilizing a special designed case sheet for this study, as seen in **(Appendix III)**.

2.1.2 Armamentarium (Instruments, Equipment, Materials)

1- Surgical set

It included dental mirror, explorer, tweezers, dental syringe, dental needle, local anesthetic solution (Lidocaine hydrochloride 2% with epinephrine 1:80,000), scalpel handle no.3, scalpel blade no.15, periosteal elevators, flap retractor, toothed tissue forceps, surgical curette, needle holder, black braded silk suture (3/0), scissors, sterile gauze, disposable suction tip, normal saline 0.9 % solution, and disposable syringes 20 cc, as shown in **(Figure 2.1)**.

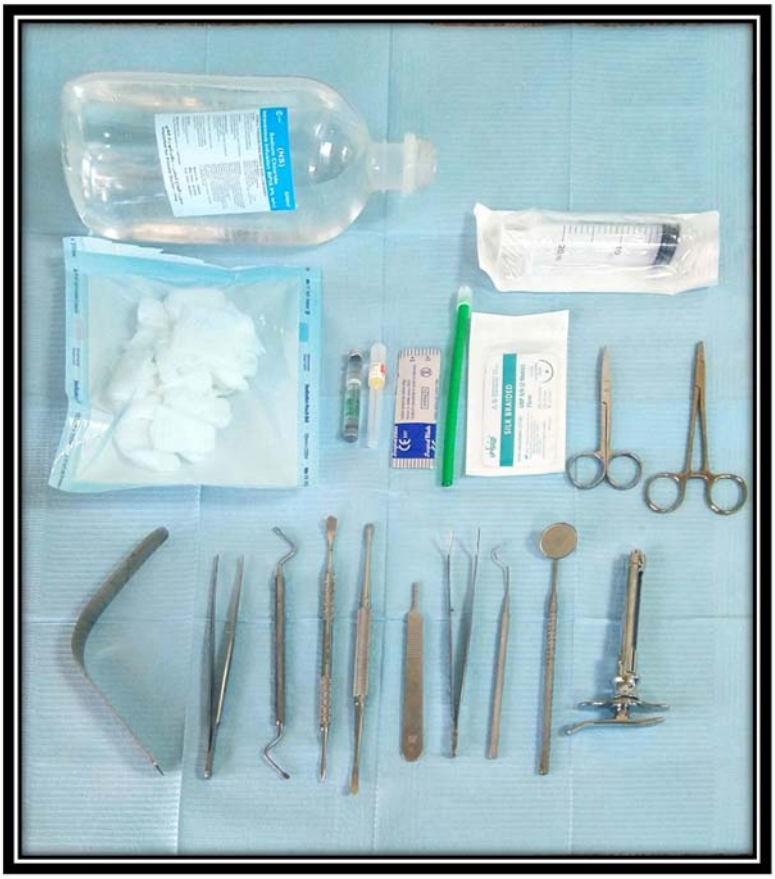


Figure 2.1: The surgical set.

2- Trephine burs surgical kit

A- Easy retrieve two-pieces trephine burs- kit with drill guide (ACE Surgical Supply Co., Inc., USA), as shown in **(Figure 2.2).**

B- Trephine head bur (outside diameter 3.2 mm, inside diameter 2.5 mm), as shown in **(Figure 2.3)**.

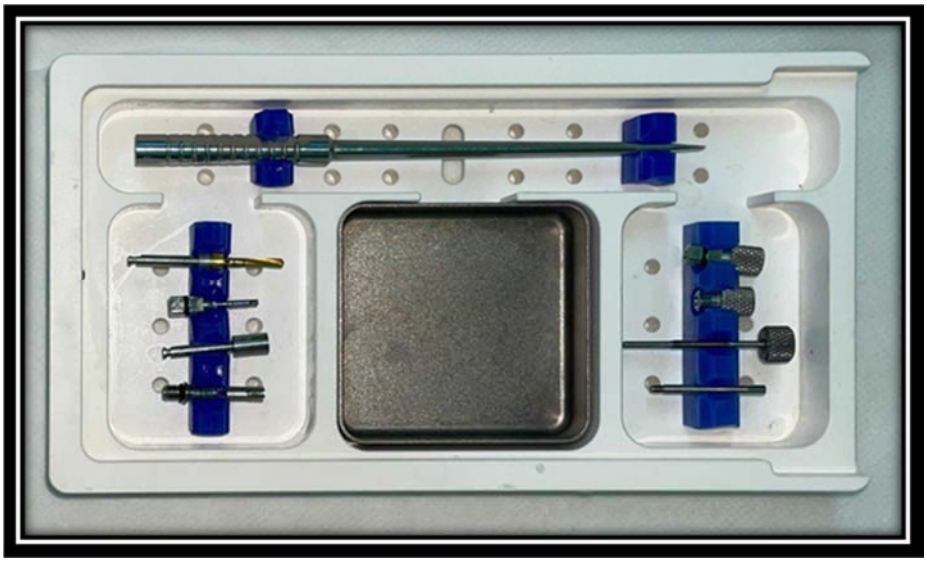


Figure 2.2: Trephine burs surgical kit (ACE Surgical Supply Co., Inc., USA).

Figure 2.3: Trephine head bur (ACE Surgical Supply Co., Inc., USA).

3- Dental implant system

- Endosseous dental implant (Superline, Dentium, Seoul, Korea), sizes 3.6mm, 4mm, and 4.5mm in diameter and 8mm, 10 mm, and 12 mm in length.
- Implant placement surgical kit (Dentium, Seoul, Korea).

The dental implant system was shown in **(Figure 2.4).**

Figure 2.4: Dental implant system (Dentium, Seoul, Korea). (A) Endosseous dental implant. (B) Implant placement surgical kit.

4- Dental implant micromotor

Dental implant micromotor (Dental surgery micromotor control unit iCT, Dentium, Seoul, Korea) set at 800 revolutions per minute (rpm) speed and torque equal 35 Ncm coupled with external irrigation system, as displayed in **(Figure 2.5).**

Figure 2.5: Dental implant micromotor (Dentium, Seoul, Korea).

5. Vernier caliper

A stainless steel Caliper (Stainless hardened steel, China) was used for preoperative space analysis (length of the edentulous alveolar ridge span, inter-arch distance) and inter-incisal distance at maximum mouth opening of the patient, as shown in (**Figure 2.6).**

Figure 2.6: Vernier caliper for preoperative space analysis (Stainless hardened steel, China).

6- Resonance frequency analysis (RFA) device Osstell® ISQ

RFA device Osstell® ISQ (Osstell®, Gothenburg, Sweden) was used for measuring primary and secondary stability, as shown in **(Figure 2.7)**.

Figure 2.7: Osstell® ISQ device for measuring implant stability (Osstell®, Gothenburg, Sweden).

7. Cone beam computed tomography (CBCT) device

Cone beam 3D system (Kavo OP 3D PRO, Biberach, Germany), with a resolution ranged from (80-400µm), for preoperative assessment of an implant site (using On demand software), set at 90 KV, 9.2 mA and 8.1s with (13 × Ø15) c FOV and 0.5 mm slice in thickness, **(Figure 2.8)**.

Figure 2.8: Cone beam 3D system (Kavo OP 3D PRO, Biberach, Germany).

8. Autoclave

Autoclave (Melag, Germany) was used for instrumets sterilization, **(Figure 2.9)**.

Figure 2.9: Autoclave used for instruments sterilization (Melag, Germany).

9. Medications

- 0.12% Chlorhexidine mouth wash (Kin, Spain).
- Amoxicillin capsules 500 mg or Azithromycin tablets 500 mg (in cases of Penicillin allergic patients).
- Metronidazole tablets 500 mg.
- Paracetamol tablets 500 mg.

2.1.3 Histological and chemical materials and equipment used for preparation of slides

1- Formic acid 10% (England).

2- Absolute alcohol (Iraq).

3- Xylene (A A G, Spain).

4- Paraffin wax (Leica, Germany).

5- Hematoxylen and eosin (H&E) (Dako, U.S.A).

6- Microscopic glass slides and covers (China).

7- Microtome (Leica, Germany) **(Figure 2.10)**.

Figure 2.10: Microtome (Leica, Germany).

8- Optical microscope with an adapter for holding the smart phone (Novel, China) **(Figure 2.11).**

Figure 2.11: Optical microscopic with a smart phone adapter (Novel, China).

2.2 Methods

2.2.1 Preoperative assessment, clinical and radiographic examination.

2.2.1.1. History

Each patient had a full medical, dental, and social history collected, which generally included any systemic condition that may impair the bone's healing potential.

2.2.1.2 Clinical examination

- **Extra oral examination:** This included examination of facial symmetry, smile line, color of skin, sclera and conjunctiva, cervical regional lymph nodes and temporomandibular joint condition.
- **Intra oral examination:** It included inspection of oral mucosa, examination of teeth for the presence of caries, abnormal mobility of adjacent teeth, presence of retained roots, any signs of pathological condition and any signs of parafunctional habits, **(Figure 2.12).**

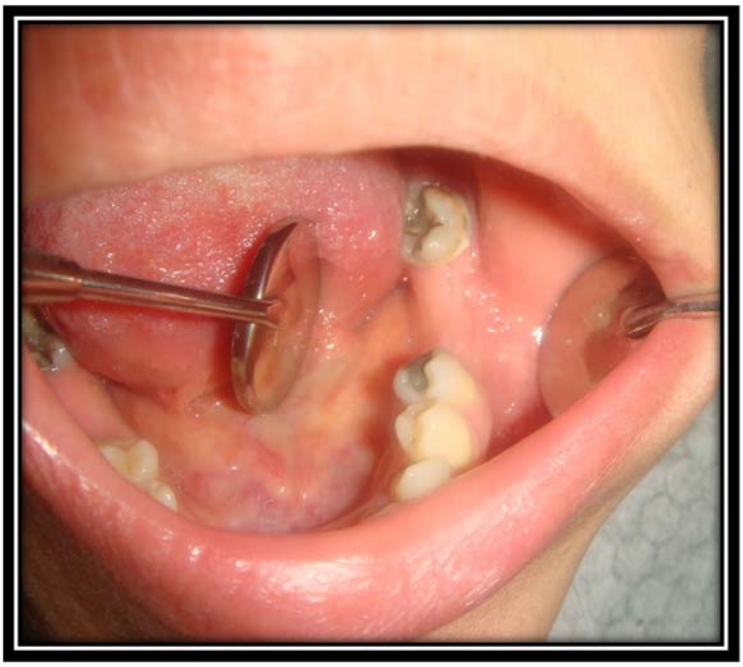


Figure 2.12: Intraoral examination for the implant site #19.

- A space analysis was done at the proposed site of the dental implant; it involved the followings:

  A) The inter-coronal (mesiodistal) distance was measured using Vernier caliper to ensure that enough space was available for

implant placement without jeopardizing adjacent roots, as well as for future prosthesis, **(Figure 2.13).**

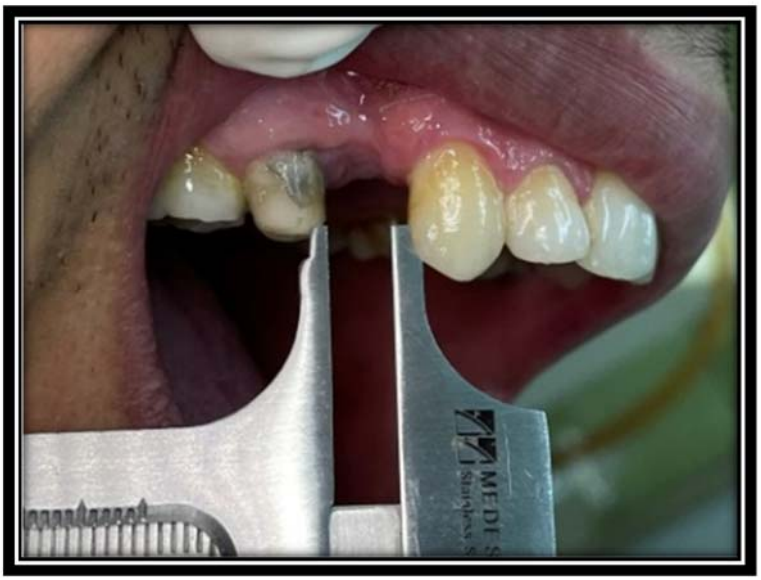


Figure 2.13: Space analysis. Intercoronal distance measurement at missing tooth site #5.

B) Inter-arch (inter-ridge) distance during occlusion was measured using Vernier caliper to have an initial idea about the length of clinical crown, **(Figure 2.14)**.

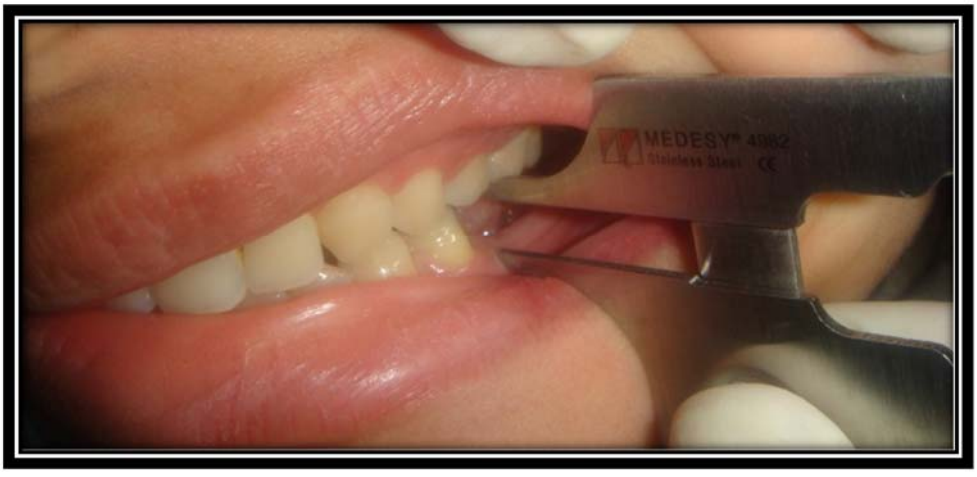


Figure 2.14: Space analysis. Interocclusal distance measurement at missing tooth site #19.

- Inter-incisal distance at maximum mouth opening was also measured, as shown in **(Figure 2.15).**

Figure 2.15: Inter-incisal distance measurement at maximum mouth opening.

2.2.1.3 Radiographic evaluation

For each patient a preoperative OPG was taken for general evaluation of jaws and dentition, the existence of any pathological lesion, and the proximity to the floor and anterior wall of the maxillary sinus, inferior alveolar canal, mental foramen, and nasal floor. Evaluation also included the divergence of the root adjacent to the operative area for proper implant angulation, **(Figure 2.16)**.

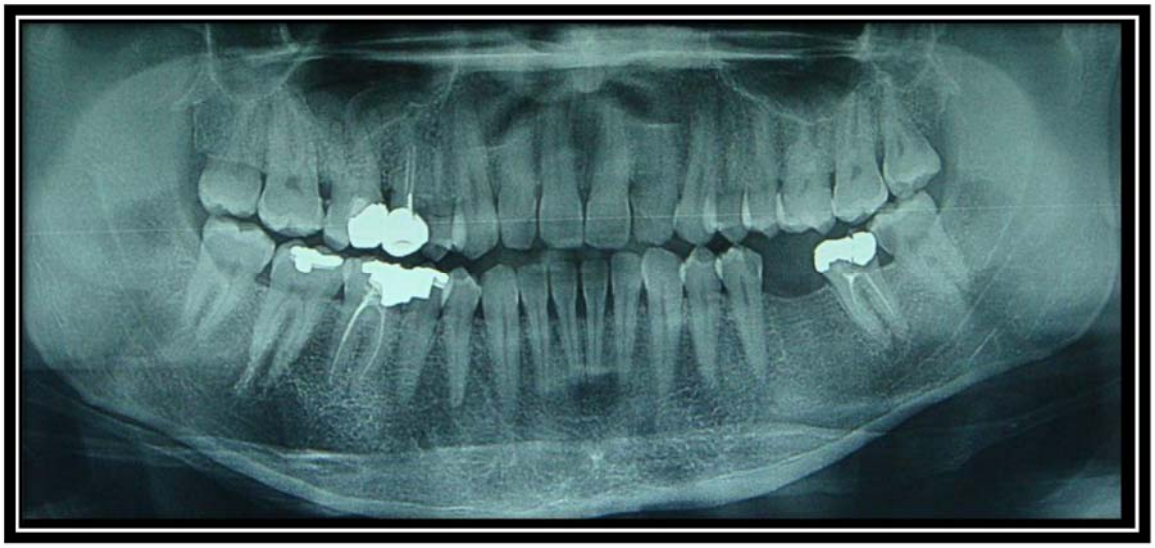
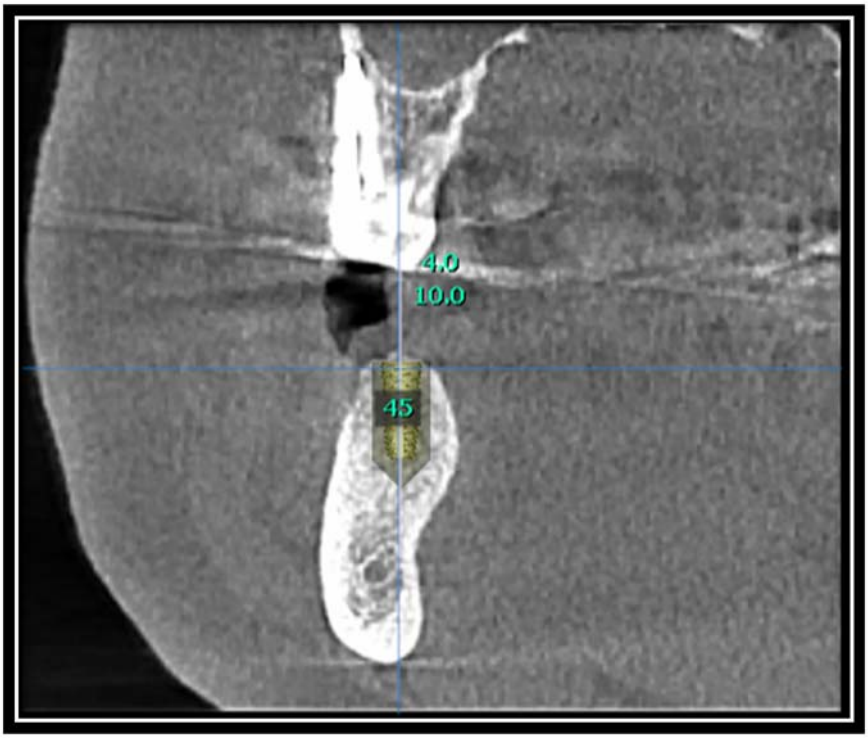


Figure 2.16: Site of missing tooth # 19 on preoperative OPG.

A preoperative CBCT (Kavo OP 3D PRO, Biberach, Germany) was taken for the patients to assess the bone density using the OnDemand3D™ software (Cybermed Inc. ©, Seoul, Korea), Bone Density Graph tool was used to determine the bone density of the entire implant site in Hounsfield units (HU) (**Mello-Machado *et al.***, **2021**), **(Figure 2.17).**

Also, further additional detailed measurements were taken to determine the exact bone height and width of alveolar ridge at proposed implant site to ensure the presence of sufficient alveolar bone ridge dimensions with a minimum 6 mm width and 10 mm height, as well as to determine the dimensions of the implant to be installed so that the implant apex is to be at least 2 mm above mandibular canal and 2 mm away from mental foramen, 1 mm bellow nasal cavity and 1 mm below the floor and the anterior wall of maxillary sinus, **(Figure 2.18)**.



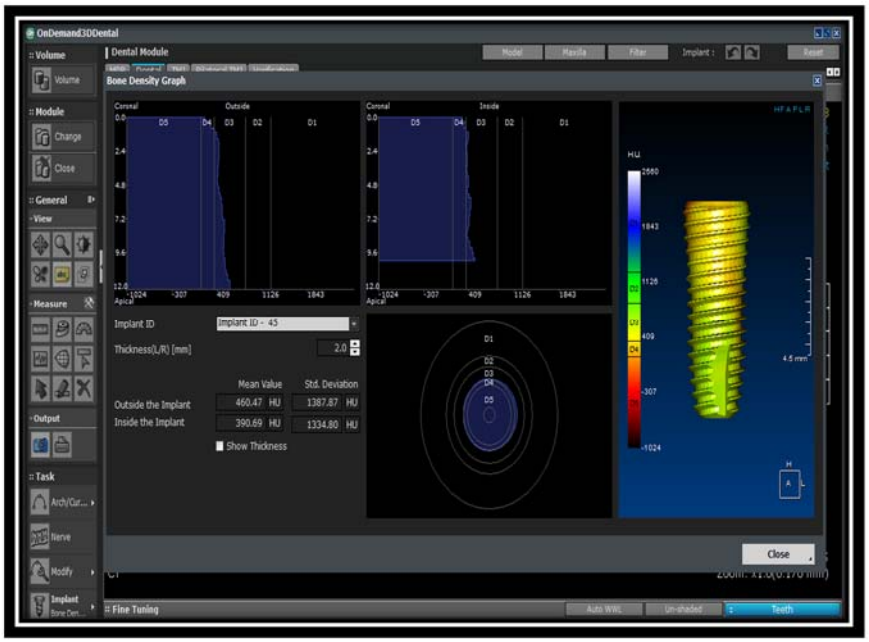


Figure 2.17: Bone density (HU) measurement of the entire implant site.

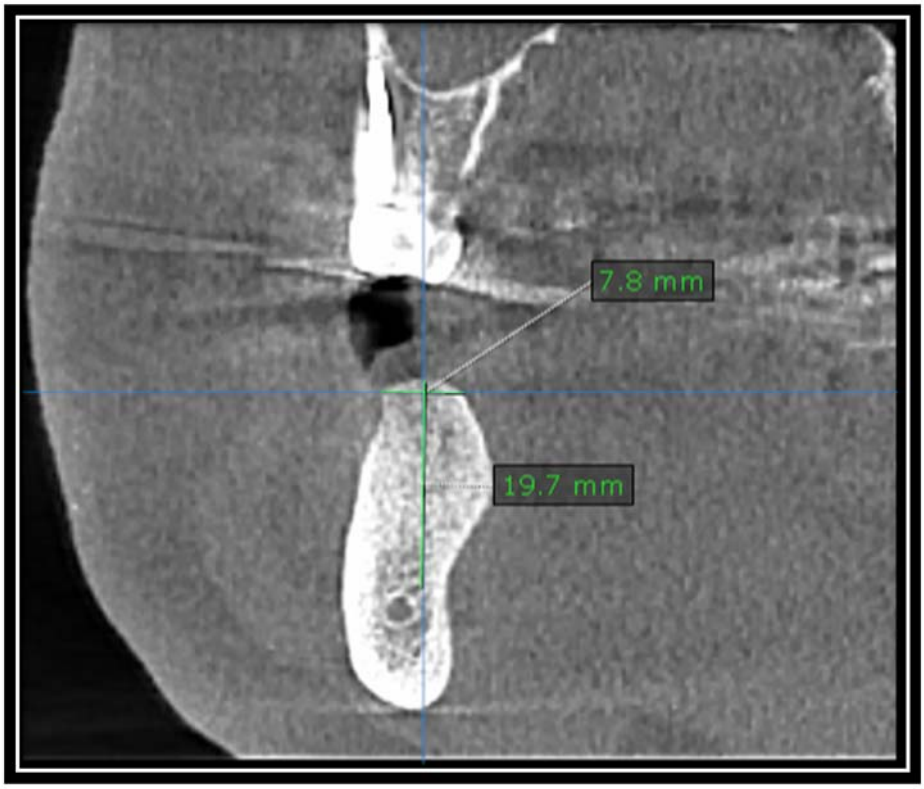


Figure 2.18: Determination the exact bone height and width of alveolar ridge at proposed implant site.

2.2.2 Surgical procedure

2.2.2.1 Patient's preparation

The nature of the surgery and any possible issues were explained to the patient.

Before surgery, the patient was instructed to gargle for about 1 minute with chlorhexidine 0.12% mouthwash, this was followed by circumoral scrubbing with Povidone-Iodine solution-soaked gauze and draping with sterile surgical drapes.

2.2.2.2 Local anesthesia and flap design

All of the surgical operations were carried out under local anesthesia using local infiltration into labial/buccal and lingual/palatal mucosa of the

planned surgical field using lidocaine hydrochloride 2% with epinephrine (1:80,000) (Huons Co., Ltd., Korea).

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A three-sided full thickness mucoperiosteal flap was reflected using periosteal elevator, **(Figure 2.19)**.

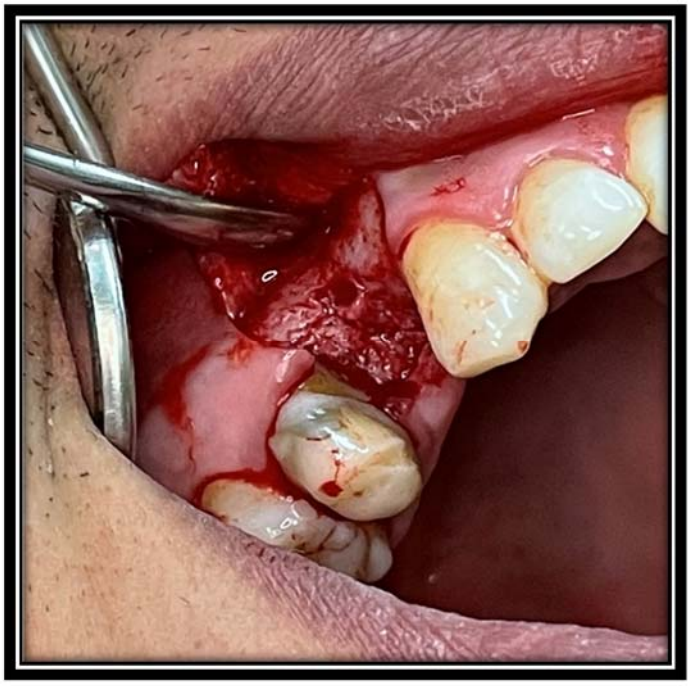


Figure 2.19: Flap design at missing tooth site #5.

2.2.2.3 Bone harvesting

Bone specimen was harvested using Easy retrieve two-pieces trephine burs- kit (ACE Surgical Supply Co., Inc., USA), with a trephine head (3.2mm outer diameter and 2.5mm inner diameter), the implant micromotor was set at rotating speed 800 rpm and torque 35 Ncm with copious irrigation of normal saline as shown in **(Figure 2.20).**

The bone specimen obtained was fixed for 24 hours in a tube containing formalin 10%, **(Figure 2.21)**.

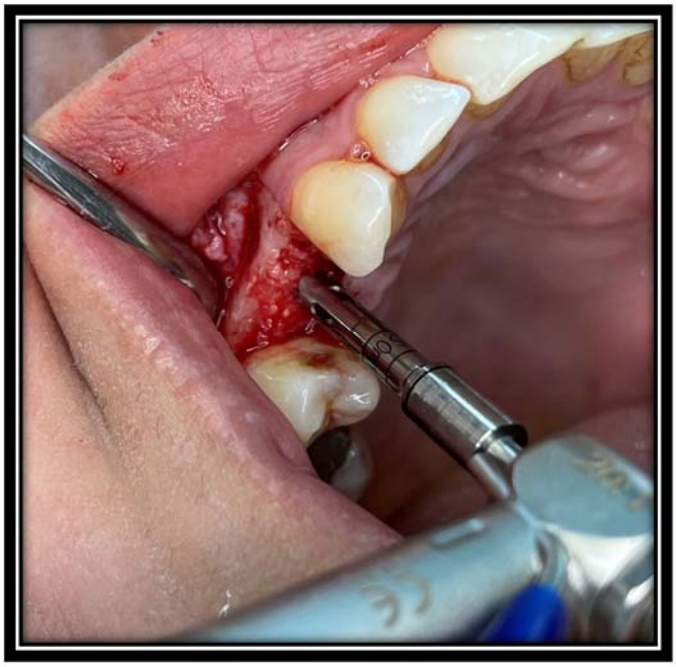


Figure 2.20: Bone harvesting using trephine bur.

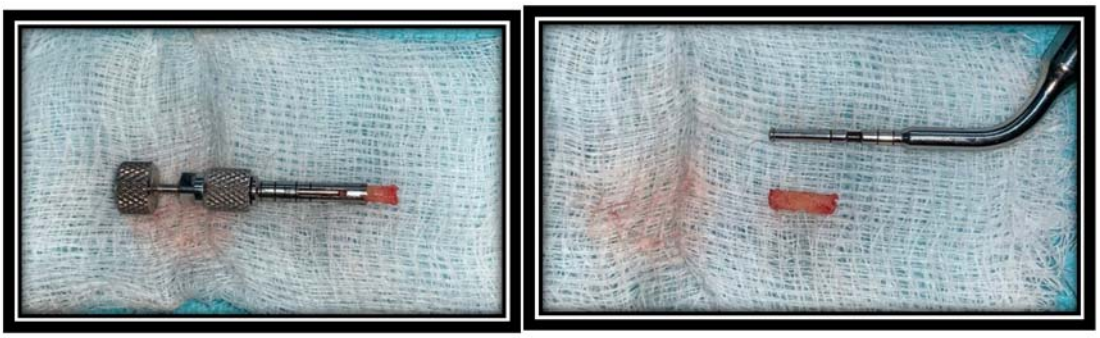


Figure 2.21: Bone specimen.

2.2.2.4 Implant bed preparation

The implant site preparation proceeded using osteotomy drills of increasing diameter corresponding to the implant dimensions with an implant micromotor (Dental surgery micromotor iCT, Dentium, Korea) rotating at a speed of 800 rpm and 35 Ncm torque with copious saline irrigation, as shown in (**Figure 2.22).**

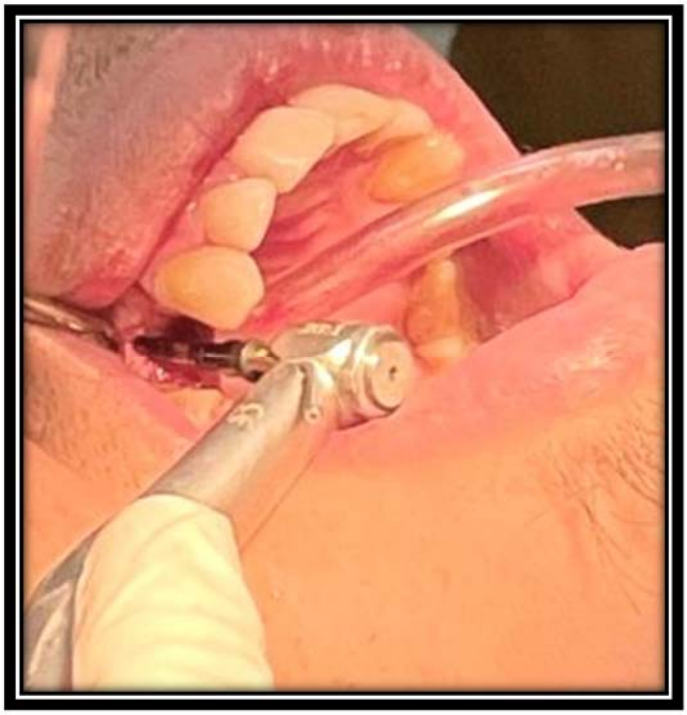


Figure 2.22: Implant site preparation using sequential drills.

Parallel pin was used to assess the correct position and alignment of the dental implant, **(Figure 2.23).**

Figure 2.23: A parallel pin in missing tooth site #5 to check alignment with adjacent teeth.

2.2.2.5 Implant insertion

The implant was installed into the osteotomy site using the motorized method with the engine set at 50 rpm and 35 Ncm torque, so that the implant platform was 0.5-1 mm below the bone level, **(Figure 2.24)**.

When the insertion torque exceeded 35 Ncm, the implant was placed to the appropriate depth using a ratchet. Accordingly in this study, implants were categorized into two groups regarding the insertion torque; one group with 35 Ncm insertion torque and the other > 35 Ncm.

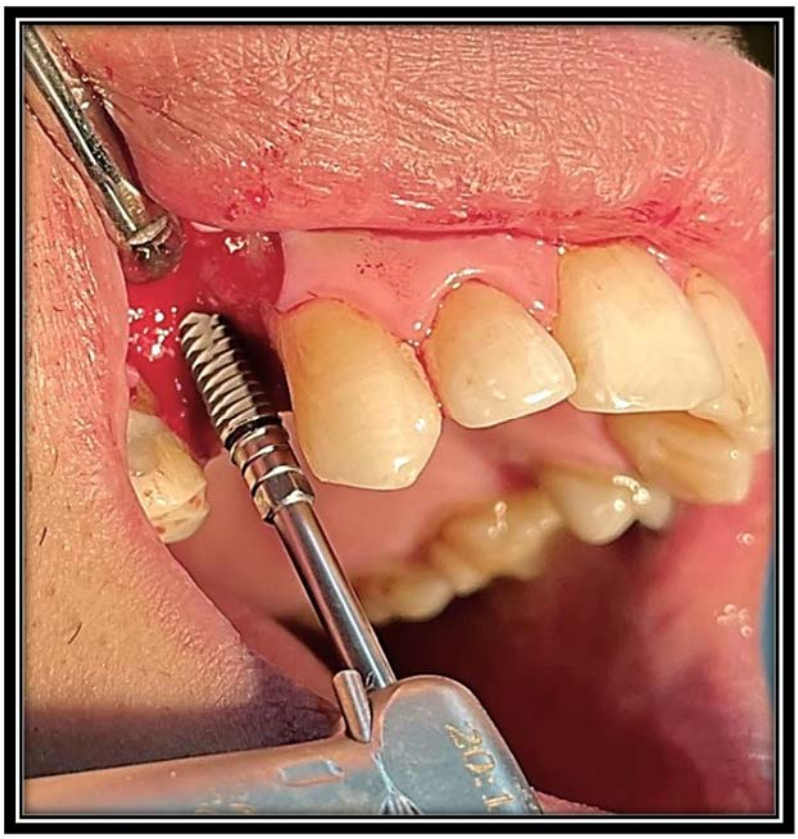


Figure 2.24: Motorized implant insertion of implant at missing tooth site #5.

2.2.2.6 Primary stability measurement (baseline)

Immediately after insertion of dental implant, a multipeg was fixed to the implant using multipeg driver and a primary stability was measured using Osstell® ISQ, **(Figure 2.25).**

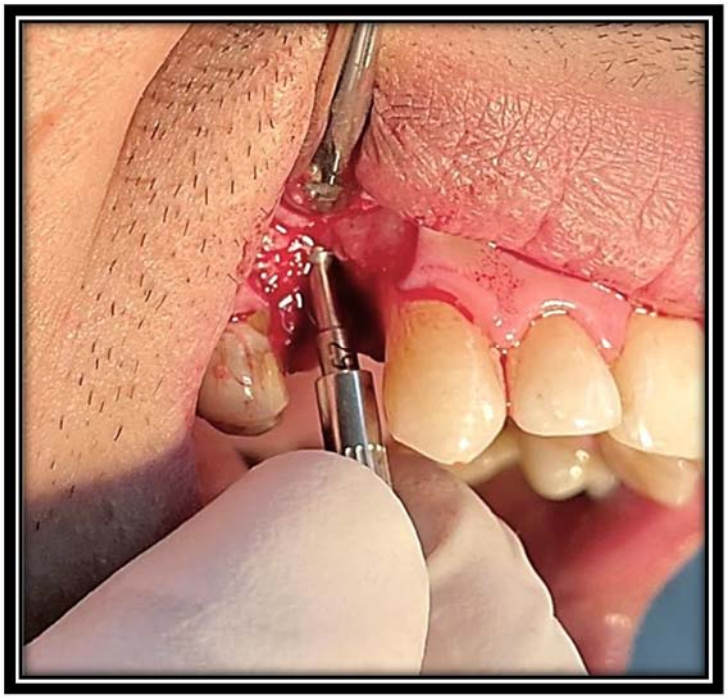


Figure 2.25: Multipeg fixation on implant fixture using multipeg driver.

Two repeated implant stability quotient (ISQ) measurements were obtained for each implant along the buccolingual and mesiodistal axis and the average of these two measurements was considered as the primary stability, **(Figure 2.26).**

Figure 2.26: Primary stability ISQ values recording using Osstell® ISQ device.

A cover screw was placed after removing the multipeg, as shown in **(Figure 2.27).**

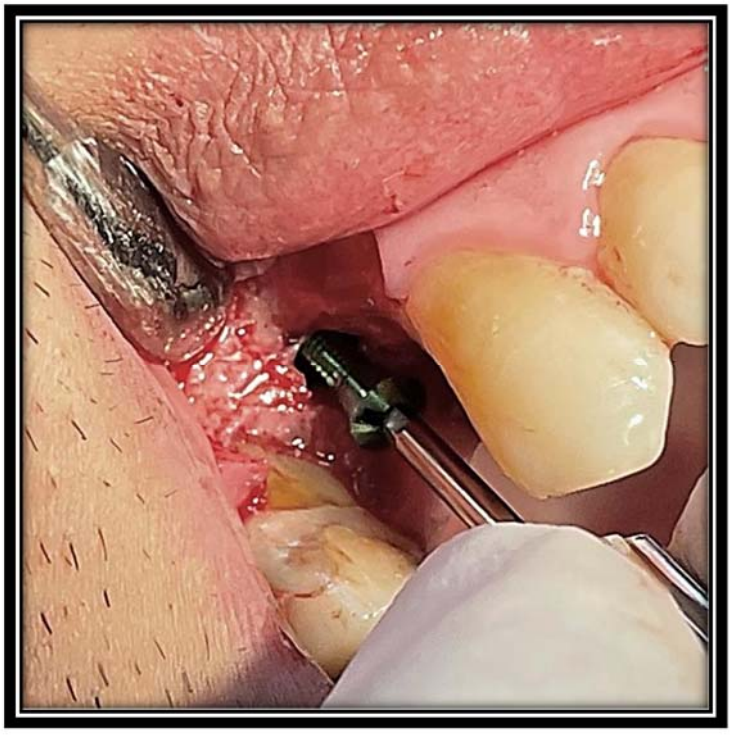


Figure 2.27: Installation of cover screw on implant fixture.

After toilet of the operated area, the flap was repositioned and sutured with 3/0 black silk interrupted suture, as shown in **(Figure 2.28).**

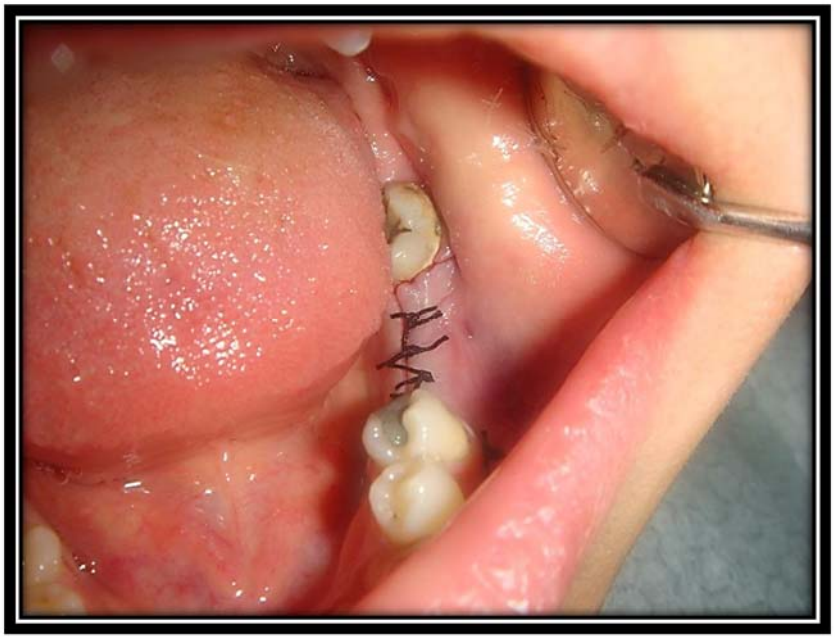


Figure 2.28: Flap repositioning and suturing for implant site #19.

2.2.2.7 Instructions and postoperative care

Patients were instructed to:

- Maintain pressure over the gauze pack applied over the operated area for about 30 minutes.
- Apply ice packs against the operated area in an alternate manner with 15 minutes on and 15 minutes off in order to reduce postoperative edema and the patients were instructed to rest and avoid any heavy exercise for the first two days after surgery.
- Avoid gargling and spitting for the first 24 hours, gentle rinse for 30 seconds after meals and at bedtime with chlorhexidine mouth wash 0.12% for 5 days and gentle brushing of teeth especially close to the surgical site starting in the second day postoperatively.

- Avoid eating for 2 hours after surgery and maintain soft diet thereafter for the first 24 hours.
- Use the prescribed antibiotics and analgesics, which included (for all Patients):

A) Amoxicillin capsules 500 mg every 8 hours or Azithromycin tablet 500 mg once daily (in case of Penicillin allergic patients) 5-7 days,

B) Metronidazole tablets 500 mg every 8 hours,

C) Paracetamol tablets 500 mg as required for 5 days after surgery.

2.2.2.8 Follow up

The patients attended for the first follow up visit 7-10 days postoperatively for sutures removal.

The patients were asked to return at 16 weeks postoperatively for a follow-up appointment. The implant was uncovered, and the implant stability was assessed with Osstell® ISQ in the same way that primary stability was measured., and a healing abutment was installed, **(Figure 2.29).**

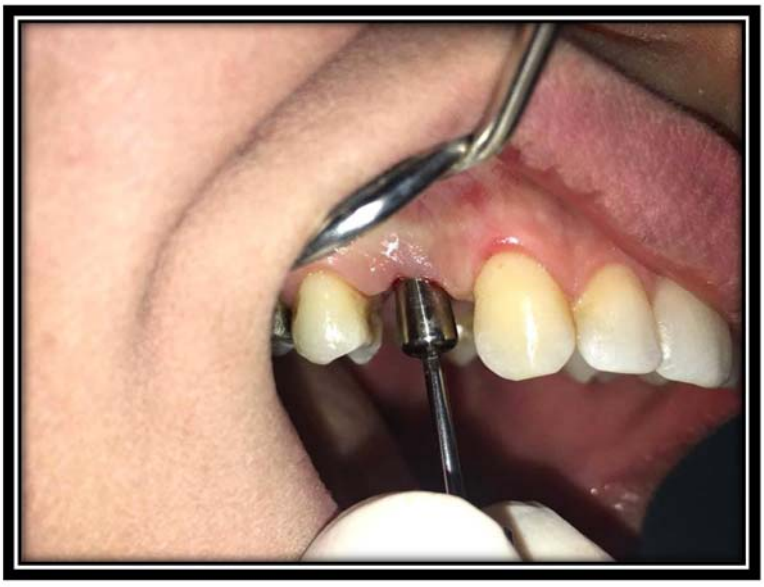


Figure 2.29: Installation of healing abutment using Hex drive.

The patient was referred for accomplishment the final implant supported fixed prostheses.

2.2.3 Histological slide preparation and examination

2.2.3.1 Method of slide preparation

The 2.5 mm diameter bone specimen that was harvested from implant site was rinsed with physiologic solution and was fixed in 10% formalin for 24 hours. Then it was decalcified with 10% formic acid for about 7 days, and checked for complete decalcification with narrow needle paced through the sample. After decalcification, the sample was dehydrated in ascending concentration of ethanol (70%-100%), processed with xylene and embedded in a paraffin wax. Then it was left to freeze for one day in the refrigerator. Following this processing the specimen was longitudinally sectioned using microtome into 5μm slices; a middle section was selected for histomorphometric analysis, as it should relate to the specimen's maximum length and diameter, placed on the slide, stained with hematoxylin/ eosin (H&E), and the slide was covered for light microscopic observation.

2.2.3.2 Acquisition of photomicrographs

Photomicrograph was acquired with 4X objective lens and a 10X eyepiece using digital smart phone camera, 12 Mega pixels (IPhone 12, Apple Inc., California, USA) with the aid of microscopic adapter for holding the smart phone, **(Figure 2.30).**

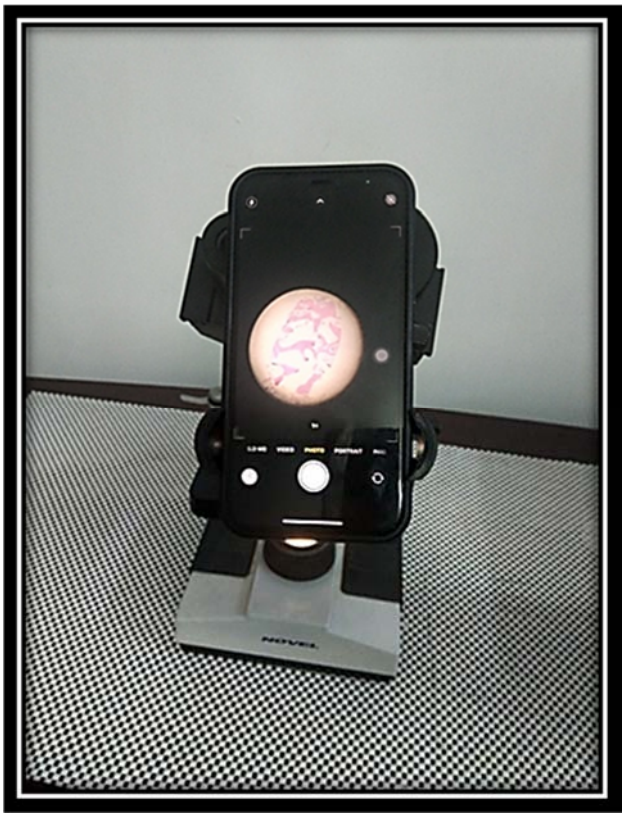


Figure 2.30: Microphotograph acquired using smart Phone.

2.2.4 Histomorphometry

Total bone perimeter length (PB), total bone area (AB), and total section area (AT) were all measured using the Imagej® v1.52a software (U.S. National Institutes of Health, Bethesda, Maryland, USA).

A) Imagej®s was downloaded from (http://imagej.nih.gov/ij/), **(Figure 2.31).**

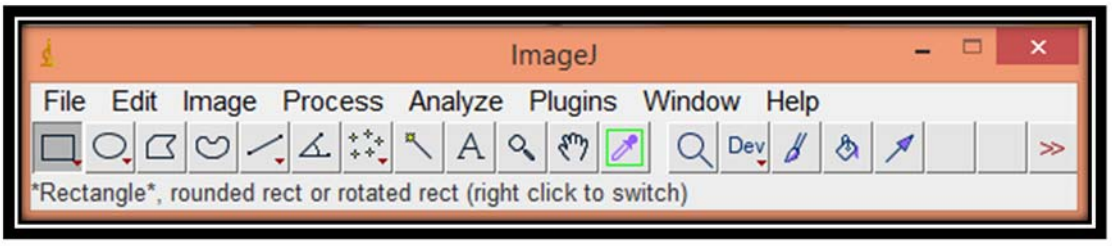


Figure 2.31: Imagej® main window.

B) The "open" command was clicked from the file menu, which opened a browser window in which we navigated and selected the image to be examined **(Figure 2.32).**

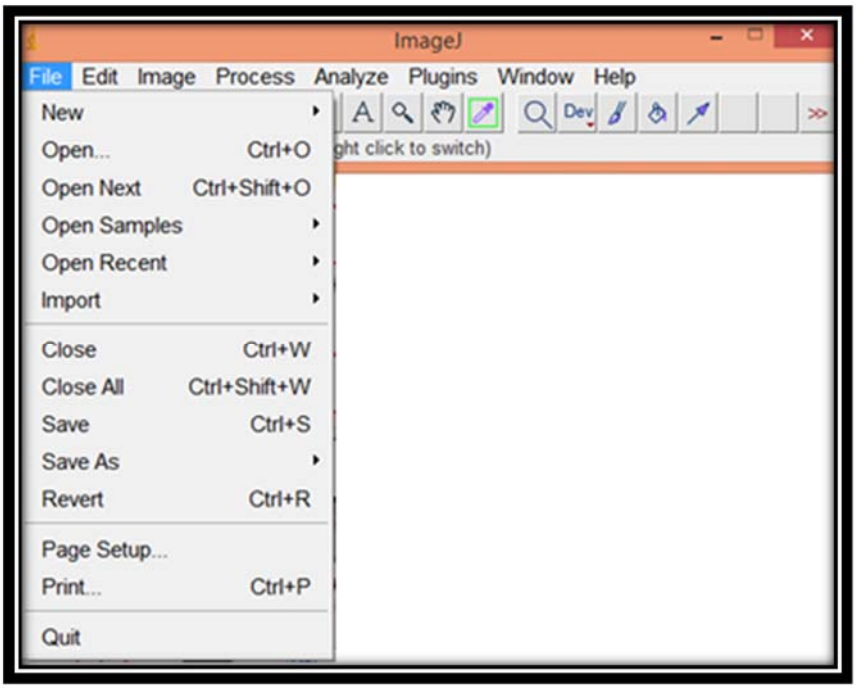


Figure 2.32: Selection of an image to be examined with "open" command.

C) After displaying the image in an Imagej® window, it might be subjected to any command inside the software. Then after, specific scale was performed to have the measurements in mm instead of pixels, by choosing the "set scale" command from the analyze menu **(Figure 2.33)**.

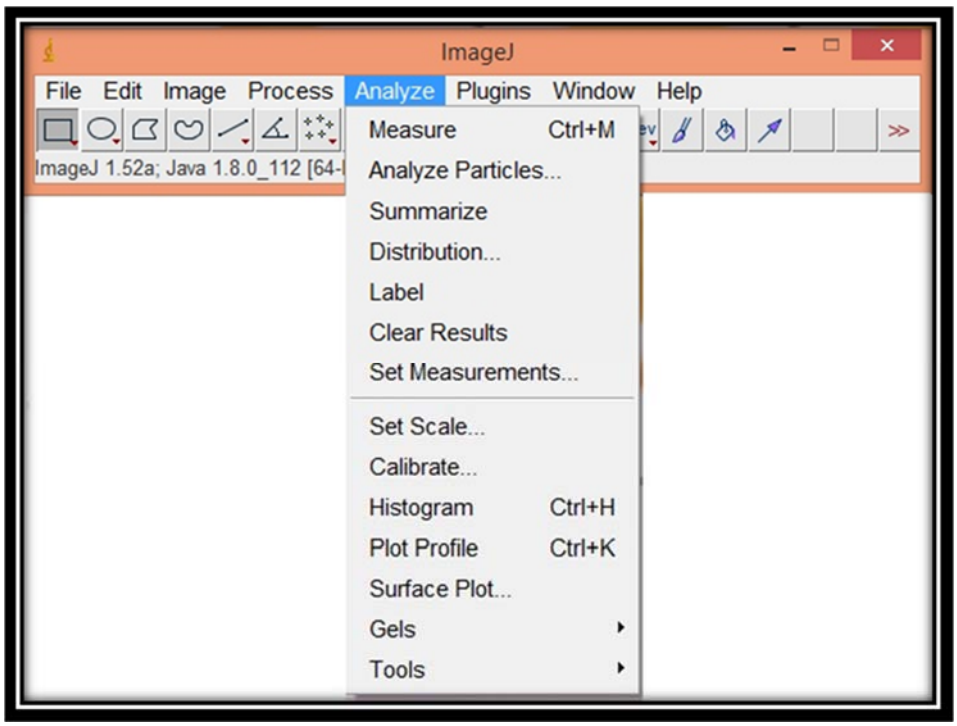


Figure 2.33: Set scale.

D. A region of interest (ROI) was determined using a selection polygon, in which the user pointed to sequential points around the perimeter of the area to be examined, and the software formed an enclosing polygon. Any following command would only affect the designated region. Holding the shift key when selecting allows for multiple selections **(Figure 2.34).**

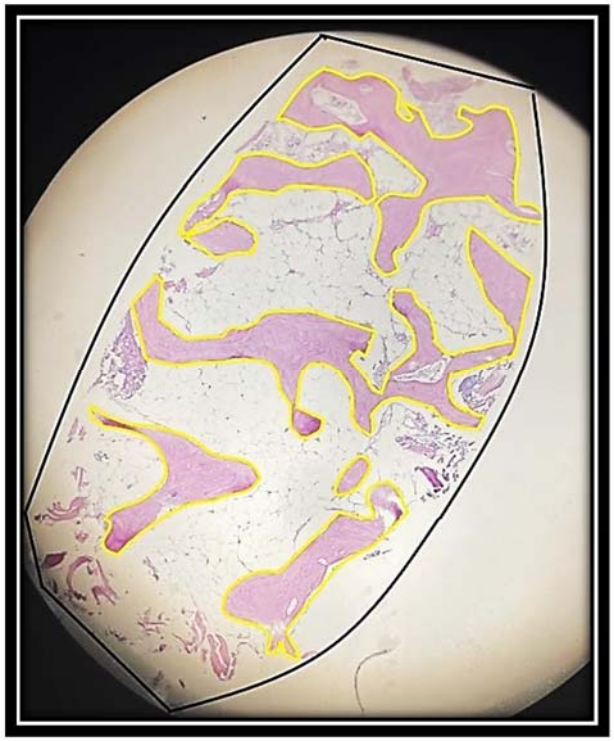


Figure 2.34: Histological section of bone specimen obtained from lower right first molar area. Histomorphometric measurements show the total section area (AT) (trabecular bone + bone marrow) in black and total bone area (AB) (trabecular bone) in yellow.

E. After finishing the selection process and setting the required measurements; from the analyze menu "measure" command was selected, and the primary 2D histomorphometric measurements (PB, AB, and AT) were obtained, **(Figure 2.35).**

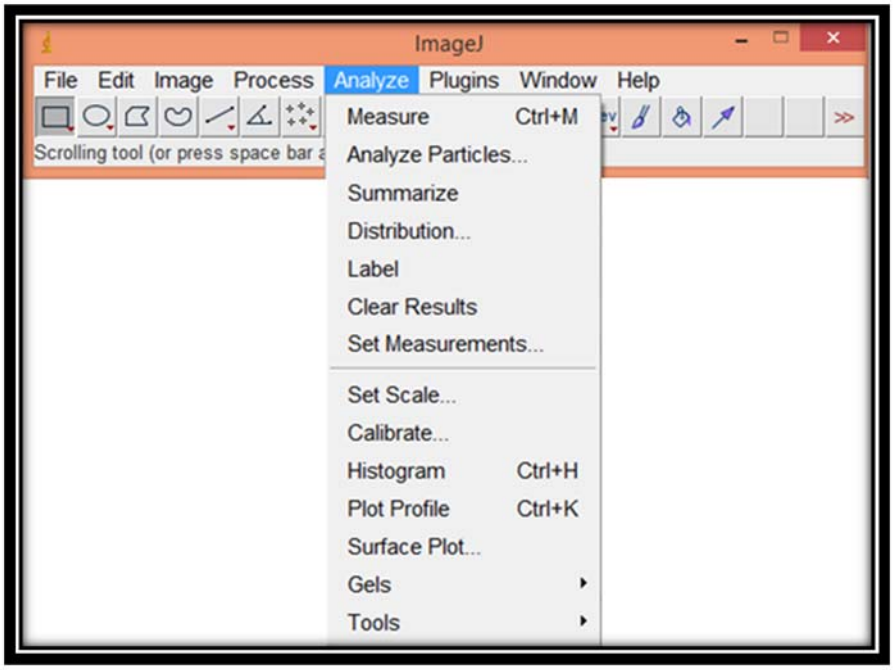


Figure 2.35: Selection the "measure" command from the analyze menu for performing primary histomorphometric measurements (PB, AB, and AT).

F. Using a formula developed by Parfitt, the primary 2D histomorphometric measurements (PB, AB, and AT) allowed us to obtain estimated 3D parameters based on the stereology (**Parfitt *et al.***, **1983**).

Standardized nomenclature, symbols, and units (**Parfitt**, **1987**) of 3D morphometric parameters assessed in this study and the formulas that were derived from, are illustrated in **(Table 2.1).**

Table 2.1: Standardized nomenclature, symbols, and units (**Parfitt**, **1987**) and the formulas (**Parfitt *et al.***, **1983**) of morphometric parameters.

Morphometric parameters	Symbol	Unit	Formulas to Calculate 3D Parameters from Primary 2D Measurement
Bone volume density	BV/TV	%	(AB/AT)×100
Bone surface fraction	BS/TV	mm^{-1}	(PB/AT)×1.199
Bone surface density	BS/BV	mm^{-1}	(PB/AB)× 1.199
Trabecular thickness	Tb.Th	mm	(2/1.199)(AB/PB)
Trabecular number	Tb.N	mm^{-1}	(1.199/2)(PB/AT)
Trabecular separation	Tb.Sp	mm	(2/1.199)(AT-AB)/PB

Abbreviations: AB = bone area; AT, total area; PB, bone perimeter; BV, bone volume; BS, bone surface; TV, tissue volume.

2.2.5 Study variables and statistical analyses

The independent variables included the bone density measured by CBCT as Hounsfield units (HU) and trabecular bone morphometric parameters, while the outcome variables were the primary and secondary stability measured as implant stability quotient (ISQ) and the insertion torque, which was categorized into two groups; one group with 35 Ncm insertion torque and the other > 35 Ncm.

The statistical analysis also included the correlation between the bone density measured in HU with the primary and secondary stability and

insertion torque, and the correlation of the histomorphometric parameters with bone density (HU) measured by CBCT and implant stability (primary and secondary) ISQ values, and insertion torque.

GraphPad Prism version 6 for Windows was used to carry out the statistical analysis (GraphPad Software, La Jolla, CA, USA). Percentages, mean, standard deviation (SD), and median were all computed as part of descriptive statistical analysis. The inferential analysis included using Shapiro-Wilk normality test, paired and unpaired t-test, Mann-Whitney test, Pearson correlation test, Spearman correlation test, One-way ANOVA, Kruskal-Wallis test with multiple comparisons test and Chi-square test. The probability value <0.05 was considered statistically significant.

2.2.6 Case presentation

A 37 year old female patient attended to the Oral and Maxillofacial department in November 2020, she presented with missing tooth #5, on clinical examination and space analysis, the mesiodistal distance and inter-arch distance were sufficient for a dental implant placement.

The patient was referred for taking CBCT that revealed the average bone density of the planned implant site (115 HU), and bone dimension were also measured.

The stages of treatment and the final result are illustrated in figures **(2.36)** through **(2.48)**.

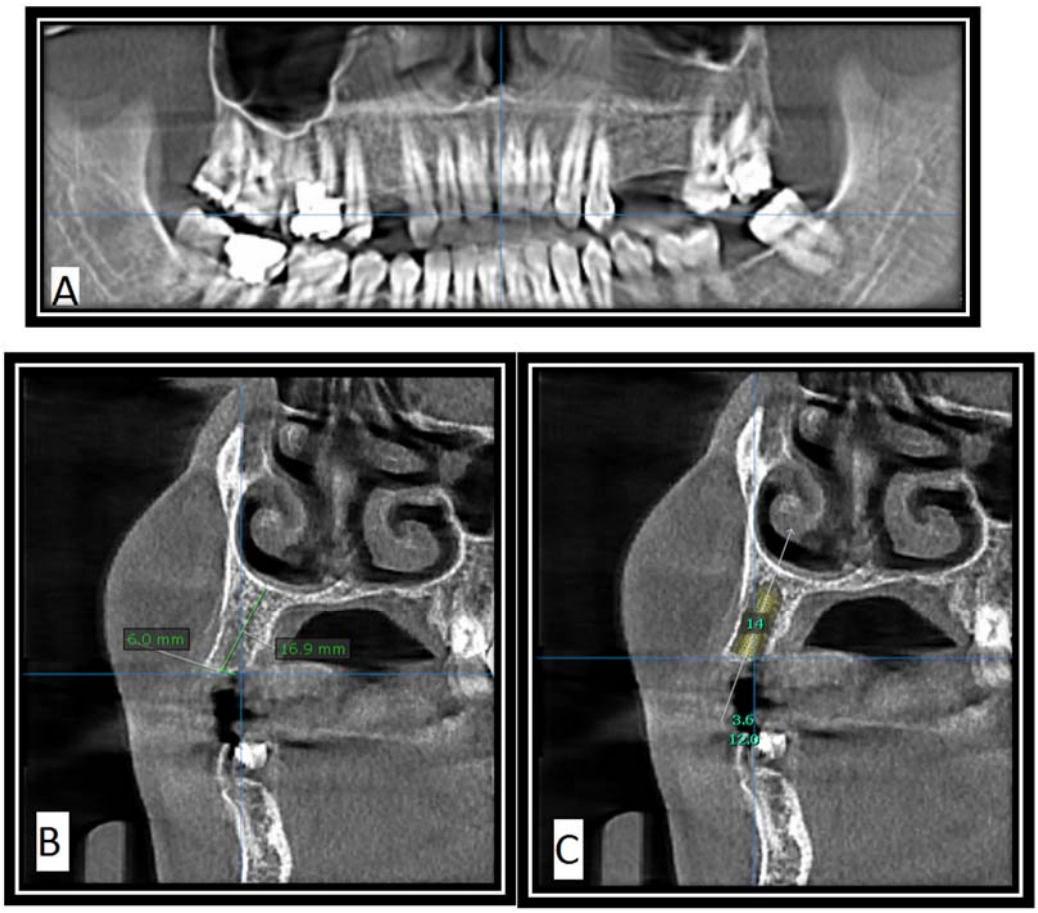


Figure 2.36: Preoperative CBCT of missing tooth site #5. **(A)** Panoramic view of missing tooth #5. **(B)** Measurement of available bone height and width of the planned dental implant site in the cross-section view. **(C)** Cross-section view showing the average bone density of the entire planned dental implant site.

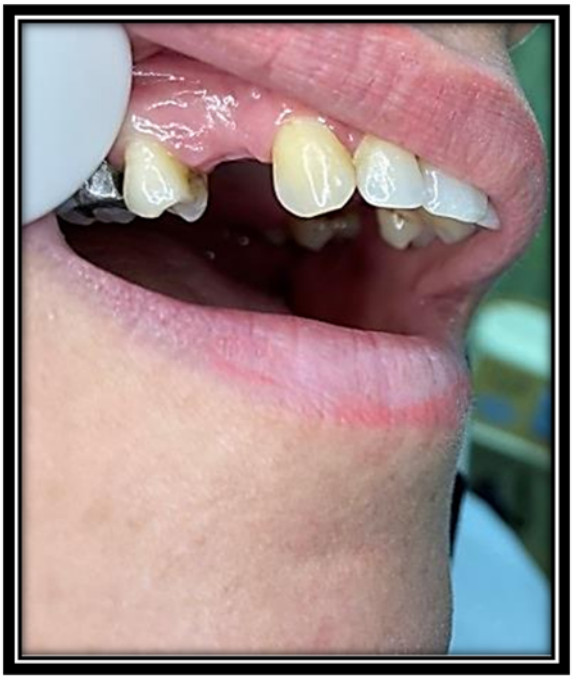


Figure 2.37: Initial preoperative clinical view.

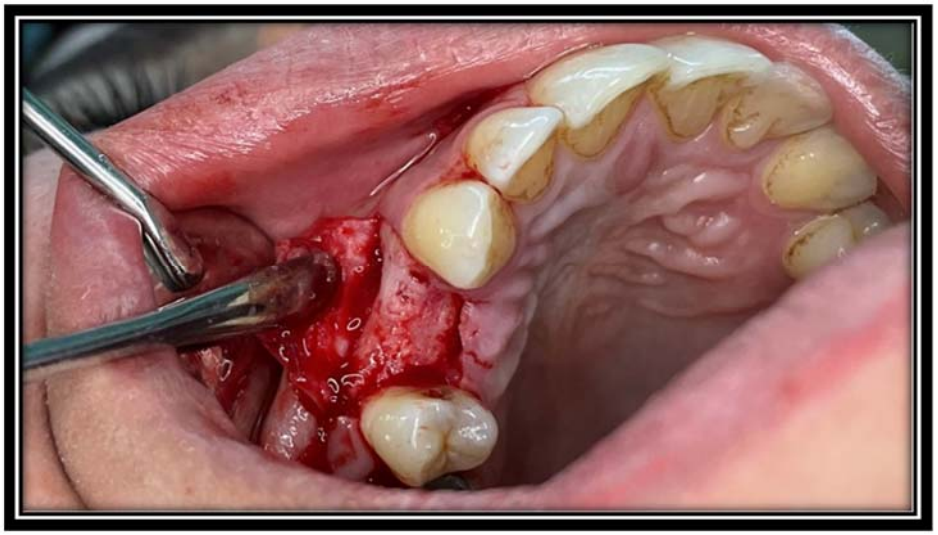


Figure 2.38: Flap reflection.

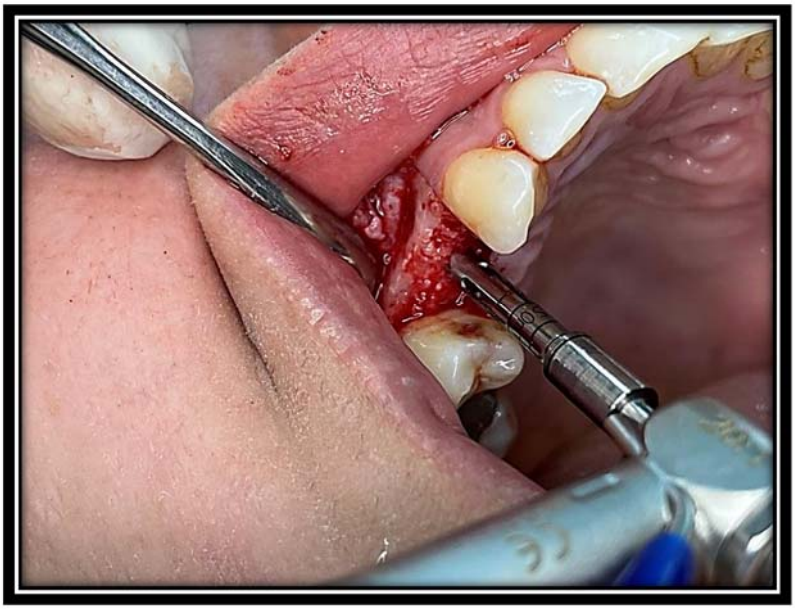


Figure 2.39: Bone harvesting using trephine bur.

Figure 2.40: Bone specimen.

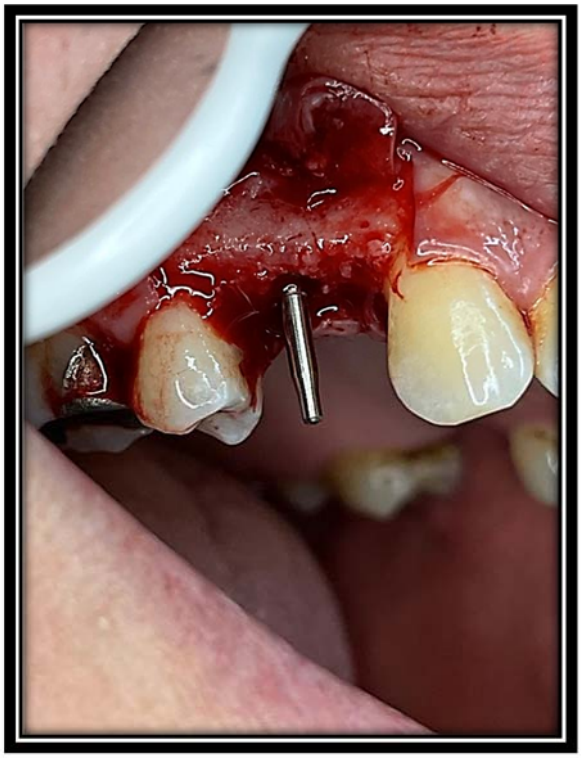


Figure 2.41: Parallel pin insertion to verify proposed implant angulation.

Figure 2.42: Sequential drilling with osteotomy drills.

Figure 2.43: Implant installation using the motorized method.

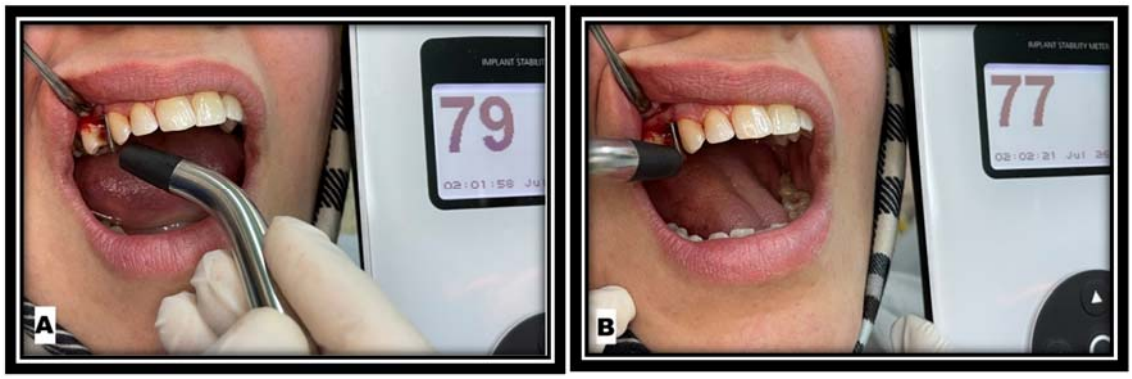
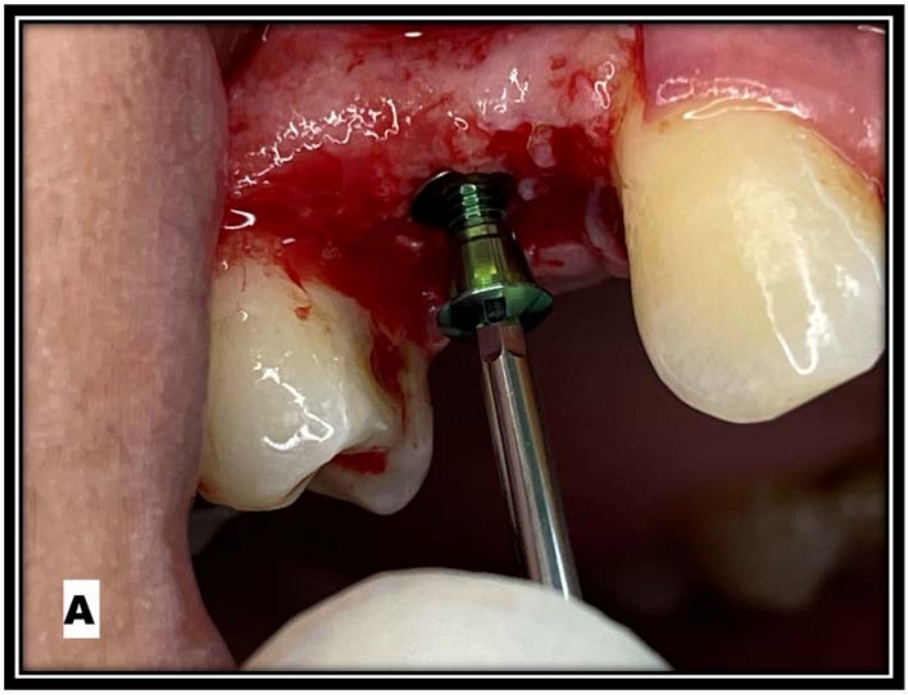


Figure 2.44: Implant stability recording using Osstell® ISQ. (a) Along the mesio-distal axis of the implant. (b) Along the bucco-palatal axis of the implant.



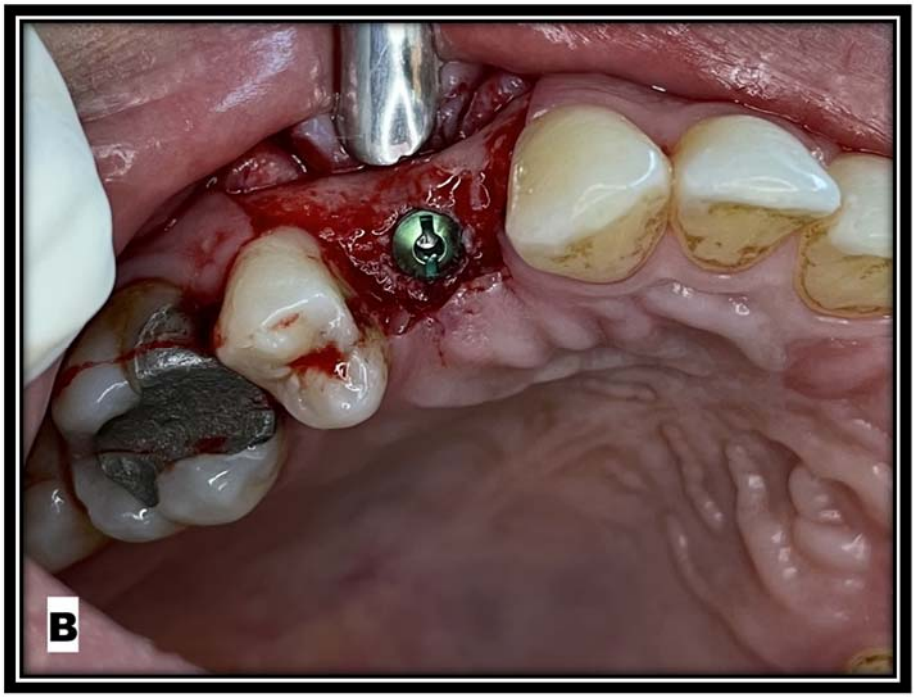


Figure 2.45: Cover screw placement with the use of hexdriver (A&B).

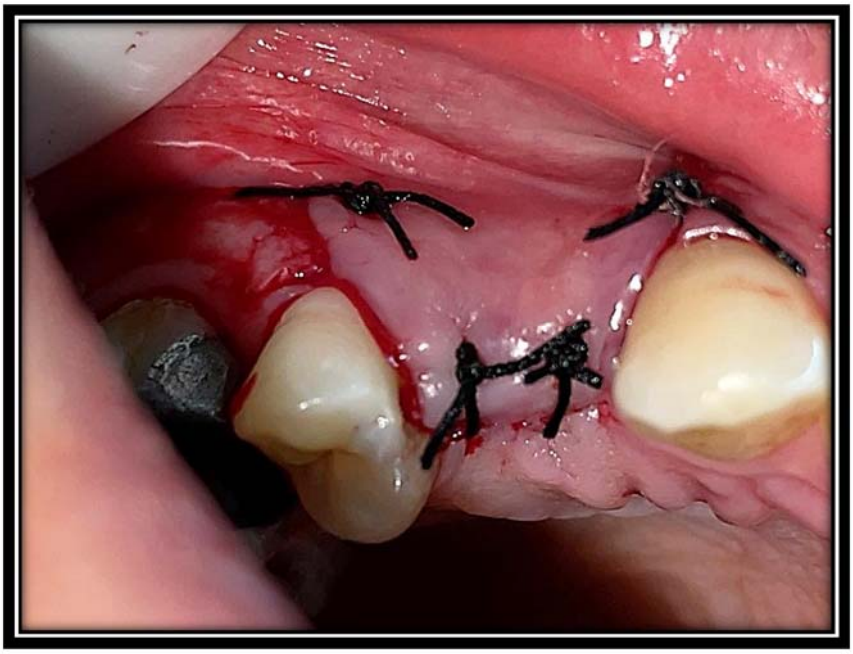


Figure 2.46: Flap repositioning and suturing.

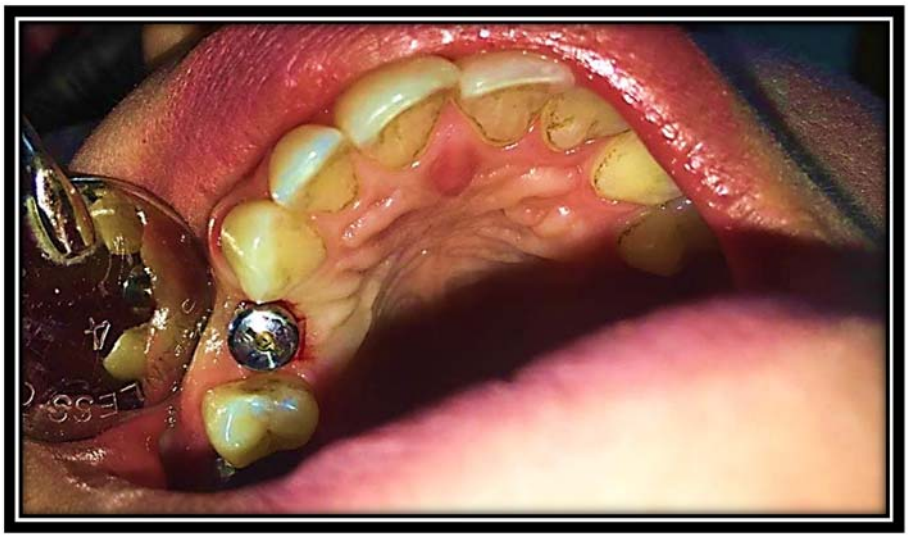


Figure 2.47: Healing abutment installation after 16 weeks (2nd stage surgery).

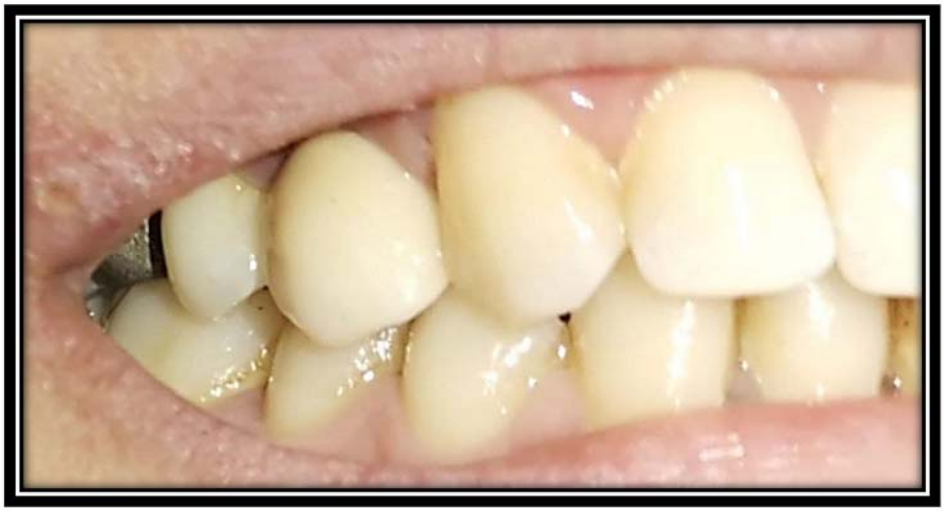


Figure 2.48: Final prosthesis.

❖ Histomorhometry

The histological section of the bone specimen obtained from missing tooth site #5, is shown in **(Figure 2.49)**.

Figure 2.49: Histological section of bone specimen from missing tooth site #5.

The findings of the primary (2D) histomorphometric measurements and the (3D) morphometric parameters that were derived from were shown in **(Table 2.2)**.

Table 2.2: The findings of the primary (2D) histomorphometric measurements and the (3D) morphometric parameters of the histological section of bone specimen.

Primary measurements (2D)	
Total area (AT)\ mm^2	6.28
Bone area (AB)\ mm^2	1.015
Bone perimeter (PB)\ mm	21.248
Histomrphometric parameters (3D)	
Bone volume density BV\TV\ %	16.162
Bone surface fraction BS\TV\ mm^{-1}	4.056
Bone surface density BS\BV\ mm^{-1}	25.099
Trabecular thickness Tb.Th\ mm	0.079
Trabecular number Tb.N\ mm^{-1}	2.028
Trabecular separation Tb.Sp\ mm	0.413

Abbreviations: 2D, Two dimensions; 3D, Three dimensions.

CHAPTER 3

RESULTS

RESULTS

3.1 Bone density and implant dimensions effect on implant stability

3.1.1 The general characteristics of the study sample

This study included 24 patients; 14 females (58.3%) and 10 males (41.7%). The mean (SD) age of the patients was 47.9 (13.94) years with a range of 25-75 years and a median of 50.5 years.

The patients received 42 DI; 33 (78.58%) were installed in the mandible and the remaining 9 (21.42%) in the maxilla.

At the end of this study all the DI were clinically stable achieving an early survival rate 100%.

3.1.2 Bone density measured by CBCT

The mean (SD) bone density of the proposed DI sites measured by CBCT was 237.5 (100.2) HU (range 28.40-451.9).

According to the median age, the patients were divided into 2 categories: ≥ 50 and < 50 years.

There was no significant difference regarding the bone density measured by CBCT in relation to the two different age groups of the patients included in this study, **(Table 3.1)**.

With respect to the gender, also there was a non-significant difference in bone density measured by CBCT between male and female, **(Table 3.1).**

Regarding the recipient jaw, the bone density of the proposed implant sites measured by CBCT of the mandible was significantly higher than that of the maxilla, as shown in **(Table 3.1)** and **(Figure 3.1)**.

Table 3.1: The differences in bone density (HU) of the proposed implant sites measured by CBCT in relation to the age, gender, and the recipient jaw.

Variables	Number of values	Mean bone density/ HU	SD	Median	P value
Age / years					
≥ 50	26	226.7	93.07	225.4	0.3767
< 50	16	255.2	111.7	254.0	[NS]*
Gender					
male	17	235.0	119.4	227.9	0.8938
female	25	239.3	87.42	230.2	[NS]*
Recipient jaw					
Maxilla	9	166.7	131.7	115.0	0.0148
Mandible	33	256.8	82.06	233.0	[S]*

Abbreviation: HU, Hounsfield unit; SD, Standard deviation; NS, Non-significant; S, Significant; *, Unpaired t-test.

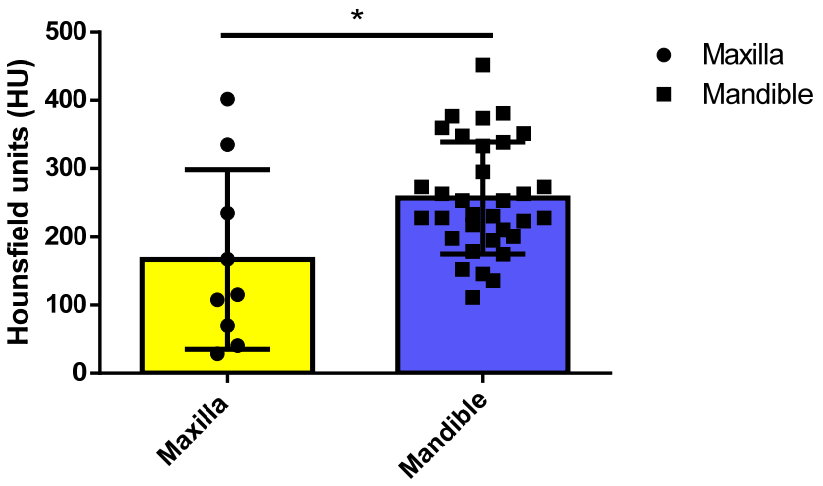


Figure 3.1: Scatter plot with bar graph showing the difference between the bone density (HU) of the maxillary and mandibular proposed DI sites measured by CBCT (P=0.0148).

3.1.3 Implant stability

The mean (SD) of the primary stability ISQ values was 79.58 (5.27), while that of the secondary stability ISQ values was 74.3 (6.34).

The difference between the primary and secondary stability ISQ values was statistically significant (p< 0.0001), **(Figure 3.2).**

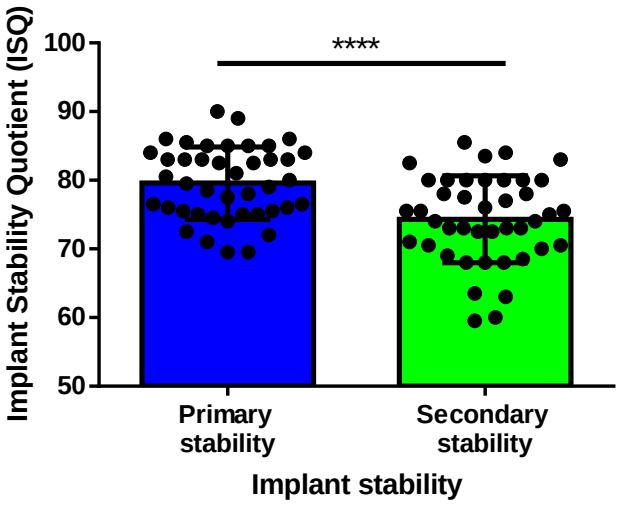


Figure 3.2: Scatter plot with bar graph showing the difference between primary and secondary stability ISQ values, (P < 0.0001).

The correlation of the secondary stability ISQ values and the primary stability ISQ values showed a weak positive correlation (r= 0.3501, p=0.023), **(Figure 3.3).**

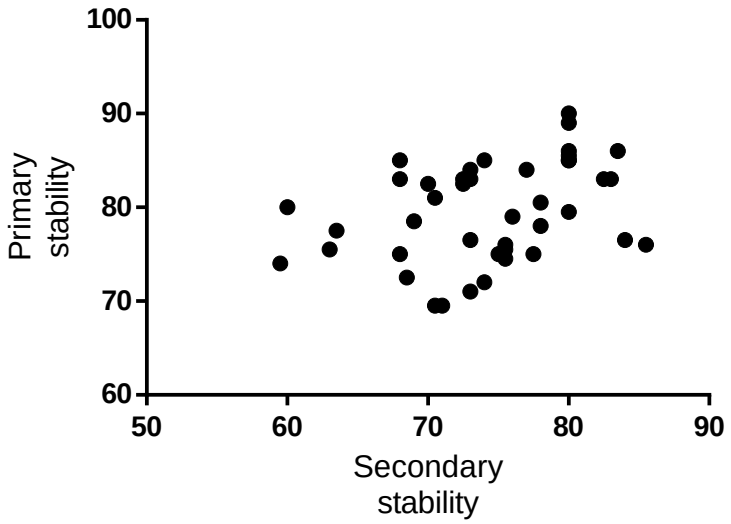


Figure 3.3: Point plot graph showing the correlation between secondary and primary stability ISQ values (r= 0.3501, p=0.023).

3.1.3.1 Correlation of the primary implant stability with the bone density of the proposed DI sites measured by CBCT

There was a moderate positive correlation between the bone density (HU) measured by CBCT and the primary stability ISQ values of DI (r= 0.4, p= 0.0099), **(Figure 3.4).**

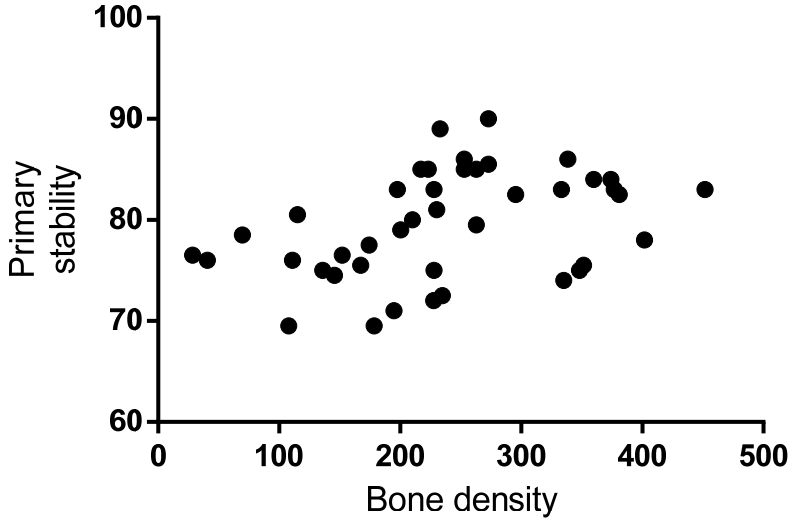


Figure 3.4: Point plot graph showing the correlation between the bone density (HU) measured by CBCT and the primary stability ISQ values of the DI **(**r= 0.4, p= 0.0099).

3.1.3.2 Correlation of the secondary implant stability ISQ values with the bone density of the proposed DI sites measured by CBCT

There was no correlation between the bone density (HU) measured by CBCT and the secondary stability ISQ values of DI (r= 0.002, p= 0.98), **(Figure 3.5).**

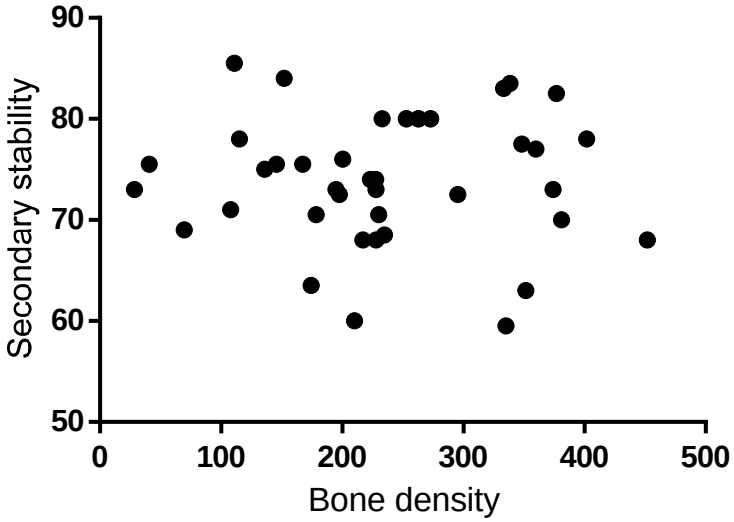


Figure 3.5: Point plot graph showing the correlation between the bone density (HU) measured by CBCT and the secondary stability ISQ values of the DI (r=0.002, p= 0.98).

3.1.3.3 The effect of the recipient jaw on the primary stability ISQ values of DI

Dental implants installed in the mandible demonstrated significantly higher primary stability ISQ values than those installed in the maxilla, **(Table 3.2).**

Table 3.2: The differences of the primary stability ISQ value in relation to the recipient jaw.

Recipient jaw	Number of values	Mean/ISQ	SD	Median	P value
Mandible	33	80.65	5.233	82.50	0.0101
Maxilla	9	75.67	3.326	76.00	[S]*

Abbreviation: ISQ, Implant stability quotient; SD, Standard deviation; S, Significant; *, Unpaired t-test.

3.1.3.4 The effect of the recipient jaw on the secondary stability ISQ values of DI

There was a non-significant difference in the secondary stability ISQ values relative to the recipient jaw, **(Table 3.3).**

Table 3.3: The differences of the secondary stability ISQ value in relation to the recipient jaw.

Recipient jaw	Number of values	Mean/ISQ	SD	Median	P value
Mandible	33	75.09	6.439	75.25	0.2026
Maxilla	9	72.00	5.874	73.00	[NS]*

Abbreviation: ISQ, Implant stability quotient; SD, Standard deviation; NS, Non-Significant; *, Unpaired t-test.

3.1.4 Insertion torque (IT)

In 22 DI (52.4%), the insertion torque (IT) was 35 Ncm, while in the remaining 20 DI (47.6%), an IT of > 35 Ncm was needed for the final seating of the DI.

3.1.4.1 The effect of bone density (HU) measured by CBCT on the IT

The DI that were installed with an IT > 35 Ncm demonstrated significantly higher bone density than those installed with an IT of 35 Ncm, **(Table 3.4).**

Table 3.4: The differences of the bone density (HU) measured by CBCT in relation to the IT.

Insertion torque/ Ncm	Number of values	Mean bone density/ HU	SD	Median	P value
IT= 35	22	207.4	107.7	210.5	0.0390 [S]*
IT> 35	20	270.7	81.5	263.0	

Abbreviation: HU, Hounsfield unit; IT, Insertion torque; SD, Standard deviation; S, Significant; *, Unpaired t-test.

3.1.4.2 Correlation of the insertion torque and the primary stability ISQ values

There was a non-significant difference in the primary stability ISQ values between the DI that were installed with an IT= 35 Ncm and those installed with an IT > 35 Ncm, **(Table 3.5)**.

Table 3.5: Correlation of the insertion torque and the primary stability ISQ values.

Insertion torque/ Ncm	Number of values	Mean/ISQ	SD	Median	P value
IT= 35	22	78.93	5.319	77.00	0.2785 [NS]*
IT> 35	20	80.30	5.265	82.75	

Abbreviation: IT, Insertion torque; ISQ, Implant stability quotient; SD, Standard deviation; NS, Non-Significant; *, Unpaired t-test.

3.1.4.3 Correlation of insertion torque and the secondary stability ISQ values

There was a non-significant difference regarding the secondary stability ISQ value between the DI that were installed with an IT= 35 Ncm and those installed with an IT > 35 Ncm, **(Table 3.6)**.

Table 3.6: Correlation of insertion torque and the secondary stability ISQ values.

Insertion torque/ Ncm	Number of values	Mean/ISQ	SD	Median	P value
IT= 35	22	73.55	6.403	73.50	0.4194
IT> 35	20	75.15	6.323	75.75	[NS]*

Abbreviation: IT, Insertion torque; ISQ, Implant stability quotient; SD, Standard deviation; NS, Non-Significant; *, Unpaired t-test.

3.1.4.4 The effect of the recipient jaw on the IT

There was a non-significant difference regarding the IT relative to the recipient jaw of DI, **(Table 3.7).**

Table 3.7: The differences of the IT in relation to the recipient jaw.

Recipient jaw	IT= 35 N/cm	IT>35 N/cm	P value
Mandible	15	18	0.1349
Maxilla	7	2	[NS]*

Abbreviation: IT, Insertion torque; NS, Non-Significant; *, Fisher's exact test.

3.1.5 Dental implant dimensions

The distribution of DI according to the dimensions is summarized in the **(Table 3.8)**.

Table 3.8: The distribution of DI according to the dimensions.

DI		Number (%)
Length/ mm	8	9 (21.4)
	10	25 (59.5)
	12	8 (19.1)
Width/ mm	3.6	12 (28.6)
	4	21 (50)
	4.5	9 (21.4)

Abbreviation: DI, Dental implant.

3.1.5.1 The effect of DI widths on the primary and secondary stability ISQ values

There was a significant difference between various widths of DI in relation to their primary ISQ values (p=0.0004), **(Table 3.9)** and **(Figure 3.6).**

Tukey's multiple comparisons test demonstrated that DI with a 4.5mm width had a significant higher primary stability than DI with 3.6 and 4 mm, **(Table 3.9).**

With regards to secondary stability, there was a significant difference between various widths of dental implants (p=0.0340), **(Table 3.9)** and **(Figure 3.7).**

Dunn's multiple comparisons test demonstrated that there was a significant difference present between DI widths 4.5 mm and 3.6 mm in relation to their secondary stability ISQ values, **(Table 3.9)**.

Table 3.9: Correlation of DI widths with the primary and secondary stability ISQ values.

Variables	Implant width/mm			P value	Multiple comparison test
	3.6	**4**	**4.5**		
Primary stability/ISQ					
Number of values	12	21	9		
Mean	77.79	78.14	85.33	0.0004 [S]*	3.6 vs. 4 [NS]
SD	4.361	4.879	3.072		3.6 vs. 4.5 [S]
Median	77.75	76.50	85.00		4 vs. 4.5 [S]
Secondary stability/ISQ					
Number of values	12	21	9		
Mean	71.33	74.48	77.89	0.0340 [S]†	3.6 vs. 4 [NS]
SD	5.994	6.623	4.372		3.6 vs. 4.5 [S]
Median	70.25	74.00	80.00		4 vs. 4.5 [NS]

Abbreviations: DI, Dental implants; SD, Standard deviation; ISQ, Implant stability quotient; S, Significant; NS, Non-significant; *One-way ANOVA; †, Kruskal-Wallis test.

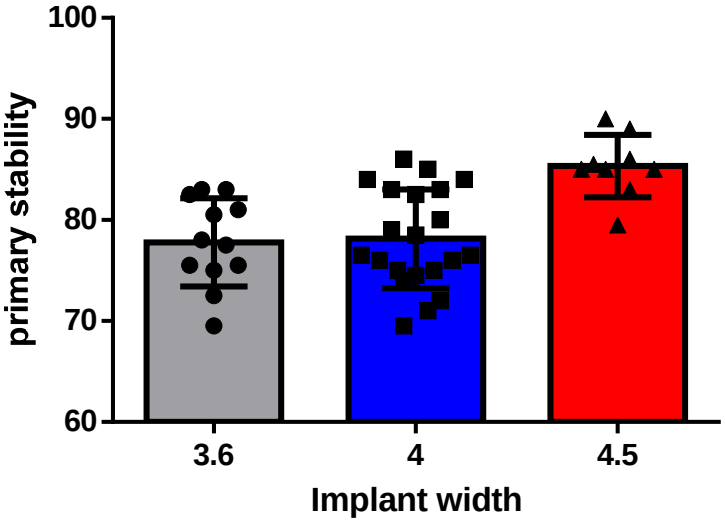


Figure 3.6: Scatter plot with bar graph showing the difference in primary stability in relation to DI width.

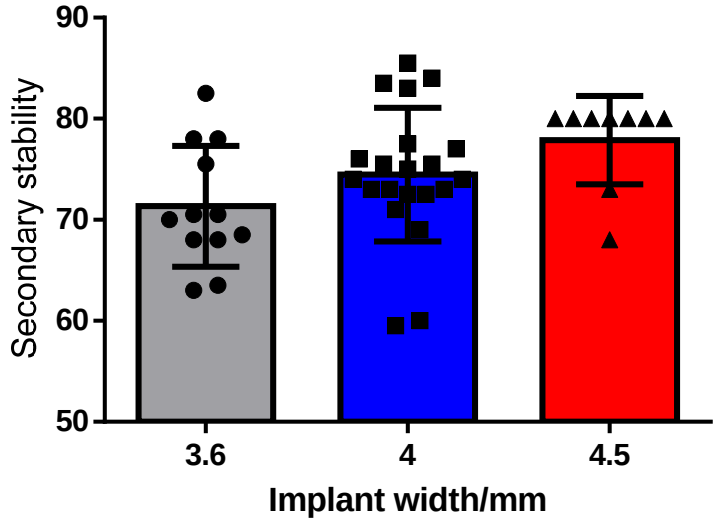


Figure 3.7: Scatter plot with bar graph showing the difference in secondary stability in relation to DI width.

3.1.5.2 The effect of DI lengths on the primary and secondary stability ISQ values

There was a non- significant difference between various lengths of dental implants in relation to their primary and secondary stability ISQ values, **(Table 3.10).**

Table 3.10: Correlation of DI lengths with the primary and secondary stability ISQ values.

Variables	Implant length/mm			P value
	8	**10**	**12**	
Primary stability/ISQ				
Number of values	9	25	8	
Mean	80.28	79.08	80.38	0.763
SD	7.041	4.92	4.56	[NS]*
Median	79.50	80.00	79.25	
Secondary stability/ISQ				
Number of values	9	25	8	
Mean	75.06	73.70	75.38	0.467
SD	6.61	6.45	6.24	[NS] †
Median	76.00	73.00	78.00	

Abbreviations: DI, Dental implants; SD, Standard deviation; ISQ, Implant stability quotient; NS, Non-significant; *One-way ANOVA; †, Kruskal-Wallis test.

3.1.5.3 The effect of DI dimensions on the Insertion torque

Regarding the IT, this study showed no significant correlation with dental implant dimensions (diameter and length), **(Table 3.11).**

Table 3.11: Correlation of Dental implant dimensions with the IT.

Implant dimensions	Insertion torque/ Ncm		P value
Diameter/mm	**35**	**> 35**	
3.6	9	3	0.1380 [NS]*
4	10	11	
4.5	3	6	
Length/mm			
8	3	6	0.4130 [NS]*
10	14	11	
12	5	3	

Abbreviation: IT; Insertion torque; NS, Non-Significant; *; Chi-square test.

3.2 Histomorphometric analysis

After excluding the distorted bone samples (n=11), 31 bone specimens were available for histomorphometric analysis, the specimens belonged to 15 patients; 9 (60%) females and 6 (40%) males.

The mean (SD) age of the patients was 45.13 (14.61) years with a range of 25-75 years and a median of 43.00 years.

So, the age was divided into 2 categories according to the median: < 50 and ≥ 50 years.

3.2.1 Descriptive statistics of the histomorphometric data of the trabecular bone

The descriptive statistics of the primary 2D measurements of the bone specimens and the descriptive statistics of the histomorphometric parameters of the trabecular bone were shown in **(Table 3.12)** and **(Table 3.13),** respectively.

Table 3.12: Descriptive statistics of the primary 2D measurements of the bone specimens.

Primary 2D measurements	Number of values	Mean	SD	Median
Total section area AT/mm^2	31	6.186	2.055	5.981
Bone area AB/mm^2	31	1.896	1.201	1.642
Bone perimeter PB/mm	31	20.73	10.10	18.62

Abbreviation: 2D, Two-dimensions; SD, Standard deviation.

Table 3.13: Descriptive statistics of the histomorphometric parameters of the trabecular bone.

Histomorphometric parameters	Number of values	Mean	SD	Median
Bone volume density BV\TV/ %	31	29.55	13.13	28.13
Bone surface fraction BS\TV/ mm^{-1}	31	4.128	2.067	3.687
Bone surface density BS\BV/mm^{-1}	31	15.44	5.968	13.73
Trabecular thickness Tb.Th/ mm	31	0.1503	0.06039	0.1457
Trabecular number Tb.N/ mm^{-1}	31	2.064	1.033	1.844
Trabecular separation Tb.Sp/ mm	31	0.3904	0.1374	0.4115

Abbreviation: SD, Standard deviation.

3.2.2 The correlation of the histomorphometric parameters of the trabecular bone with the age of the patients

Data showed that there was no significant difference in any of the histomorphometric parameters of the trabecular bone regarding the age of the patients, **(Table 3.14).**

Table 3.14: The differences in the histomorphometric parameters of the trabecular bone regarding the age of the patients.

histomorphometric parameters	Age group/ years	Number of values	mean	SD	Median	P value
Bone volume density BV/TV/ %	< 50	13	30.68	17.1	25.71	0.688 [NS]*
	≥ 50	18	28.72	9.79	29.23	
Bone surface fraction BS/TV / mm^{-1}	< 50	13	4.798	3.04	3.88	0.209 [NS]#
	≥ 50	18	3.645	0.642	3.603	
Bone surface density BS/BV/ mm^{-1}	< 50	13	17.06	6.41	15.71	0.203 [NS]*
	≥ 50	18	14.27	5.51	13.04	
Trabecular thickness Tb.Th /mm	< 50	13	0.134	0.05	0.127	0.217 [NS]*
	≥ 50	18	0.161	0.06	0.153	
Trabecular number Tb.N / mm^{-1}	< 50	13	2.399	1.52	1.940	0.209 [NS]#
	≥ 50	18	1.823	0.32	1.802	
Trabecular separation/ mm	< 50	13	0.371	0.17	0.406	0.667 [NS]#
	≥ 50	18	0.404	0.10	0.413	

Abbreviation: SD, Standard deviation; NS, Non-Significant; *, Unpaired t-test; #, Mann Whitney test.

3.2.3 The correlation of the histomorphometric parameters of the trabecular bone with the gender of the patients

Males received 13/31 (41.9%) DI, while females received 18 (58.1%) DI. There was no significant difference in any of the histomorphometric parameters of the trabecular bone regarding the gender of the patients, **(Table 3.15).**

Table 3.15: The differences of the histomorphometric parameters of the trabecular bone regarding the gender of the patients.

Histomorphometric parameters	Gender	Number of values	mean	SD	Median	P value
Bone volume density BV/TV/ %	male	13	31.40	15.05	27.55	0.513 [NS]*
	female	18	28.21	11.82	29.74	
Bone surface fraction BS/TV / mm^{-1}	male	13	3.696	1.177	3.571	0.179 [NS]#
	female	18	4.440	2.513	3.703	
Bone surface density BS/BV/ mm^{-1}	male	13	13.45	5.248	12.12	0.116 [NS]*
	female	18	16.88	6.180	14.72	
Trabecular thickness Tb.Th /mm	male	13	0.172	0.069	0.165	0.086 [NS]*
	female	18	0.1345	0.049	0.136	
Trabecular number Tb.N / mm^{-1}	male	13	1.848	0.588	1.786	0.179 [NS]#
	female	18	2.220	1.256	1.851	
Trabecular separation/ mm	male	13	0.4106	0.155	0.416	0.496 [NS]*
	female	18	0.3758	0.125	0.393	

Abbreviation: SD, Standard deviation; NS, Non-Significant; *, Unpaired t-test; #, Mann Whitney test.

3.2.4 Correlation of the histomorphometric parameters with the recipient jaws

Table 3.16: Distribution of implants according to the gender and jaws.

	Maxilla	Mandible	Fisher's exact test
Male	4	9	0.6894
Female	4	14	

Statistical analysis of the data for this study showed a significant correlation between the recipient jaw and bone surface density (p=0.0054), and also with trabecular thickness (p=0.010), while other histomorphometric parameters showed a non-significant correlation to the recipient jaw, **(Table 3.17).**

Table 3.17: The differences of the histomorphometric parameters of the trabecular bone regarding the recipient jaws.

morphometric parameters	Variables	Number of values	Mean	SD	Median	P value
Bone volume density/ %	Maxilla	8	24.49	16.37	18.08	0.087 [NS]*
	Mandible	23	31.31	11.71	31.36	
Bone surface fraction BS/TV/ mm^{-1}	Maxilla	8	4.906	3.865	3.814	0.956 [NS]*
	Mandible	23	3.858	0.88	3.687	
Bone surface density BS/BV/mm^{-1}	Maxilla	8	19.94	4.120	19.47	0.005 [S]*
	Mandible	23	13.87	5.766	12.12	
Trabecular thickness Tb.th/mm	Maxilla	8	0.104	0.024	0.102	0.01 [S]#
	Mandible	23	0.166	0.061	0.165	
Trabecular number Tb.N/mm^{-1}	Maxilla	8	2.453	1.932	1.907	0.956 [NS]*
	Mandible	23	1.929	0.44	1.844	
Trabecular separation Tb.Sp/mm	Maxilla	8	0.438	0.225	0.427	0.548 [NS]*
	Mandible	23	0.373	0.091	0.406	

Abbreviation: SD, standard deviation; NS, Non-Significant; S, Significant; *, Mann Whitney test; #, Unpaired t-test.

3.2.5 Correlation of the bone volume density and the average bone density measured by CBCT

The correlation between the bone volume density and the average bone density measured by CBCT was considered strong and statistically significant (r= 0.735, p=< 0.0001), **(Figure 3.8)**.

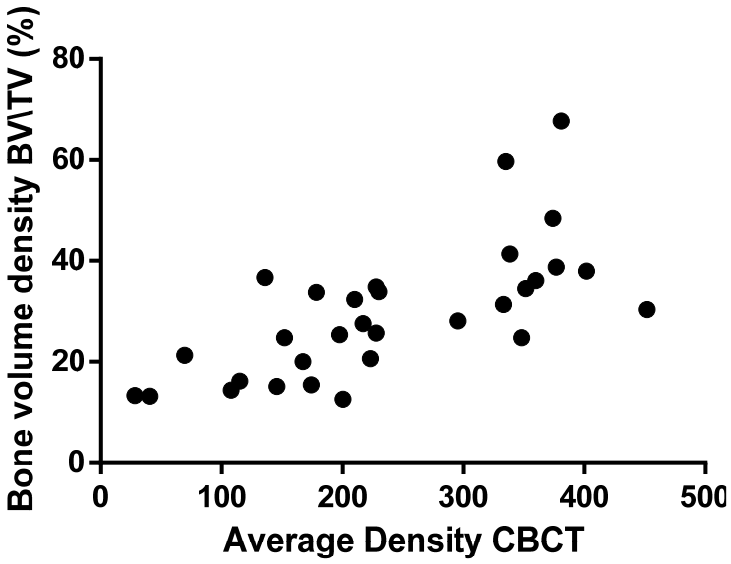


Figure 3.8: Correlation of the bone volume density (%) and the average bone density (HU) measured by CBCT.

3.2.6 Correlation of bone surface fraction and average bone density measured by CBCT

There is a weak positive correlation between bone surface fraction and average bone density measured by CBCT (r= 0.236, p=0.199), **(Figure 3.9).**

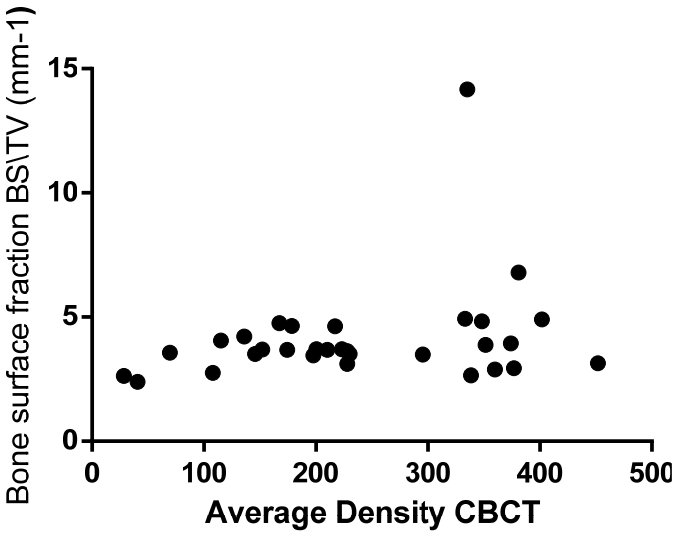


Figure 3.9: Correlation of bone surface fraction and average bone density (HU) measured by CBCT.

3.2.7 Correlation of bone surface density and average bone density measured by CBCT

There was a significant moderate inverse correlation between bone surface density BS/BV and average bone density measured by CBCT (r= -0.513, p=0.003), **(Figure 3.10).**

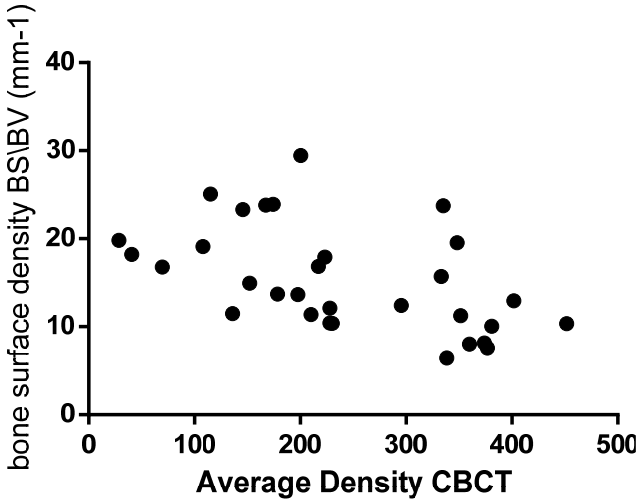


Figure 3.10: Correlation of bone surface density and average bone density (HU) measured by CBCT.

3.2.8 Correlation of the trabecular thickness and the average bone density measured by CBCT

The correlation between the trabecular thickness and the average bone density measured by CBCT is considered strong and statistically significant (r= 0.575, p=0.0007), **(Figure 3.11).**

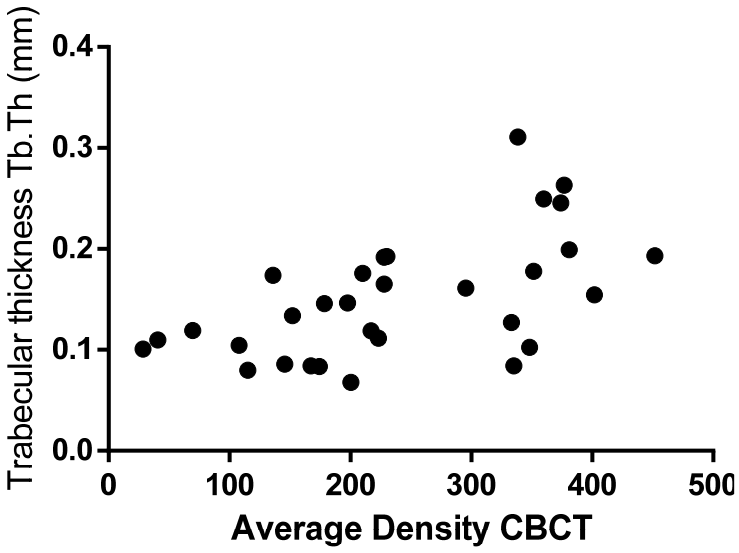


Figure 3.11: Correlation of trabecular thickness and average bone density (HU) measured by CBCT.

3.2.9 Correlation of trabecular number and average bone density measured by CBCT

There is a weak positive correlation between the trabecular number and the average bone density measured by CBCT (r= 0.236, p= 0.199), **(Figure 3.12).**

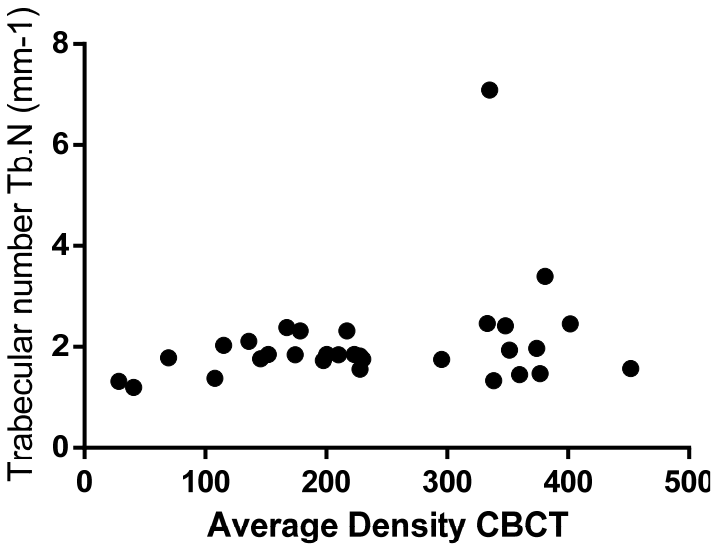


Figure 3.12: Correlation of trabecular number and average bone density (HU) measured by CBCT.

3.2.10 Correlation of trabecular separation and average bone density measured by CBCT

There is a significant moderate inverse correlation between the trabecular separation and the average bone density measured by CBCT (r= -0.585, p=0.0005), **(Figure 3.13).**

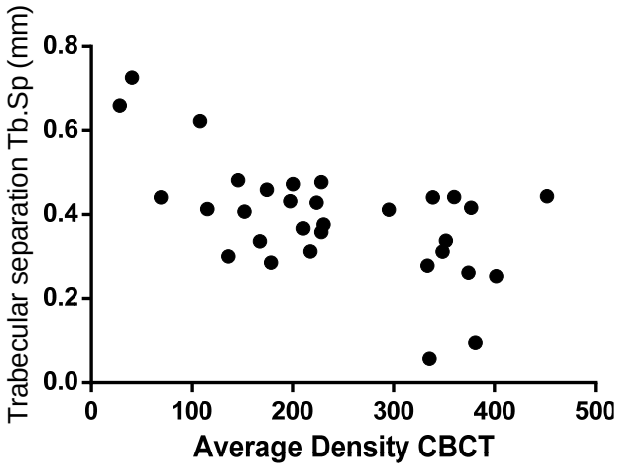


Figure 3.13: Correlation of trabecular separation and average bone density measured by CBCT.

3.2.11 Correlation of bone volume density and average primary stability

There is a weak positive correlation between bone volume density and average primary stability (r= 0.3084, p= 0.091), **(Figure 3.14).**

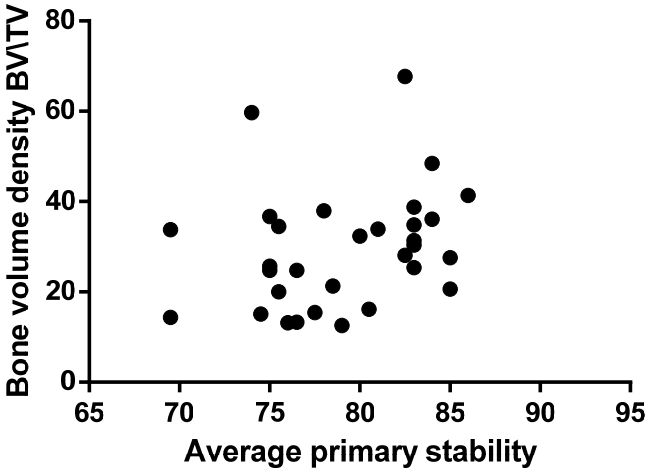


Figure 3.14: Correlation of bone volume density and average primary stability.

3.2.12 Correlation of bone surface fraction and average primary stability

Bone surface fraction showed no correlation regarding average primary stability (r= -0.148, p=0.426), **(Figure 3.15).**

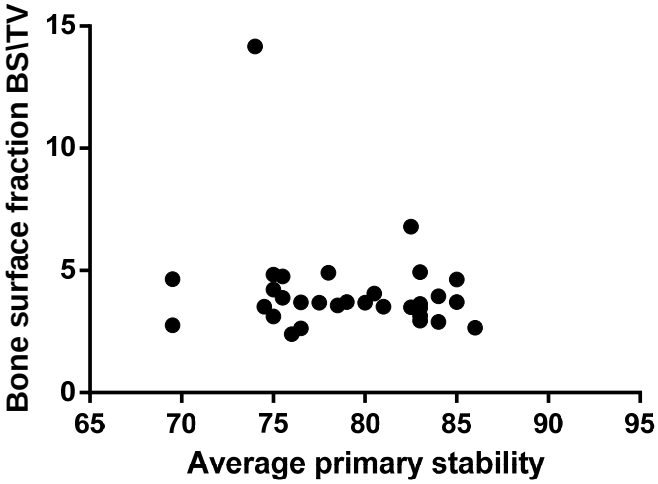


Figure 3.15: Correlation of bone surface fraction and average primary stability.

3.2.13 Correlation of bone surface density and average primary stability

Bone surface density showed a significant inverse correlation to the average primary stability (r= -0.431, p=0.015), **(Figure 3.16).**

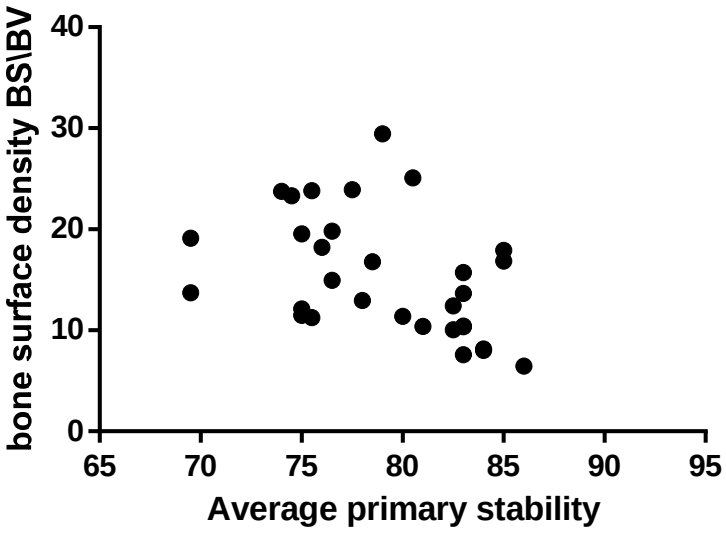


Figure 3.16: Correlation of bone surface density and average primary stability.

3.2.14 Correlation of trabecular thickness and average primary stability

Data showed a significant moderate positive correlation between the trabecular thickness and the average primary stability (r= 0.520, p=0.002), **(Figure 3.17).**

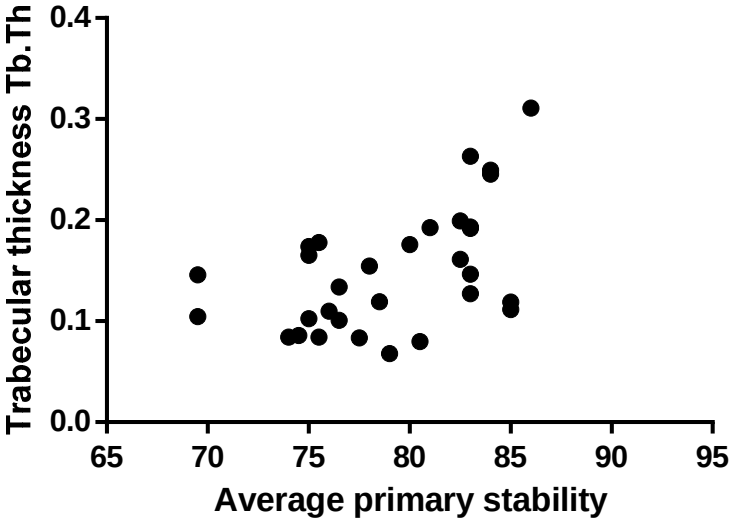


Figure 3.17: Correlation of trabecular thickness and average primary stability.

3.2.15 Correlation of trabecular number and average primary stability

No correlation was present between the trabecular number and the average primary stability (r= -0.148, p=0.426), **(Figure 3.18)**

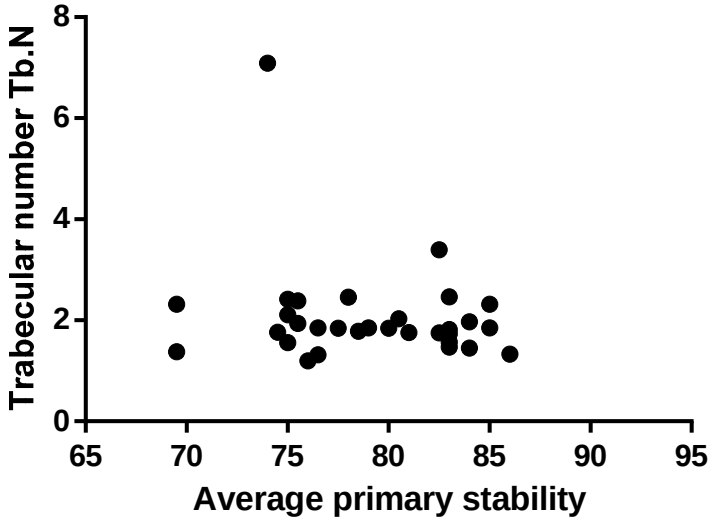


Figure 3.18: Correlation of trabecular number and average primary stability.

3.2.16 Correlation of trabecular separation and average primary stability

Trabecular separation also showed no correlation to the average primary stability (r= -0.124, p=0.504), **(Figure 3.19).**

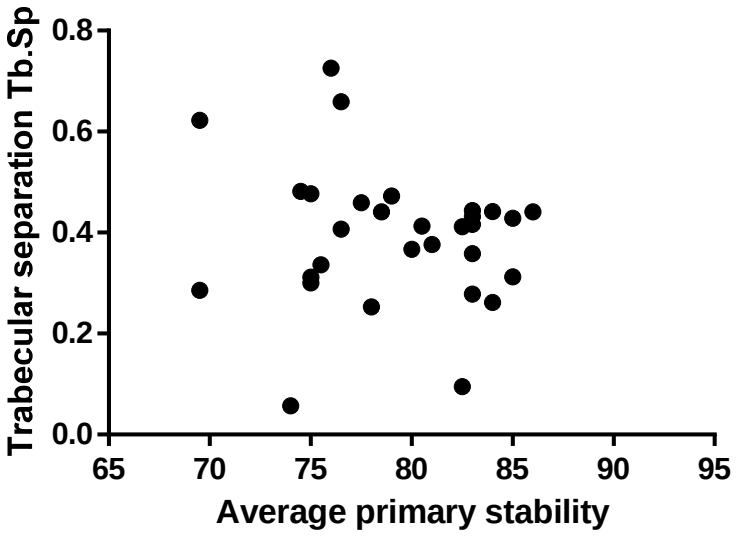


Figure 3.19: Correlation of trabecular separation and average primary stability.

3.2.17 Correlation of the histomrphometric parameters with the secondary stability

There was no significant correlation between any of the histomrphometric parameters and the secondary stability ISQ values, **(Table 3.18).**

Table 3.18: Correlation of histomrphometric parameters and the average secondary stability.

	Average secondary stability/ ISQ versus Bone volume density BV\TV/ %	Average secondary stability ISQ versus Bone surface fraction BS\TV/ mm-1	Average secondary stability/ ISQ versus bone surface density BS\BV/ mm-1	Average secondary stability/ ISQ versus Trabecular thickness Tb.Th/ mm	Average secondary stability/ ISQ versus Trabecular number Tb.N/ mm-1	Average secondary stability/ ISQ versus Trabecular separation Tb.Sp/ mm
r	-0.08178	-0.04462	-0.09150	0.2002	-0.04462	0.1923
P value	0.6619 [NS]	0.8116 [NS]	0.6245 [NS]	0.2803 [NS]	0.8116 [NS]	0.3001 [NS]

Abbreviation: NS, Non-Significant.

3.2.18 Correlation of histomorphometric parameters and insertion torque

From all the histomrphometric parameters, only the trabecular thickness showed a significant difference regarding the insertion torque (p=0.046), as shown in **(Table 3.19) and (Figure 3.20)**.

Table 3.19: Correlation of the histomorphometric parameters and the insertion torque.

Histomrphometric parameters	Variables	Number of values	Mean	SD	Median	P value
Bone volume density/ %	IT = 35 Ncm	17	28.38	15.12	24.76	0.198 [NS]*
	IT > 35 Ncm	14	30.96	10.61	33.44	
Bone surface fraction BS/TV/mm^{-1}	IT = 35 Ncm	17	4.494	2.691	3.699	0.561 [NS]*
	IT > 35 Ncm	14	3.684	0.744	3.660	
Bone surface density BS/BV/mm^{-1}	IT = 35 Ncm	17	16.80	5.232	16.79	0.166 [NS]#
	IT > 35 Ncm	14	13.79	6.569	11.90	
Trabecular thickness Tb.th/mm	IT = 35 Ncm	17	0.13	0.0416	0.119	0.046 [S]#
	IT > 35 Ncm	14	0.173	0.072	0.168	
Trabecular number Tb.N/ mm^{-1}	IT = 35 Ncm	17	2.247	1.346	1.849	0.561 [NS]*
	IT > 35 Ncm	14	1.842	0.372	1.830	
Trabecular separation Tb.Sp/ mm	IT = 35 Ncm	17	0.391	0.164	0.41	0.98 [NS]#
	IT > 35 Ncm	14	0.389	0.101	0.389	

Abbreviation: IT, Insertion torque; SD, standard deviation; NS, Non-Significant; S, Significant; *, Mann Whitney test; #, Unpaired t-test.

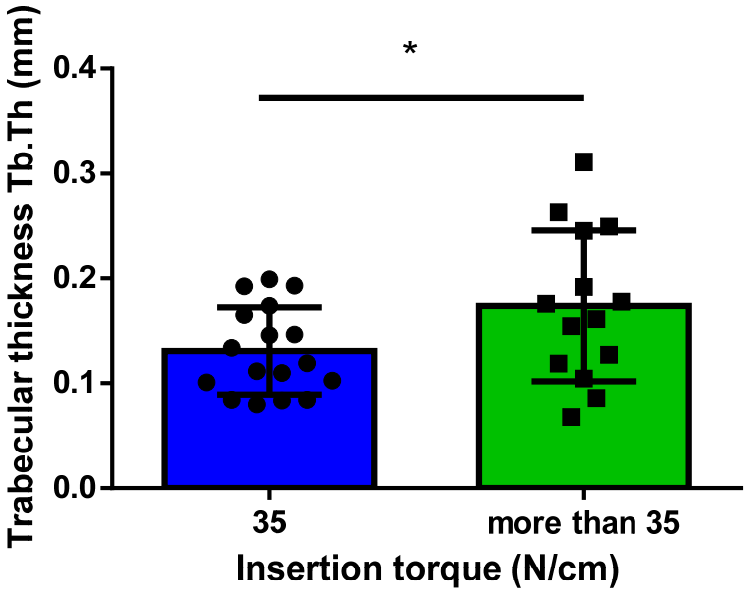


Figure 3.20: Correlation of the trabecular thickness and the insertion torque.

CHAPTER 4

DISCUSSION

DISCUSSION

4.1 The general characteristics of the study sample

In the present study, the majority of patients (58.3%) who received dental implants were females. This trend was also observed in another Iraqi study (**Hindi and Bede**, **2020**). This may be attributed to the fact that females lose their teeth more than males; since the ultimate stage of oral disease therapy sought by most females was extraction. This might be related to the social mind set in which dental treatment is seen as low priority due to its high cost (**Anand and Kuriakose**, **2009**).

The man age of the patients in this study was 47.9 years, which is about the same mean age of (46.6) years demonstrated in a recent Iraqi study concerned with the determination of the stability and marginal bone level change around early loaded SL Active implants (**Salih**, **2020**).

The majority of the implants (78.6%), in this study, were installed in the mandible. This is in accordance with a retrospective study showed that the lower teeth tended to be extracted more than the upper teeth (**Akinbami and Godspower**, **2014**).

Four mm diameter implants were the most frequently used in this study (50%) since the minimum alveolar ridge width (6mm) which was one of the inclusion criteria of this study, was adequate for the insertion of the widest implant diameter feasible in compliance with the requirement of leaving at least 1 mm of circumferential bone surrounding the implant **(Jenson *et al.*, 2017)**.

Concerning the implant length, 10 mm length implants were the most frequently used (59.5%) in this study, since the minimum available bone height required in the inclusion criteria of the present study should be no less than 10mm, and the implant length was determined using CBCT measurements of available bone height after taking into account the safety distance from any vital structures.

4.2 Bone density measured by CBCT

Bone density is a crucial element to consider whenever predicting implant stability. "A good surgical technique and good stability favors implant Osseointegration" (**Alghamdi**, **2018**).

In specific circumstances, the mineral content of the alveolus in complete or partial edentulous jaws may have diminished considerably because of disuse atrophy, increasing the risks of implant insertion into the compromised regions (**Cassetta *et al.***, **2014b**). Several studies have proposed various approaches for evaluating bone density, but all of them include measurement during implant site preparation or after implant placement (**Turkyilmaz *et al.***, **2008**).

Studies have emphasized that radiographic bone quality assessment should be an essential part of pre-surgical implant planning, because it is a commonly available and generally noninvasive way of evaluating jaw bone quality. CBCT is a popular imaging technique in dentistry. It allows for high-resolution viewing of high-contrast features of the oral area (bone, teeth, and air cavities). CBCT is increasingly used to assess bone quality, particularly for preoperative implant planning (**Pauwels *et al.***, **2015**).

There have been several trials to evaluate the possibility of converting CBCT gray values to actual density measurement. In a clinical

investigation aiming at identifying the association between gray density levels based on CT and CBCT,, the gray density values measured in the CBCT group were higher than those measured in the CT group ranging from 229 to 1,042 VV and from 167 to 989 HU, respectively (**Arisan *et al.***, **2013**). The authors stated that the cause of this occurrence was linked to numerous technical reasons such as x-ray beam hardening and scattered radiation, resulting in a reduction in the dynamic contrast of CBCT scanners when compared to multislice CT.

However, a high correlation between HU generated from multislice computed tomography (MSCT) and CBCT voxel gray values has been found, indicating that CBCT may be useful in bone density evaluation. (**Naitoh *et al.***, **2010**; **Nomura *et al.***, **2010**; **Reeves *et al.***, **2012**; **Parsa *et al.***, **2012**; **Cassetta *et al.***, **2014a**).

4.2.1 Correlation of age, gender, and recipient jaw with bone density

In this study there were no differences in bone density with respect to the age categories (divided according to the median into ≥ 50 and < 50years), and the gender of the patients which is keeping with Kim et al. (**Kim *et al.***, **2021**), who showed that there were no significant differences according to age and genders in the measured bone density (HU) in different sites of the patients jaws.

Other studies, however, reported different results in relation to age and gender, where higher bone densities were demonstrated in older individuals (**TURKYILMAZ *et al.***, **2006**; **Turkyilmaz *et al.***, **2007**; **Salimov *et al.***, **2014**), in males (**Salimov *et al.***, **2014**), or in females and younger individuals (**Fuster-Torres *et al.***, **2011**).

Dutra *et al.* (**2005**) reported that gender and dental condition have an effect on bones that are consistently undergo remodeling.

On the contrary, **Klemetti *et al.*** (**1994**) revealed that mandibular alveolar bone mineral density was impacted by masticatory muscle action rather than the gender differences.

The bone density of the mandible obtained in this study was significantly higher than that of the maxilla, which is in agreement with other studies (**Fuster-Torres *et al.***, **2011**; **Salimov *et al.***, **2014**). The differing density of the two arches may be connected to evolutionary pressure to maintain the skull suitably light; it may also come from various prenatal and postnatal development processes that the two bone structures go through. Furthermore, the variations in bone density levels and distribution between the two jaws are consistent with earlier studies suggesting that these discrepancies may be due to the mandible serving as a force absorption unit and the maxilla acting as a force distribution unit. (**Di Stefano *et al.***, **2019**).

4.2.2 Correlation of primary stability ISQ values with bone density

In this study, there was a significant positive correlation between the bone density and the primary stability ISQ values of DI. This is in accordance with the findings of other studies (**Song *et al.***, **2009**; **Merheb *et al.***, **2018**; **Al-Jamal and Al-Jumaily**, **2021**).

Researchers demonstrated that primary stability arises from the compression of bone and it is linked to the mechanical engagement of implant with the surrounding bone and it depends on the quantity and quality of local bone in addition to other factors(**STRUB *et al.***, **2012**).

Moreover, **Farré-pagès *et al.*** (**2011**) demonstrated that the stability of DI varied according to the location. They found increased primary implant stability in locations of higher bone density in the CT (HU), such as the anterior and posterior mandibular regions. As a result, the higher the HU value, the higher the primary stability as assessed by ISQ values. This finding is also supported by (**Isoda *et al.***, **2012**; **Salimov *et al.***, **2014**).

On the other hand, other study (**Youssef *et al.***, **2015**), where all the implants that installed in the mandible were radiographed by CBCT immediately post operatively and at 3 and 6 month intervals to assess the bone density around the implants, the authors indicated that there was no significant relationship between the implant stability and bone density. This variation among studies may be explained by different study designs and small sample size (10 implants) included, that were placed in only one site of the jaw (posterior mandible), and the fact that primary stability depends, beside bone quality and density, on other factors such as the surgical protocols, implant types, diameters, and various designs (**Ryu *et al.***, **2014**).

4.2.3 Correlation of secondary stability ISQ values with bone density

In this study, there was no correlation observed between the bone density and the secondary stability of DI. This is in agreement with (**Youssef *et al.***, **2015**). Secondary stability is considered as a biological stability which depends mainly on bone remodeling and formation of new bone on the implant surface during the healing phase (osseointegration) (**Quesada García *et al.***, **2009**).

4.2.4 Correlation of insertion torque with bone density

In this study, insertion torque showed a significant correlation with bone density; DI that were installed with an IT > 35 Ncm demonstrated significantly higher bone density than those installed with an IT of 35 Ncm. This finding is in keeping with the results of other studies(**Salimov *et al.***, **2014**; **Hakim *et al.***, **2019**).

Insertion torque is commonly thought to be a factor to consider when assessing the suitability of primary stability (**Ribeiro-Rotta *et al.***, **2014**; **Wentaschek *et al.***, **2015**). In clinical studies, rotational strength during insertion was found to be directly related to primary implant stability. Nevertheless, Extremely high insertion torque levels may over-compress the cortical bone, resulting in early marginal bone loss (**Marconcini *et al.***, **2018**), whereas low insertion torque values could impede early healing and bone-to-implant interface quality (**Makary *et al.***, **2012**). To avoid micro-movements, a torque of 25 to 50 Ncm is recommended (**Trisi *et al.***, **2009**).However, (**Farré-pagès *et al.***, **2011**) stated that they cannot predict the implant insertion torque based on the bone density values (HU).

The variations of these findings regarding the correlation between bone density and insertion torque values could be due to the various methods used to collect the bone density and insertion torque data, among different studies.

4.3 Implant stability ISQ values

Meredith *et al.* (**1996**) stated RFA is a method that may be used as a research tool and is beneficial in assessing the implant behaviour in surrounding tissue. Also, **Jaramillo *et al.*** (**2014**) reported that RFA

technologies in Osstell® Mentor and Osstell® ISQ provide nearly perfect reproducibility, repeatability, and precision.

In this study, the correlation of the secondary stability and the primary stability showed a weak positive correlation. Despite the fact that the mean ISQ value recorded in secondary stability measurement was considered high, there was a significant decrease in the secondary stability in relation to the primary stability. This is in accordance with (**Gómez-Polo *et al.***, **2016**), where they found that primary and secondary stability values were not closely correlated. They claimed that increased primary stability does not imply increased secondary stability. Conversely, higher primary ISQ values tended to drop over time, whilst lower values tended to rise.

Nedir et al. (2004), in their study, observed that ISQ values ≥ 70 decreased by about 5 ISQ values after 3 months from DI placement. This might be attributed to the mechanical relaxation and/or bone remodeling as a response to the presumably high stresses induced by implant placement (**Andersson *et al.***, **2008**).

However, this result is in disagreement with the findings of other studies (**Huwiler *et al.***, **2007**; **Youssef *et al.***, **2015**), in which the mean ISQ values tended to rise over the different observation periods during the integration and healing phase of the implants.

The variations among these results may be due to different types, designs and surface treatment of DI used in these studies, which were reported to have a significant influence on the bone of low density (**Glauser *et al.***, **2007**).

In this study, DI installed in the mandible demonstrated significantly higher primary stability ISQ values than those installed in the maxilla. This agree with (**Farré Pagés *et al.***, **2011**; **Salimov *et al.***, **2014**), and it may be

explained by the fact that the mandible is characterized by denser bone than the maxilla (**Di Stefano *et al.***, **2019**). This was also reflected by the fact that bone density recorded in this study was significantly higher in the mandible than the maxilla.

Secondary stability, on the other hand, demonstrated a non-significant association relative to the recipient jaw, which concords with (**Gómez-Polo *et al.***, **2016**), who stated that regardless of bone type, the progressive development of bone surrounding the implant associated with secondary stability compensates for any differences in mechanical anchoring primary stability.

4.4 Insertion torque (IT)

The most commonly used methods for assessing primary implant stability are IT and RFA (**Lozano-Carrascal *et al.***, **2016).** The link between these methods is poorly understood in the literature. The downside of IT is that it can only be measured once, at the moment of implant placement, whereas RFA may be utilized during the whole implant treatment phases (**Levin**, **2016**).

However, some authors demonstrated that in clinical practice, the IT is still a simple and accurate metric for assessing the primary stability of DI (**Degidi *et al.***, **2013**).

In this study, there was a non-significant difference in primary stability ISQ values between the DI that were installed with an IT of 35 Ncm and those installed with IT > 35 Ncm. This coincides with (**Degidi *et al.***, **2012**), where they reported that IT and RFA appeared as two independent features of primary stability. This view was also supported by a systematic review (**Lages *et al.***, **2018**), were the authors concluded that

regardless of the implant dimensions and protocol used in the previous studies, there was no relationship between the two methods of assessing primary stability, it proposed that the two values should be assessed separately, because a high torque does not always imply a high ISQ and vice versa.

The plausible explanation could be due to the relaxation that would take place immediately after implant insertion. This can have an effect on both ISQ and bone implant contact measurements. Furthermore, it is well understood that both ISQ and bone contact measurements may be influenced by the viscoelastic nature of the bone and possibly simultaneous relaxation that occurs directly after implant placement (**Açil *et al.***, **2017**).

However, other studies (**Farré-pagès *et al.***, **2011**; **Gómez-Polo *et al.***, **2016**), reported a significant relationship between IT and primary stability ISQ values, indicating that a higher IT predicts greater primary ISQ values.

In this study, there was no relation between secondary stability and IT of DI. This finding is in a line with (**Gómez-Polo *et al.***, **2016**), and can be attributed to the fact that bone remodeling and bone apposition on DI surface (osseointegation) that occurs during the healing period may reduce the effect of implant IT.

A non-significant difference regarding IT was obtained relative to the recipient jaw of DI. This concords with (**Farré-pagès *et al.***, **2011**), where they found no statistically significant differences according to different jaws locations. They observed only a slight trend of IT increase in the mandible than in the maxilla (42.34 and 40.22 Ncm, respectively).

On the other hand, **Salimov *et al.*** in **2014** indicated higher IT values for DI placed in the mandible when compared to the maxilla.

4.5 The effect of dental implant dimensions on implant stability

In this study, wider DI were associated with significantly higher primary stability ISQ values. This is supported by other studies (**Salimov *et al.***, **2014**; **Kim *et al.***, **2017**),they demonstrated that increased primary stability ISQ values in implants with greater widths, may arise from increased contact area between the bone and the implant surface. Also wider DI demonstrated significantly higher secondary stability compared to narrower implants used in this study, this was also observed in another study (**Gómez-Polo *et al.***, **2016**).This observation can be explained by the fact that wider DI can potentially engage a larger amount of the Osseo-integrated interface.

On the other hand, other studies (**Veltri *et al.***, **2014**; **Ivanova *et al.***, **2021**) found no difference regarding the effect of DI diameter upon secondary stability ISQ values.

With respect to the relation of insertion torque with the DI width, the results of this study are in contrast to other studies (**Salimov *et al.***, **2014**; **Gómez-Polo *et al.***, **2016**), that reported higher insertion torque values were associated with greater diameters of DI. This in line with other study, using conical implants, demonstrated that no significant difference was found between diameter (3.75 mm or 4.2 mm) and insertion torque (**Lozano-Carrascal *et al.***, **2016**).

In this study, DI length demonstrated no significant effect on implant stability ISQ values (primary and secondary) or insertion torque, which is in keeping with other studies (**Gómez-Polo *et al.***, **2016**; **Hakim *et al.***, **2019**), yet in contrast with (**Hong *et al.***, **2012**), who reported a significant difference in insertion torque values in relation to the DI length.

4.6 Histomorphometric analysis

In the periimplant healing phase, the trabecular bone tissue is regarded to be the most significant (**Davies**, **2003**). So, studying trabecular bone microarchitecture is critical for understanding its mechanical competency (**Chappard *et al.***, **2008**), and its impact on the outcome of dental implant therapy (**Ribeiro-Rotta *et al.***, **2014**).

Histomorphometry has long been regarded as the gold standard for analyzing bone microarchitecture (**Chappard *et al.***, **2005**). However, micro CT has been proposed as another standard reference method due to its excellent resolution and accuracy for both 2D and 3D analyses of bone structure, as well as it is faster than histomorphometry (**Chappard *et al.***, **2011**). Nevertheless, some studies reported that histomorphometry and micro CT provide complementary information regarding jawbone microarchitecture, but the poor agreement between the methods warned that their results should not be used interchangeably (**Dias *et al.***, **2015**).

In this study, the demineralization approach and paraffin embedding were employed to analyze bone tissue; as was demonstrated in the searched literature, no evidence was observed that the demineralization process could significantly alter histomorphometric results, especially in such a tiny sample size as was utilized in the current study (**Dias *et al.***, **2015**).

Histomorphometric analysis is not without limitations, of these is the distortion of bone sample, either during harvesting or during preparation in the laboratory, in this study 11 (26.1 %) bone specimens became distorted, and were subsequently discarded, leaving 31 specimens for histomorphometric analysis. Distortion of bone specimen was also reported by other studies (**Wang *et al.***, **2017**) where 12/50 sample (24%) were also discarded due to distortion leaving 38 specimens for analysis with μ-CT.

4.6.1 Correlation of the histomorphometric parameters with the recipient jaws

In vivo evaluation of bone microarchitecture in the human maxilla and mandible may aid in understanding its impact on bone strength and whether or not it can cause changes in the implant-bone interface following loading (**Rebaudi *et al.***, **2004**). Furthermore, bone tissue microarchitecture is one parameter determining "bone quality," which is still considered to be connected to clinical outcomes of implant stability and implant longevity (**Aksoy *et al.***, **2009**; **Gomes de Oliveira *et al.***, **2012**).

Analysis of the data for this study showed that the trabecular thickness were significantly higher in the mandible than in the maxilla, and this is in agreement with (**Blok *et al.***, **2013**), who scanned alveolar bone specimens at different regions of both the maxilla and the mandible derived from ten dentate human cadavers using high resolution microCT, they indicated that trabecular thickness were significantly higher in the mandible than in the maxilla.

However, another study showed a little variation regarding trabecular thickness among different bone quality categories derived from alveolar bone biopsies of the maxilla and the mandible taken from 30 human cadavers (**Lee *et al.***, **2017**).

Also, in this study bone surface density was significantly more in the maxilla than in the mandible. This is in accordance with other authors , who observed higher mean values of bone surface density in D4 type of bone quality (**Lee *et al.***, **2017**). Additionally, other study recorded the highest mean value of bone surface density in the posterior maxilla among other regions in both jaws (**Kim *et al.***, **2013**).

This association of bone surface density with jaw areas that are characterized by low bone density can be explained by the fact that less dense bone has a rod/ sphere-like pattern trabeculae, and higher surface area, therefor, a greater bone surface density (**Gomes de Oliveira *et al.***, **2012**).

Other histomorphometric parameters in this study showed a non-significant correlation to the recipient jaw, which is in agreement with (**Kim *et al.***, **2013**), who reported no significant differences present among bone volume density, trabecular number, and trabecular separation with regards to different sites in both jaws.

On the other hand, other researchers reported that bone volume density, trabecular number, trabecular separation varied significantly among different bone quality categories (**Lee *et al.***, **2017**). The authors stated that bone quality depended on trabecular separation and number rather than bone surface and trabecular thickness.

4.6.2 Correlation of histomorphometric parameters with the average bone density measured by CBCT

The results of this study showed that the bone density measured by CBCT correlated positively with bone volume density and trabecular thickness while there was a negative correlation with bone surface density and trabecular separation.

These findings are in line with a recent study (**Kim *et al.***, **2021**), that compared trabecular bone density measurement in HU with trabecular microstructure parameters using CBCT obtained from 58 patients. The authors demonstrated significant positive correlations found between bone

volume fraction, trabecular thickness, trabecular number and bone density HU measured by CBCT, while trabecular separation was negatively correlated to the HU. They concluded that it was preferable to employ trabecular thickness, trabecular number, and trabecular separation when evaluating the structural properties of trabecular bone, and they believed that the measure of bone volume density or HU is for evaluating overall bone. Another study assessed the accuracy of CBCT in evaluating trabecular bone density using MSCT and micro-CT, respectively, as reference gold standards (**Parsa *et al.***, **2015**). The researchers demonstrated strong correlations between CBCT and MSCT density measurements (r = 0.89) and between CBCT and micro-CT bone volume density measurements (r = 0.82). Additionally, radiographic gray scale density as determined by CBCT in another clinical study was shown to be positively correlated with bone volume density (r = 0.8350) and also significantly correlated with trabecular separation (r = –0.535), whereas, no significant correlations were reported regarding bone surface density, trabecular thickness, and trabecular number as determined by micro CT analysis of 38 bone specimens harvested from posterior mandible (**Wang *et al.***, **2017**).

Moreover, other authors (**Blok *et al.***, **2013**) reported a significant positive correlation linked between bone density and trabecular thickness of alveolar bone specimens that were obtained from the mandible and maxilla of ten human cadavers and scanned with a high-resolution micro CT system. They suggested that trabecular thickness and bone volume density may be predictive of implant osseointegration success.

4.6.3 Correlation of histomorphometric parameters with primary implant stability ISQ values

Regarding the correlations between the trabecular bone morphometric parameters and the primary implant stability in this study, the data showed a significant moderate positive correlation between the trabecular thickness and the average primary stability ISQ values. This is in agreement with the findings of other study (**Kang *et al.***, **2016**), the authors of this study found a significant positive correlation between trabecular thickness and primary stability of DI placed into swine bone specimens as measured by impact response frequency.

Moreover, other researchers reported a significant correlation of the trabecular thickness around the entire implant with the primary stability ISQ values of DI placed into 21 hemimandible bones of human cadavers (**Pauwels *et al.***, **2017**).

Conversely, in another study (**Ribeiro-Rotta *et al.***, **2014**) utilizing a micro CT device to analyze 46 alveolar bone biopsies harvested from different sites of the maxilla and the mandible of 32 partially edentulous volunteers, poor or no correlation was present between primary stability ISQ values with 3D bone microarchitecture.

However, in this study, bone surface density showed a significant negative correlation with the average primary stability ISQ values, this is in accordance with other authors who demonstrated that the implant stability would increase when bone surface density is decreased as the bone had thick trabeculae or a plate-like trabecular pattern (**Gomes de Oliveira *et al.***, **2012**; **Kang *et al.***, **2016**).

In this study, the bone volume density showed a weak positive correlation in relation to the average primary stability ISQ values. This is in

agreement with previous studies (**Roze *et al.***, **2009**; **Ribeiro-Rotta *et al.***, **2014**) that made similar observations, yet in contrast to other studies that demonstrated a significant positive correlation between bone volume density and primary ISQ values (**Kang *et al.***, **2016**).

No significant correlations were observed in this study among bone surface fraction, trabecular number, and trabecular separation with the primary stability ISQ values. This is in accordance with other previous studies data (**Roze *et al.***, **2009**; **Ribeiro-Rotta *et al.***, **2014**).

4.6.4 Correlation of histomorphometric parameters with insertion torque

With respects to the insertion torque in this study, only the trabecular thickness showed a significant difference, where higher IT value correlated with increased trabecular thickness. This correlation seems to be reasonable, since it was clearly reported that one of the crucial factors that might affect IT was the bone quality of the recipient site (**Goswami *et al.***, **2015**), and as was observed in this study, trabecular thickness correlated positively with the bone density measured by CBCT, hence increasing IT was proportional to the increase of the trabecular thickness.

This finding is in keeping with (**Arsan *et al.***, **2021**), who observed that trabecular thickness measured by CBCT was significantly correlated to the insertion torque of DI placed into fresh bovine blocks.

Additionally, other authors explored the effect of bone micromorphology on primary intra-osseous stability of DI placed into anterior and posterior regions of completely edentulous maxilla and mandible of human cadaver. They concluded that IT was significantly

correlated with trabecular thickness and trabecular number and trabecular separation (**Akça *et al.***, **2006**).

In contrast to these findings, other study demonstrated that there was no significant correlation between any bone structure parameter and insertion torque around the entire DI (**Pauwels *et al.***, **2017**).

4.6.5 Correlation of histomorphometric parameters with secondary implant stability ISQ values

In this study, no significant correlation between any of the bone histomorphometric parameters and the secondary stability ISQ values was recorded. This is in line with a previous study (**Ribeiro-Rotta *et al.***, **2014**) that reported no correlation was present between micro-CT 3D bone microstructure parameters and uncovering ISQ values (secondary stability).

A possible explanation is that the secondary stability is a biological phenomenon not related to the structural characteristics of bone that are more associated with the mechanical primary stability (**Quesada García *et al.***, **2009**).

4.7 Limitations of the study

- The main limitations of this study that might have affected the generalizations obtained are mainly related to the small sample size involved, which mainly resulted from the restrictions and the lockdown imposed in association with COVID 19 pandemic during the conduction of this study, this had a major impact on obtaining a larger sample size. The number of bone specimens obtained was further reduced by the

distortion associated with harvesting or during histological processing of the specimen.

- Clinically, dental implant sites could not be matched precisely with the radiographic planned implant sites on CBCT, because surgical guides were not being used in this study.

CHAPTER 5

CONCLUSIONS AND SUGGESTIONS

CONCLUSIONS AND SUGGESTIONS

5.1 Conclusions

Within the context of this study's limitations, it is possible to conclude that:

1) The findings of this study indicate that CBCT may be considered as useful preoperative method to assess bone density and predict the implant stability, and so detecting the proper surgical procedure that should be followed, choosing the appropriate type and designs of dental implant (DI), and finally taking the right decision regarding the immediate or delay time of loading of the dental implant.

2) With regard to the DI dimensions in this study, the diameter of DI showed a significant correlation with both the primary and secondary stability ISQ values, but no significant difference was noted in relation to the insertion torque.

For the various lengths of DI utilized in this study, no significant difference was observed with any of the implant stability parameters namely, the ISQ values and the insertion torque values.

3) The histomorphometric parameters that significantly correlated positively with the bone density measured by CBCT were the bone volume density and trabecular thickness, while bone surface density and trabecular separation demonstrated negative correlations.

The primary stability of dental implant (ISQ values, insertion torque values) correlated significantly positively with the trabecular

thickness and primary ISQ values correlated negatively with bone surface density.

Regarding secondary stability, no significant correlation between any of the bone histomorphometric parameters and the secondary stability ISQ values was recorded.

4) The above findings confirmed that the combination of bone density and structure can be considered as important predictors for dental implant stability.

5.2 Suggestions

1. Conducting similar study with a larger sample size and longer follow up period.
2. Conducting similar study using micro CT for the assessment of trabecular bone microstructure parameters, and assess the correlations with the histomorphometric findings.
3. Further studies might be conducted to allow for the development of morphometric criteria for evaluating the bone quality requisite for osseointegration to occur and to withstand the loading pressures caused by mastication.
4. Conducting further studies using immunohistochemistry tests to evaluate the bone forming cells activity, and its relation with osseointegration and secondary stability assessment.

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APPENDICES

APPENDICES

Appendix I

College of Dentistry – University of Baghdad

Ethical Approval Application Form

Project title: Evaluation of bone quality and density in human jaw bone and their effects on the stability of dental implant.		
Researcher's Name	**Degree**	**Affiliation**
1. Ali Tareef Noaman	**B.D.S., M.Sc.**	**Oral and maxillofacial surgery department**
2.		
3.		
4.		
5.		
Date to start: 1 .6. 2019	**Expected Date to finish: 1 .3. 2021**	

	Yes	**No**	**N/A**
Is there any conflict of interest?		✓	
Will the investigators receive funding from any organization? If **Yes** please specify		✓	
Will financial recompense be offered to participants?		✓	
Will the study take place inside the institution? If **No** please specify	✓		
Is the sample size adequate for the study?	✓		
Will the investigators inform the participants that their participation is voluntary?	✓		
Will the investigators obtain written consent for participation?	✓		
Will the investigators obtain permission from parents or legal guardians?	✓		
Will the investigators inform the participants that they may withdraw from the research at any time and for any reason?	✓		
Will the investigators ensure the anonymity of participants and confidentiality of data	✓		

Does the study involve potentially vulnerable groups: children, pregnant women, prisoners, handicapped, mentally disabled or educationally or economically disadvantaged people?		✓	
Could the study induce pain, psychological stress, discomfort, anxiety or cause harm or negative consequences beyond the risks encountered in normal life? If **Yes** please specify		✓	
Will the investigators be prepared to terminate the study at any stage if they believe that the continuation of the study will result in injury, disability or death of the subject?	✓		
Will the participants receive a placebo or undergo a sham surgery?		✓	
Will tissue samples (including blood) be obtained from participants?	✓		
Will the study involve prolonged or repetitive testing?	✓		
Will the study be performed by qualified scientific personnel?	✓		

N/A Not applicable

	Name	**Signature**	**Date**
Applicant	Ali Tareef Noaman		
Supervisor (if applicable)	Assist. Prof. Dr. Salwan Y. Bede		
Chairman of Scientific Committee	Assist. Prof. Dr. Sahar Shakir Al-Adili		
Head of Department	Assist. Prof. Dr. Sahar Shakir Al-Adili		

Notes:

Please include the protocol and the patient information sheet and concent form.

العدد: ٣٦
التاريخ: ١٠ /١/ ٢٠١٩
رمز البحث: ٠٣٦١١٨

م/ قبول بحث

إلى الزميل الدكتور **علي طريف نعمان** المحترم
والزميل الدكتور **سلوان يوسف** المحترم

نود اعلامكم بأن لجنة اخلاقيات البحوث في كلية طب الأسنان – جامعة بغداد اطلعت على مشروع البحث المقدم من قبلكم والموسوم:

The **Evaluation of bone quality and density in human jaw bone and their effects on the stability of dental implant.**

ولا ترى اللجنة ما يمنع من القيام بالبحث من الجانب الاخلاقي.

مع التقدير.

د. أكرم فيصل الحويزي
رئيس لجنة اخلاقيات البحوث

University of Baghdad
College of Dentistry

Research Ethics
Committee

Ref. number: 36

Date: 10/1/2019

Decision of the Research Ethics Committee

Dear Dr. Ali Tareef Noaman

Dr. Salwan Y. Bede

Research title: Evaluation of Bone Quality and Density in Human Jaw Bone and their Effects on the Stability of Dental Implant

Protocol reference number: 036118

I am pleased to inform you that the research ethics committee gave a favorable ethical opinion for the above research on the basis of the following submitted items that have been received and reviewed by the committee:

- ✓ Application form and checklist.
- ✓ Study protocol.
- ✓ Patient information sheet and consent form (Arabic version).
- ✓ Patient information sheet and consent form (English version).

Prof. Dr. Akram F. Alhuwaizi

Chairman of the Research Ethics Committee

Email: ethical.approval@codental.uobaghdad.edu.iq

Appendix II

College of Dentistry – University of Baghdad

Patient Information Sheet

You are invited to participate in a scientific research **In Oral and Maxillofacial Department**. Please take your time to read the following information carefully before you decide whether or not you wish to participate. You can ask for clarifications or any more information about the study from the researcher and you can discuss this with outsiders.

Information about the research (to be written by the researcher in a simple language answering the following questions when applicable)

1. Study title: **Evaluation of Bone Quality and Density in Human Jaw Bone and their Effects on the Stability of Dental Implant.**

2. What is the purpose of this study? **Assess the stability of the dental implants (primary and secondary stability) in different bone types i.e. bone quality and density.**

2. Where will the study be conducted? **University Of Baghdad/ Dentistry College.**

3. What are the procedures to be followed and what will you be asked to do at each visit? **Nothing other than routine dental implant procedure.**

4. How long will the participation in the study last? **Four months only.**

5. If you decided to take part in the study, will the treatment be different from the treatment you would get otherwise? **No.**

6. Who should not enter the study? **No specific exclusion criteria.**

7. What will be the benefits of the study?
   a) To the participant? **Achieve high success rate for dental implants in the future.**
   b) To the investigator? **Adding further knowledge and understanding of the factors that affect the success rate of the dental implants.**

8. What are the possible risks of taking part? **No expected risks present.**

9. If you feel severe discomfort or pain during the study, would you be able to take any relief medication? **Yes.**

10. Will your participation in the study interfere with your daily activities? **No.**

11. Will you be informed of the results of the study? **Yes, if you want.**

If you agree to participate in this study, we will ensure your confidentiality with no one except the study researchers have the right to access your dental (medical) notes.
Participation in this study is entirely voluntary and you are free to refuse to take part or to withdraw from the study at any time without having to give a reason and without this affecting your future medical care or your relationship with medical staff looking after you.

Thank you for reading this Information Sheet and considering your participation in this study

Consent Form

	Please tick to confirm
I confirm that I have read and understood the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.	
I understand that my participation is voluntary and that I am free to withdraw at any time without any medical/dental care affected.	
I understand that relevant sections of my medical notes and data collected during the study may be looked at by individuals from the College of Dentistry – University of Baghdad where it is relevant to my taking part in this research. I give permission to these individuals to have access to my records.	
I agree to take part in the above study.	

Regarding any information and records taken during the research please specify your acceptance to share them as you desire:					
	Personal data	X-rays	Extra-oral photographs	Intra-oral photographs	Others
Confidential					
For consultation					
For teaching					
For conferences					
For publication					

	Name	**Signature**	**Date**
Participant			
Parent/guardian (if appropriate)			
Person taking consent			

Person to contact:

Name:

Phone No.:

Email:

1 copy for the participant; 1 copy for the researcher

كلية طب الأسنان جامعة بغداد

إستمارة معلومات المريض

أنت مدعو(ة) للمشاركة في بحث علمي سيجرى في **فرع جراحه الفم والوجه والفكين** الرجاء أن تأخذ(ي) الوقت الكافي لقراءة المعلومات التالية بتأن قبل أن تقرر(ي) إذا كنت تريد(ين) المشاركة أم لا. بإمكانك طلب إيضاحات أو معلومات إضافية عن أي شيء مذكور في هذه الاستمارة أو عن هذه الدراسة ككل من الباحث كما يمكنك مناقشتها مع أي شخص آخر.

معلومات عن البحث (يجب أن تكتب من قبل الباحث بلغه بسيطه مجيبة عن الأسئله التاليه قدر الإمكان)

1. عنوان الدراسة: **تقييم نوعيه وكثافه عظم الفك للانسان وتاثيرات ذلك على ثباتيه زرعات الاسنان**.
2. ما هو الغرض من هذه الدراسة؟ **محاوله التنبؤ بثباتيه زرعات الاسنان في عظم الفك للانسان.**
3. أين سوف تجرى الدراسه؟ **جامعه بغداد \ كليه طب الاسنان**.
4. ما هي الإجراءات التي يجب اتباعها وما الذي سيطلب مني القيام به في كل زيارة؟ **لاتوجد اي متطلبات اضافيه عن الاجراءات الروتينيه المتبعه في عمليات زراعه الاسنان .**
5. إلى متى ستستمر مشاركتي في الدراسة؟ **لمده اربعه اشهرفقط**.
6. إذا قررت المشاركة في الدراسة، هل سيختلف العلاج عن العلاج الذي سأحصل عليه بخلاف ذلك؟ **كلا.**
7. من يجب أن لا يدخل في الدراسة؟ **لا يوجد اي استثناءات خاصه بالبحث.**
8. ماذا ستكون فوائد الدراسة:

(أ) لطفلك او لك ؟ **الحصول على نسبه نجاح عاليه لعمليات زراعه الاسنان مستقبلا.**

(ب) للباحث ؟ **فهم وادراك اوسع للعوامل التي تؤثر على نجاح عمليات زراعه الاسنان في الفك.**

9. ما هي المخاطر المحتملة للمشاركة؟ **لاتوجد اي مخاطر محتمله خاصه بالبحث.**
10. عندما اشعر بعدم راحة أو ألم أثناء الدراسة، هل سأتمكن من تناول اي دواء مهدئ؟ **نعم.**
11. هل ستتداخل مشاركتي في الدراسة مع أنشطتي اليومية؟ **كلا.**
12. هل سأبلغ بنتائج الدراسة؟ **نعم في حال رغبتك بذلك.**

في حال وافقت على المشاركة في هذه الدراسة، سيبقى اسمك طي الكتمان. لن يكون لأي شخص، ما لم ينص القانون على ذلك، حق الاطلاع على ملفك الطبي باستثناء الباحثين المسؤولين عن الدراسة.
تعتبر المشاركة في هذه الدراسة تطوعية تمامًا وأنت حر(ة) في رفض المشاركة أو الانسحاب من الدراسة في أي وقت دون الحاجة إلى إعطاء سبب ودون أن يؤثر هذا على الرعاية الطبية المستقبلية أو علاقتك مع الطاقم الطبي الذي يعتني بك.

نشكرك على قراءة ورقة المعلومات هذه والنظر في مشاركتك في هذه الدراسة

موافقة للإشتراك في بحث علمي

	الرجاء التأشير للموافقة
أؤكد بأني قد قرأت وفهمت المعلومات التي تخص البحث أعلاه وقد كان لدي الوقت الكافي لطرح الأسئلة المتعلقة بالموضوع وتمت الإجابة على أسئلتي جميعا.	
أتفهم أن مشاركتي في البحث تطوعية وأني حر(ة) في الإنسحاب من المشاركة في أي وقت بدون أن يؤثر ذلك على الرعاية الطبية المقدمة لي.	
أتفهم أن معلوماتي ذات الصلة بالبحث سوف يتم الإطلاع عليها من قبل الإشخاص المسؤولين عن البحث في كلية طب الأسنان – جامعة بغداد وأعطي الموافقة بذلك.	
أوافق على المشاركة في البحث المذكور أعلاه.	

فيما يتعلق بأي معلومات أو بيانات تأخذ خلال البحث، يرجى تحديد موافقتكم على نشرها حسب رغبتكم					
	بيانات شخصيه	أشعه	صور الوجه	صور الفم	أخرى
تبقى سريه					
لغرض الأستشارات					
لغرض التعليم					
في المؤتمرات					
لغرض النشر في المجلات العلميه					

	الإسم	**التوقيع**	**التأريخ**
المشترك			
الأب/الأم أو الوصي (عند الحاجه)			
الشخص المسؤول عن مليء الأستماره			

شخص يمكن الأتصال به:

الاسم:

رقم الهاتف:

البريد الإلكتروني:

1 نسخه للمشترك، 1 نسخه للباحث

Appendix III

University of Baghdad - College of Dentistry
Department of Oral & Maxillofacial Surgery

Study case sheet

Personal data

Name: Age:
Gender: Occupation:
Phone number: Date: / /

No

Medical history:……

Medications _____ Allergy_____

Social habits:

Smoking Alcohol Others

Parafunctional habits: Bruxism Clenching

Clinical examination:

Extraoral examination:

Facial symmetry TMJ Lymph nodes

Intraoral examination:

- Oral hygiene: Good Fair Poor
- Intercoronal distance of the recipient implant site
- Inter-arch distance
- Inter-incisal distance at maximum opening

Jaw treated: **maxilla** **mandible** **both**

Tooth (teeth No. site)

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
32	**31**	**30**	**29**	**28**	**27**	**26**	**25**	**24**	**23**	**22**	**21**	**20**	**19**	**18**	**17**

Radiographic examination (CBCT):

The width of the bone at the planned implant site

Available bone height at the planned implant site

Pre-operative bone density assessment of planned implant site

Tooth No. site	Average\ HU	Standard deviation (SD)

Surgical procedure:

Number of DI placed

Dental implant dimensions

Insertion torque:

Primary stability:

Tooth No. site	Mesiodistal\ ISQ	Buccopalatal/buccolingual\ ISQ	Mean

Follow up (2nd stage surgery):

Secondary stability (16 weeks postoperatively)

Tooth No.	Mesiodistal\ ISQ	Buccopalatal/buccolingual\ ISQ	Mean

Histomorphometric data

Primary measurements (2D)	
Total area (AT)\ mm^2	
Bone area (AB)\ mm^2	
Bone perimeter (PB)\ mm	
Histomrphometric parameters (3D)	
Bone volume density BV\TV\ %	
Bone surface fraction BS\TV\ mm^{-1}	
Bone surface density BS\BV\ mm^{-1}	
Trabecular thickness Tb.Th\ mm	
Trabecular number Tb.N\ mm^{-1}	
Trabecular separation Tb.Sp\ mm	

Abbreviations: 2D, Two dimensions; 3D, Three dimensions.

الخلاصة

الخلفية: لقد ثبت أن جودة العظام السنخية في موقع زراعة الأسنان لها تأثير كبير على النجاح أو الفشل العظمي للزرع ، حيث يكون خطر فشل الزرع مرتفعًا نسبيًا عندما تكون جودة العظام رديئة. يمكن أن يساعد الفحص الإشعاعي قبل الجراحة لجودة العظام في التنبؤ باستقرار الغرسة الأولية وتوجيه اختيار بروتوكول التحميل قبل وضع الغرسة في منطقة محددة.

الهدف من هذه الدراسة هو تقييم ثبات غرسات الأسنان (الثبات الأولي والثانوي) في أنواع العظام المختلفة, أي جودة العظام وكثافتها.

المواد وطرق العمل: شملت هذه الدراسه 24 مريضا خضعوا لـ 42 عملية زراعة أسنان. تم توفير 31 عينة عظمية لتحليل القياس النسيجي لـ 15 مريضاً. تم قياس كثافة العظام في موقع الزرع المخطط له قبل الجراحة باستخدام CBCT. تم حصاد عينة العظام باستخدام اداة التنقيب (قطر خارجي 3.2 مم وقطر داخلي 2.5 مم). تم قياس ثبات الغرسة باستخدام Osstell® ISQ. تم تسجيل قيم حاصل استقرار الغرسة (ISQ) فورًا بعد الجراحة (الاستقرار الأولي) وبعد 16 أسبوعًا (الاستقرار الثانوي). تم تصنيف قيمة عزم االأدخال على أنها 35 نيوتن سم أو> 35 نيوتن سم. تم تثبيت عينات العظام، ونزع الكالسيوم منها ، وتقطيعها طوليًا إلى شرائح 5 ميكرومتر ، وتصبيغها بتقنيات الهيماتوكسيلين / إيوسين. تم إجراء القياسات باستخدام برنامج ImageJ. تم قياس المعلمات المورفومترية للعظام التربيقية بما في ذلك كثافة حجم العظام ، ونسبة سطح العظام ، وكثافة سطح العظام ، وسمك التربيق ، وعدد التربيق ، والفصل التربيقي.

النتائج: كان متوسط الاستقرار الأولي (الانحراف المعياري) ، ISQ (5.27) 79.58 والذي كان أعلى بكثير من متوسط الاستقرار الثانوي 74.31 (6.34) ISQ (p <0.0001) . كان هناك ارتباط إيجابي معتدل لكثافة العظم مع الاستقرار الأولي (r = 0.4، p = 0.0099) ولا يوجد ارتباط مع الاستقرار الثانوي (r = 0.003، p = 0.9867). كانت كثافة العظام لـ غرسات الأسنان مع مع عزم الادخال 35 نيوتن سم أقل بشكل ملحوظ من مع عزم الأدخال > 35 نيوتن سم (p=0.0390). تم تسجيل استقرار أفضل مع الغرسات الأوسع, بينما أظهر طول غرسة الأسنان علاقة غير معنوية مع (الاستقرار الأولي والثانوي) p = 0.7633 و 0.4670 على التوالي ، ومع عزم الأدخال.

فيما يتعلق بالمعلمات الشكلية للعظم التربيقي ، فإن الفك المستلم يرتبط ارتباطًا وثيقًا بكثافة سطح العظام وسمك التربيق. ترتبط كثافة العظام المقاسة بواسطة CBCT بشكل كبير مع كثافة حجم العظام ، وكثافة سطح العظام ، وسمك التربيق ، والفصل التربيقي. ارتبط عزم الإدخال بشكل كبير مع سمك التربيق. ترتبط قيم حاصل استقرار الغرسة الأولية ارتباطًا وثيقًا بكثافة سطح العظام وسمك التربيق. لم يتم الكشف عن ارتباط كبير فيما يتعلق بالثبات الثانوي.

الخلاصة: يمكن اعتبار التصوير المقطعي المحوسب طريقة موثوقة لتقييم كثافة العظام في موقع الزرع المقترح. يمكن اعتبار الجمع بين كثافة العظام التربيقية وهيكلها بمثابة مؤشرات مهمة لاستقرار الزرع.

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة بغداد
كلية طب الأسنان

تقييم جودة العظم وكثافته في عظم الفك البشري وتأثيره على استقرارغرسة السن: دراسة سريرية وأشعاعية ونسيجية

أطروحة مقدمة إلى مجلس كلية طب الأسنان / جامعة بغداد كجزء من متطلبات نيل درجة دكتوراه فلسفة في جراحة الفم والوجه والفكين

من قبل

علي طريف نعمان
بكالوريوس في طب وجراحة الفم والأسنان
ماجستير في جراحة الفم والوجه والفكين

بأشراف

أ.د. سلوان يوسف حنا
بكالوريوس في طب وجراحة الفم والأسنان
زميل المجلس العراقي للأختصاصات الطبية
جراحه الفم الوجه والفكين

1443 هـ 2022 م