BONE MINERAL DENSITY OF THE MANDIBLE AS PREDICTOR OF OSTEOPOROSIS AMONG MALAYS

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by

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LIST OF ABBREVIATIONS

AEC	Automatic Exposure Control
AI	Antegonial Index
BMD	Bone Mineral Density
CCD/CMOS	Charge Coupled Devices / Charge Metal Oxide Semiconductors
CBCT	Cone Beam Computed Tomography
CTCI	Computed Tomography Cortical Index
CTI I	Computed Tomography Mandibular Index Inferior
CTI S	Computed Tomography Mandibular Index Superior
CTMI	Computed Tomography Mental Index
DICOM	Digital Imaging and Communications in Medicine
DPA	Dual Photon Absorptiometry
DXA	Dual-energy X-ray Absorptiometry
DXL	Dual X-ray Absorptiometry and Laser
DXR	Digital X-ray Radiogrammetry
ED	Effective Dose
ESD	Entrance Surface Dose
FD	Fractal Dimension
GI	Gonial Index
GV	Gray Value
Hospital USM	Hospital Universiti Sains Malaysia
ICRP	International Commission on Radiological Protection
KAP	Kerma Area Product

LED	Light-emitting Diodes
MCI	Mandibular Cortical Index
MCT	Mandibular Cortical Thickness
MCW	Mandibular Cortical Width
MI	Mental Index
MOSFET	Metal Oxide Semiconductor Field Effect Transistors
NCRP	National Council on Radiation Protection and Measurements
OPG	Orthopantomography
PMI	Panoramic Mandibular Index
PMI I	Panoramic Mandibular Index Inferior
PMI S	Panoramic Mandibular Index Superior
PMT	Photomultiplier Tube
QCT	Quantitative Computed Tomography
QUS	Qualitative Ultrasound
ROI	Region of Interest
SEXA	Single Energy X-ray absorptiometry
SFD	Shadow Free Diagnostic
SPA	Single photon absorptiometry
TL	Thermoluminescence
TLD	Thermoluminescent Detector
WHO	World Health Organization

KETUMPATAN MINERAL TULANG MANDIBEL SEBAGAI PERAMAL OSTEOPOROSIS DALAM KALANGAN ORANG MELAYU

ABSTRAK

Hubungan antara kekuatan tulang kraniofasial dan tulang rangka lain yang berkaitan dengan osteoporosis dikaji dengan mengukur ketumpatan mineral tulang (BMD). Tujuan kajian ini adalah untuk membandingkan dan mengaitkan ketumpatan tulang rahang bawah dan tulang lain menggunakan penyerapan sinar-x dual tenaga (DXA) dan Tomografi Berkomputer Pemancar Kon (CBCT). Kepekaan TLD 100H yang didedah kepada DXA juga diuji. Untuk perbandingan nilai BMD, kepala fantom diimbas dengan protokol pemerolehan data yang berbeza dan kedudukan fantom yang berbeza untuk pemeriksaan DXA mandibel. Untuk mengkaji korelasi mandibel dengan tulang rangka lain, pesakit yang telah menjalani pemeriksaan CBCT dibawa untuk menjalani pemeriksaan DXA mandibel, tulang belakang dan tulang pinggul. Pengukuran linear kemudian dibuat pada imej CBCT pesakit. Hasil dari pengukuran imej CBCT dan keputusan dari pemeriksaan DXA diambil untuk analisis statistik. Data dianalisis menggunakan ujian-T, Korelasi Pearson, Korelasi Spearman, Kruskal Wallis dan Mann Whitney. Dapatan menunjukkan bahawa tiada perbezaan yang signifikan dalam nilai BMD apabila menggunakan protokol pemerolehan data yang berbeza dan terdapat perbezaan yang signifikan dalam nilai BMD apabila menggunakan kedudukan yang berbeza ketika mengimbas menggunakan pengimbas DXA. Kajian ini juga mendapati bahawa tidak ada korelasi yang signifikan antara BMD dari mandibel dengan tulang rangka lain dari DXA dan terdapat perbezaan yang signifikan antara ketumpatan mandibel dari CBCT dan DXA. Hubungan songsang yang kuat wujud antara indeks mandibel tomografi berkomputer inferior (CTI I) dan indeks mandibel tomografi terkomputer superior (CTI S) dengan status tulang (tulang belakang). Bagi dosimeter pendarcahaya terma (TLD), kepekaan TLD-100H berbanding TLD-100 adalah 23 kali lebih tinggi apabila didedahkan pada sinar-x radiografi umum dan 1.26 kali apabila terdedah kepada tenaga DXA. Kesimpulannya, penilaian kepadatan mandibel untuk meramal osteoporosis adalah mungkin dengan menggunakan indeks CTI I dan CTI S.

BONE MINERAL DENSITY OF THE MANDIBLE AS PREDICTOR OF OSTEOPOROSIS AMONG MALAYS

ABSTRACT

Relationship between craniofacial bone strength and other skeletal bone associated with osteoporosis were studied by measuring bone mineral density (BMD). The aim of this study is to compare and correlate the bone density of the mandible and other skeletal bone using Dual Energy X-ray Absorptiometry (DXA) and Cone Beam Computed Tomography (CBCT). The sensitivity of TLD 100H exposed to DXA also tested. For comparison of BMD value, the head phantom was scanned with different data acquisition protocol and patient positioning for mandibular DXA examination. For correlation of mandible with other skeletal bone, patient who had underwent CBCT examination underwent DXA examination of mandible, spine and hip. Linear measurement was then being made on the CBCT images of patients. The result from the measurement of CBCT image along with the result from DXA examination was taken for statistical analysis. The data was analysed using T-test, Pearson's correlation, Spearman's correlation, Kruskal Wallis and Mann Whitney. The result shows that there is no significant difference in BMD value using different data acquisition protocol and there was significant difference in BMD value using different positioning when scanning using DXA scanner. The study also found that there was no significant correlation between BMD of the mandible and other skeletal sites from DXA and significant difference was found between density of the mandible from CBCT and DXA. A strong negative correlation exists between computed tomography mandibular index inferior (CTI I) and computed tomography mandibular index superior (CTI S) with bone status (spine). As for TLD, sensitivity of TLD-100H

compared TLD-100 was about 23 times higher when exposed to general radiography x-ray and 1.26 times when exposed to DXA energy. In conclusion, the evaluation of mandibular density to predict osteoporosis is possible using CTI I and CTI S indices.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Bone is one of the hardest structures in the human body. This structure supports the weight of the body, allow for body movements, and protect internal organs. Each bone of the body serves a particular function and vary in size, shape, and strength based on the functions. Bone density is the amount of bone in a volume and it is measureable by measuring the bone mineral density (BMD) (Sozen et al., 2017). There are a number of different ways to measure BMD; dual-energy x-ray absorptiometry (DXA), dual photon absorptiometry (DPA), quantitative computed tomography (QCT), qualitative ultrasound (QUS). Assessment of BMD is considering useful and even necessary, in many clinical situations such as in oral and systemic diseases, implant planning, therapeutic evaluation and follow-up.

The normal bone metabolism, the modelling (or growth) process happened during childhood and adolescence and the remodelling process occurs throughout the life and becomes dominant when the bone reaches its peak mass (typically in early 20s). Bone growth peaks during the third decade of life and then it reduces with advancing age (Choksi et al., 2018; Kranioti et al., 2019). In women, the reduction accelerates for 5 to 10 years after menopause. Many things can affect the development of healthy bone. Genetic abnormalities, nutritional deficiencies, hormonal disorders and lifestyles can affect the formation of bone. When the bone starts to breakdown and the level of bone formation decreased, this lead to structural abnormalities to the bone and make the bone more fragile. If this process progressed more than normal, it could lead to osteopenia and osteoporosis.

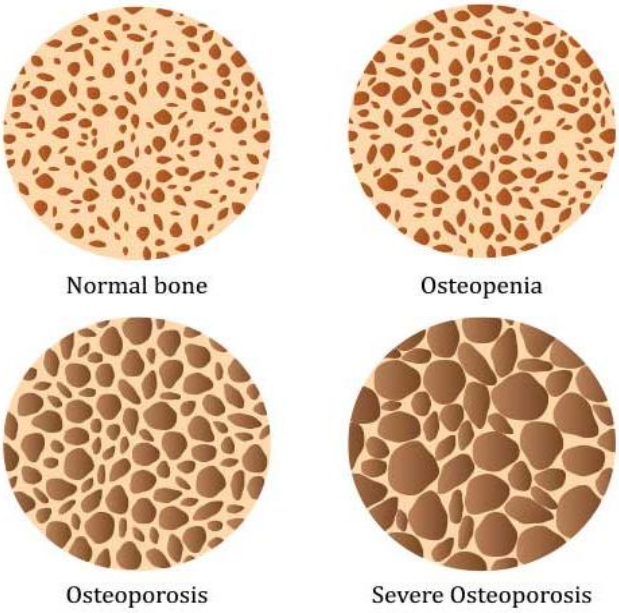

Figure 1.1: Differences between normal, osteopenia, osteoporosis and severe osteoporosis bone (Karim, 2019)

Osteoporosis is defined as a skeletal disorder characterised by compromised bone strength predisposing a person to an increased risk of fracture (Malaysian Osteoporosis Society, 2015). Osteoporosis occurs in all populations and at all ages. It is a silent disease without any symptoms in most patients until fractures occurred. The clinical diagnosis of this disease is done by observing the fractures in bones that formed with little trauma that occurred due to a reduction in bone mineral density (Cakur et al., 2009). Osteopenia is a condition where there are some bone loss and bones are subsequently weaker, but not sufficient to be considered osteoporosis (Australian Institute of Health and Welfare, 2019). An individual who has developed osteopenia is not necessarily progress to have osteoporosis, but they have greater risk of doing so. The difference between normal bone, osteopenia, osteoporosis and severe osteoporosis is shown in Figure 1.1.

Osteoporosis related fractures have been recognised as a major health problem in the elderly (Cheung et al., 2018). Similar to trends in many countries such as India (Mithal et al., 2014); Singapore (Wang et al., 2019); China, Japan, Taiwan and Hong Kong (Cheung et al., 2016)) with increasing life expectancy, Malaysia is projected to have a rising number of elderly individuals. The common sites of fracture are the spine, wrist and hip. Hip fractures are associated with high morbidity and a mortality rate of up to 20% in the first year.

Osteoporosis remains under-diagnosed and undertreated in Malaysia and the prevalence is not well known or documented other than from the 1997 study on hip fractures (Malaysian Osteoporosis Society, 2015). The report also had reported that in 1997, the incidence of hip fracture in Malaysia among individuals age above 50 years was 90 per 100,000. There was a noticeable growth in the incidence among the older age group. The incidence of hip fracture is consistently higher in women. In Malaysian community, the highest incidence of hip fractures was among Chinese compared to the Malays and Indians. Chinese women accounted for 44.8% of hip fractures. The inpatient hospital cost for hip fractures in 1997 was projected to be RM22 million (Malaysian Osteoporosis Society, 2015).

The gold standard for the diagnosis of osteoporosis is the measurement of BMD using DXA, which is measured at the hip and lumbar spine (Borga et al., 2018; Choksi et al., 2018). DXA system either use switched-pulse dual-energy system (the x-ray tube potential is switched rapidly between 100 and 140 kVp alternating at 60 per second) or filter and split the spectrum system (dual energy x-ray beam is produced by placing a metal filter in the beam to split the spectrum into high and low energy parts) to scan the image. When a human body is scanned by x-ray, it produces two-dimensional image on the film. The human body is not a homogeneous absorber. It comprises different component such as fat mass, lean mass and bone. A single energy x-ray beam cannot discriminate among the different components. For this, dual energy x-ray technique was utilised. BMD measurement using DXA has countless clinical significance in the early detection and diagnosis of osteoporosis. X-ray absorption is the basic mechanism for discrimination between organs in a body under x-ray observation.

World Health Organization (WHO) defines osteoporosis in postmenopausal women and men age 50 years and older on the basis of the BMD value shown in Table 1.1 (Choksi et al., 2018). From the BMD values measured in DXA examination, the system automatically calculates the T-score and Z-score. T-score is the value that shows how much the individual bone mass differs from the bone mass of an average healthy 30-year-old adult. T-score value is applied for the BMD measurement of postmenopausal women and men aged 50 years and older. The Z-score is the value that compares the individual bone density to the average bone density of people the same age and gender. Z-score is the value which usually used for children, premenopausal women, and men younger than age 50 years old. Typically, the Z-scores of -2 or lower are considered to be below the expected range for particular age.

Table 1.1: WHO classification of osteoporosis based on BMD values from DXA.

Bone Condition	Classification of DXA value
Normal	BMD > –1.0 standard deviation (SD) of young adult reference range (T-score > –1.0)
Osteopenia	BMD between -1.0 SD and - 2.5 SD below the young adult mean (–1.0 > T-score > – 2.5)
Osteoporosis	BMD < - 2.5 SD of the young adult mean (T-score < – 2.5)
Severe/ Established Osteoporosis	BMD < - 2.5 SD of the young adult mean with the presence of 1 or more fragility fractures

WHO: World Health Organization, BMD: Bone Mineral Density, DXA: Dual Energy X-ray Absorptiometry, SD: standard deviation.

1.2 Mandible and Bone Assessment in Dentistry

Mandible or lower jaw is the biggest, strongest and lowest bone in the human facial skeleton (Standring et. al, 2016). The mandible sits beneath the maxilla. It is the only movable bone of the skull and it is connected to the temporal bone by the temporomandibular joint. The mandible consists of a horizontal body (anteriorly) and two vertical rami (posteriorly). The body and the rami meet on each side at the angle of the mandible.

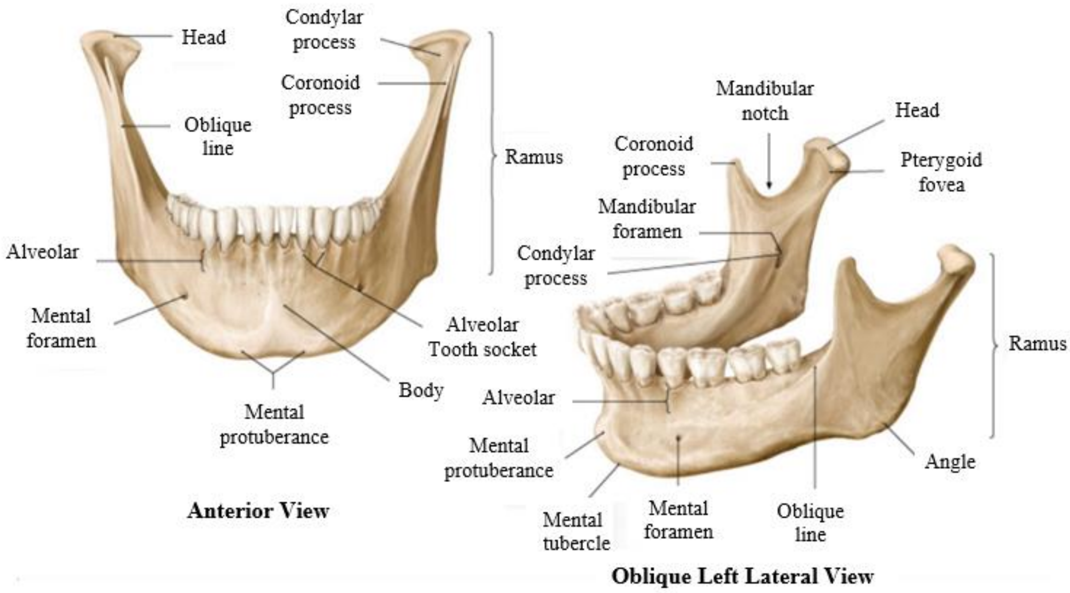

Figure 1.2: Anatomy of mandible in anterior view and oblique left lateral view (adapted from Standring et al., 2016).

The body of the mandible is curved, and shaped like a horseshoe with two borders; alveolar border (situated superiorly) serve to hold the lower teeth and base (situated inferiorly) as the site of attachment for the digastric muscle medially. The body is marked in the midline by the mandibular symphysis (mentum) (this is a small ridge of bone that represents the fusion of the two halves during development). The symphysis encloses a triangular eminence; the mental protuberance, which forms the shape of the chin. Lateral to the mental protuberance is the mental foramen (situated below the second premolar tooth on either side). It acts as a passageway for mental nerve and vessels structures. A foramen refers to any opening through which the neurovascular structures can pass through.

There are two mandibular rami, which project perpendicularly upwards from the angle of the mandible. Each ramus contains head and neck of condyle and coronoid process. Condylar head is situated posteriorly, and articulates with the temporal bone to form the temporomandibular joint. Neck of the condyle supports the head of the condyle, and site of attachment of the lateral pterygoid muscle. For coronoid process, it serves as the site of attachment of the temporalis and masseter muscles. The internal surface of the ramus is marked by the mandibular foramen, which acts as a passageway for inferior alveolar nerve and vessels. The neurovascular bundle travel through the mandibular foramen, into the mandibular canal, and exit at the mental foramen. Figure 1.2 shows the anatomy of mandible in anterior view and oblique left lateral view.

In dentistry, many procedures made are related to bone. To make diagnosis or to plan the treatment, the bone must be assessed. There are many bone assessment tools have been used to diagnose diseases and to plan treatment. The most frequent way to assess bone is through radiographic x-ray examination. There are three types of x-ray examination in dentistry; intraoral examination, orthopantomography (OPG) or panoramic examination and cone beam computed tomography (CBCT).

The use of noninvasive methods to determine bone quality is crucial. In dentistry, the methods ranging from morphometric methods to advance imaging methods are in progress to find the practical method to be use in clinical practice. The practical method will enable the early detection of disease related to bone such as osteoporosis from the mandible. The radiomorphometric indexes was commonly applied to assess jaw bone (Devlin and Horner, 2002; Geary et al., 2015). Through this application, linear measurement (measurement of distance or length between two point) and visual evaluation of cortical bone in mandible were utilised. The radiomorphometric indexes that had been used includes the following; mandibular cortical index (MCI), a visual evaluation method, antegonial index (AI), gonial index (GI), mental index (MI) and panoramic mandibular index (PMI).

Other than radiomorphometric indexes, the radiographic gray scale also has been utilised. It is a practical unit that represents the relative deviation of the measured linear attenuation of a material from that of water. Current CBCT units do not use a standard scaling system fractal dimension (FD) analysis method. This method base on the idea that bone strength also depends on bone structure and morphology. This is a mathematical method that identify the complex shapes and structural models that provides numerical results.

1.3 Radiation Dose

Radiation is always present around us. In fact, our life has progressed in a world contain significant levels of ionising radiation. This radiation comes from naturally occurring radiation like from ground, space and even within our bodies. Apart from natural background radiation, the radiation exposure also comes from manmade radiation; commercial and industrial activity radiation and medical exposure.

Numerous radiation dose parameters are used in diagnostic radiology, the most commonly used are absorbed dose and effective dose (ED). Absorbed dose, expressed in grays (Gy), is a measure of the energy per unit mass deposited in the tissue and organs of the body. The ED, expressed in Sieverts (Sv), is calculated from absorbed doses and tissue weighing factor of the organ or tissue exposed to x-rays. Appropriate weighting factors related to radiogenic risk for body organs and tissues have been published by the International Commission on Radiological Protection (ICRP). The ED was introduced to allow estimation of radiogenic risks when various organs receive different levels of doses.

The dose measured can be used to establish dose reference level (DRL). There are a few dosimetric quantities that can be used in establishing the DRL; entrance surface dose (ESD), incident air kerma, kerma area product (KAP) and peak skin dose. The Ministry of Health Malaysia had prepared the guide 'Malaysian Diagnostic Reference Levels in Medical Imaging (Radiology)' in accordance to regulation 54 in Atomic Energy Licensing Regulation (Basic Safety Radiation Protection). Respective medical institutions are encouraged to obtain local data in their setup in order to compare with the national DRLs. DRLs from the survey for dental and bone densitometry are presented in the Table 1.2 below.

Table 1.2: Recommended DRLs for dental radiology and BMD (Kementerian Kesihatan Malaysia, 2013).

Examination Type	**DRL**
Intraoral	3.18 mGy (based on ESD)
Panoramic	0.016 $mGy.m^2$ (based on KAP)
AP Spine	0.5 mGy (in ESD)
L/R Hip	0.6 mGy (in ESD)

1.4 Dosimeter for Dose Measurement

Dosimeter is a device that measures exposure to ionising radiation. It has two main functions; for human radiation protection and for measurement of the dose in medical and industrial processes. For human radiation protection, workers exposed to radiation, such as radiographers, nuclear power plant workers, doctors using radiotherapy and those in laboratories using radionuclides are required to wear the dosimeters. By doing this, an occupational exposure record can be prepared.

To serve its function, radiation dosimeters must exhibit several desirable characteristics. The desirable dosimeter properties are characterized by accuracy and precision, linearity, dose or dose rate dependence, energy response, directional dependence and spatial resolution. The precision of dosimetry measurements specifies the reproducibility of the measurements under similar conditions. High precision is associated with a small standard deviation of the distribution of the measurement results. The accuracy of dosimetry measurements is the proximity of their expectation value to the ‘true value’ of the measured quantity. Ideally, the reading of dosimeter should be linearly proportional to the dosimetric quantity. However, beyond a certain dose range, a non-linear proportion sets in. The linearity range and the non-linearity behavior of dosimeter depend on the type of dosimeter and its physical characteristics.

Another desirable characteristic of dosimeters is the independent to the dose rate. The response of a dosimeter at two different dose rates should remain constant. The dosimeter also should be independent of energy over a certain range of radiation qualities. The variation of the response of a dosimeter with radiation quality requires correction. The angle of incidence of radiation also varies the response of dosimeter. This variation of response is due to their construction details, physical size and the energy of the incident radiation. The ideal dosimeter also should allow the determination of the dose from a very small volume. However, not all dosimeters can satisfy all characteristics. The choice of a radiation dosimeter and its reader must therefore be made judiciously, taking into account the requirements of the measurement situation.

There were a few common types of dosimeters for ionising radiation which includes electronic personal dosimeter (EPD), MOSFET dosimeter, film badge dosimeter, thermoluminescent dosimeter (TLD) and optically simulated luminescence (OSL). TLD have been used for dosimetry of ionising radiation for nearly 100 years. The variety of materials and their different physical forms allow the determination of different radiation qualities over a wide range of absorbed dose (from µGy to several Gy). The main advantages of TLD are their small physical size and free of cables or auxiliary equipment is required for the dose measurement. Some of the TLD material also was tissue equivalent.

1.5 Problem Statement

DXA is a gold standard for measuring density of the bone, but there is no standard data acquisition protocol and patient positioning for measuring bone density of the jaw using DXA machine. The standard data acquisition protocol and patient positioning was not established for jaw because jaw is not the type of the bone that directly related to osteoporosis. For the purpose of scanning mandible using DXA, researchers had used different available data acquisition protocol and patient positioning. Author believed that, there is no study yet has been done to compare the BMD value of the jaw measured using different data acquisition protocol and different patient positioning. The aim of this study is to compare the BMD value (of the jaw bone) measured using two different data acquisition protocols and patient positioning (posteroanterior (PA) and lateral position) using DXA Hologic Discovery A.

With reference to previous study on jaw bone, many had studied the correlation between BMD of the spine and femurs to the BMD of the jaw, however, the result is contradicted. Factors such as geographic, races or ethnic, and lifestyle may contribute to this. In Malaysia, the study on the BMD of the jaw bone and its correlation to BMD of other skeletal site that related to osteoporosis have not been done yet. The aim of this study is to find the correlation between the BMD of the mandible and BMD of the spine and hip which is used to diagnose osteoporosis among Malays. The Malay race was chosen as it was the majority population in Malaysia.

Many dental radiographic indices had been used to assess jaw bone density including panoramic and CBCT. Panoramic images usually suffer from superimposition, unequal magnification, and geometric distortion. Therefore, linear measurements obtained from panoramic images always have inherent limitations. Factors such as differences in technical equipment and patient positioning will affect the magnification ratio on panoramic radiographs. In contrast to panoramic images, CBCT images allow three-dimensional visualization of dentomaxillofacial structures without superimposition, magnification or distortion, thus enabling an accurate measurement on CBCT images. This study done to evaluate the agreement of the measurement from these two techniques.

In radiation field, among an important thing discussed is the radiation dose. If the dose is very low, another concern was about the suitable radiation detector for measuring dose. DXA is one of the low radiation dose examination. The study regarding the dose to the patient and staff during DXA examination had been done using various types of TLD. However, to obtain an integrated dose well above the minimum detectable threshold dose of certain types of TLD, multiple exposures were necessary; up to few hundreds of exposures (Blake et al., 2006; Boudousq et al., 2003). The dose range for the vertebra and hip DXA examination is up to 1.16 mGy (Ministry of Health Malaysia, 2009) thus need high sensitivity dosimeter. TLD-100H (the material consists of Lithium Fluoride activated with magnesium, copper and phosphorus) is 10 to 35 times more sensitive than the conventional TLD-100 (the material consists of Lithium Fluoride activated with magnesium and titanium). It also has a lower energy response in kilo-voltage energy ranges (DeWerd et al., 1983; Wu et al., 1984; Azorin et al., 1990). Thus, this study aims to find the sensitivity of TLD-100H in DXA energy range.

1.6 Significance of Study

It was believed that the dedicated scan type protocol for the mandible or jaw is not yet available in any DXA machine from any manufacturer. The manufacturer also did not provide any standard patient positioning for mandibular DXA. This study was done to evaluate the difference between available scan type and patient positioning on their analysis results. A few combinations of scan type and positioning were applied to the phantom to evaluate this before the technique applied on patient. The DXA machine used in this study was one of the latest DXA machine available on the market.

The correlation between the dental radiographic indices and density of other skeletal sites (spine and femur) and bone status will provide the early detection on low bone density. As the patients with dental problems tend to consult the dentist regularly, dentists are in a good position to help identify people with low bone density and to encourage them to talk to their doctors about their bone health. Based on this result, the role of dentist in early detection of osteoporosis can be highlighted. Apart from that, knowledge about jaw regions with low bone density may assist in treatment planning and determination of dental implant prognosis.

By comparing the measurement value from different sources of image (panoramic and CBCT), this will provide the knowledge on the agreement of measurement from panoramic compared to CBCT.

1.7 Objectives

1.7.1 General

The general objective of this study is to investigate the BMD of the jaw bone, spine and hip and its relationship with osteoporosis among Malay and TLD sensitivity in DXA exposure.

1.7.2 Specific

The specific objectives for this study are:

1. To validate and compare the value of BMD of the jawbone using DXA with different positioning and data acquisition protocol in phantom.
2. To determine the correlation between BMD of the jaw bone and the spine and hip using DXA among Malays.
3. To compare and correlate bone density from DXA and CBCT.
4. To compare and correlate between CBCT indices and panoramic indices.
5. To determine sensitivity of TLD-100H in DXA exposure.

1.8 Thesis outline

This thesis is about the bone mineral density of the mandible to predict osteoporosis among Malay. The thesis contains six chapters includes; introduction, literature review, materials and methods, results, discussion and conclusion. Chapter one is introduction chapter. It covers about background of study, mandible and bone assessment in dentistry, radiation dose, dosimeter for dose measurement, problem statement, significance of study and objectives of the current works. In chapter two, it gives a liturature review on BMD and DXA, jaw and osteoporosis, and radiation dose. In chapter three, the materials and methods was explained. In this chapter, the equipment and tools used and methods of research have been described with the aid of flowcharts and diagrams. The types of test used for statistical analysis also explained in this chapter. Chapter four contains the result of the study. The result was presented in tales and graphs.Chapter five discuss the results obtained from the study. Chapter six concludes the ovjectives of the study.

CHAPTER 2

LITERATURE REVIEW

2.1 BMD and DXA

Bone density or bone mineral density is the amount of bone tissue in a certain volume of bone (g/cm^3) (Chaudhary et al., 2019). It reflects the strength of bones, the higher the mineral content, the denser and stronger the bone is. In clinical medicine, bone density measurement is a useful tool for diagnosis. It was done to assess the condition of bone and used as indirect indicator of osteoporosis and fracture risk. However, this parameter only provides information regarding the quantity of minerals in bone, which is only one component of bone strength. Treatments for reduction of bone density give beneficial effects on bone turnover, microarchitecture, and mineralization, which help for the reductions in fracture risk above and beyond changes in BMD.

There are various types of BMD tests that are non-invasive. Most tests differ according to which bones to be measured to determine the BMD result. These tests include, Dual-energy X-ray absorptiometry (DXA), Single Energy X-ray absorptiometry (SEXA), Dual X-ray Absorptiometry and Laser (DXL), Quantitative computed tomography (QCT), Quantitative ultrasound (QUS), Single photon absorptiometry (SPA), Dual photon absorptiometry (DPA) and Digital X-ray radiogrammetry (DXR). DXA is currently the most widely used and had been considered as a gold standard for measuring bone density (Borga et al., 2018; Choksi et al., 2018). The DXA test works by measuring a specific bone or bones, usually the spine, hip and wrist. The results of the bone density are computed by proprietary software base on the attenuation pattern of x-ray striking the detector. The scan images obtained are only for confirming the correct positioning of the patient and correct placement of the regions of interest (ROI) and not to be used for diagnosis. The density of these bones is then compared with an average index based on age and sex. The final results are obtained in terms of standard deviation from the normal. The resulting comparison is used to determine the risk for fractures and the stage of osteoporosis in individual. The average bone mineral density of normal individuals is around 3.88 g/cm^2 in males and 2.90 g/cm^2 in females. Individuals with a BMD below than 1.0 g/cm^2 need special care. The BMD of the spine region is ranging from 1000 to 1200 g/cm^2. The range of BMD for the forearm is from 700 to 800 g/cm^2.

DXA is established as the reference method to measure BMD with acceptable accuracy errors and good precision and reproducibility (El Maghraoui and Roux, 2008). The WHO has established DXA as the best densitometry technique for assessing BMD in postmenopausal women based on the definitions of osteopenia and osteoporosis of its results. There are a few advantages of DXA include measurement of BMD at multiple skeletal sites, short investigation time and ease of use (El Maghraoui and Roux, 2008). DXA technology can measure virtually any skeletal site, but in clinical use it has been concentrated on the lumbar spine, proximal femur, forearm and total body. It has standard data acquisition protocol for measuring BMD of lumbar spine, hip, forearm, whole body and for small animals. Each of these protocols has a different algorithm that dedicated for a specific region. The manufacturer also set a standard for patient positioning for each scan protocol. Due to its advantages, DXA also used for measuring bone density of the mandible.

DXA measurement of BMD of the jaws was first described in 1993 (Corten and Hof, 1993). Due to growth interest in measurement BMD of the jaw, researchers had carried out the study that use DXA for measurement of BMD in the mandible and maxilla (Asutay et al., 2015; Buyukkaplan et al., 2008; Gulsahi et al., 2010; Hedstrom et al., 2010; Horner and Devlin, 1998a; Horner et al., 1996; Naitoh et al., 2007; Taguchi et al., 1996). However, the standard data acquisition protocol (scan type) and patient positioning were not available for mandibular or jaw scanning in DXA system. Due to this, different available data acquisition protocol and patient positioning had been applied. Some studies positions the subject laterally (Drozdzowska et al., 2002; Esfahanizadeh et al., 2013; Estrugo-Devesa et al., 2018; Horner and Devlin, 1998a; Tonguc et al., 2012) and other position is posteroanterior (PA) position (Cakur et al., 2009). In all of these studies, they use either vertebral or forearm protocol. Kelly and Lefebvre (1993), the Principal Scientist at Hologic Company had suggested using forearm protocol for mandibular DXA scanning. The use of forearm protocol was suggested because the protocol has been optimized for bone mineral analysis in the presence of air, soft tissue, and bone which usually present in mandible scans.

Buyukkaplan and Guldag, (2012) cited that the knowledge on BMD of the jaws is gaining importance in contemporary dental practice due to its role in the treatment planning, management and prognosis of dental procedures such as osseointegrated implants, periodontal disease and grafting. Apart from the above role, the low bone density in the jaw can result in other dental problems such as tooth loss, lose or ill-fitting dentures and may have less optimal outcomes from oral surgical procedures.

2.2 Jaw and Osteoporosis

2.2.1 Relationship Between BMD of the jaw, other skeletal sites and bone status.

Malaysia’s population in 2019 is projected at 32.6 million with the composition of population of 60 years and over is 10.3 per cent which comprised of 4.2 million people (Department of Statistics Malaysia, 2019). The population aged over 50 years in Malaysia is estimated to rise from 5.3 million in 2013 to 13.9 million in 2050 (Subramaniam et al., 2019). The increase in elderly population will increase the prevalence of osteoporosis. The need of the densitometry test is crucial for prevention of fractures. In 2006, there were only 44 DXA machines available in Malaysia with the majority located in Kuala Lumpur (Muslim et al., 2012). Therefore, it is not practicable to screen postmenopausal Malaysian women using DXA as this test is not commonly available in all states. This has resulted in the consideration of other method for detecting low bone density. One way of assessing bone density is through the dental radiograph. Osteoporosis was found to have an effect on craniofacial and oral structures and has been found to be connected with periodontal bone loss (Aspalli et al., 2014) and tooth loss (Taguchi et al., 1999).

The relationship between BMD of the jaw and other skeletal sites has received growing attention over the past few years. In search for oral radiographic changes linked with osteoporosis, most researchers have focused on measures jaw bone mass and morphology (White, 2002). Wowern et al. (1994) reported that the subjects with osteoporotic fractures have low mineral content in the mandible. While others (Klemetti et al., 1993; Taguchi, Tanimoto, et al., 1996) reported that BMD of buccal (not trabecular) mandibular bone correlates with subjects that have low skeletal BMD. Few studies (Estrugo-Devesa et al., 2018; Horner et al., 1996) reported that mandibular BMD evaluated by DXA correlates significantly with BMD measurements of other important skeletal site (proximal and distal radius, femoral neck and lumbar vertebrae). They also suggest the use of the BMD measurement at the body of mandibles as potential clinical application of dental radiographs in detection of osteoporosis as it produces higher correlation coefficients and the greater sensitivity and specificity. Another study (Bodic et al., 2012) found no relationship between bone density of the mandible and other skeletal sites (iliac bone). Esfahanizadeh et al. (2013) had found positive correlation between BMD values of the femur and lumbar vertebrae and those of all the jaw regions (body, ramus, anterior regions of the mandible and the anterior of the maxilla) under study.

2.2.2 Density of the jaw from DXA and CBCT

With the advanced in technology, CBCT was introduced in dental practice. This technology had been increasingly being utilised by the dentist. CBCT is regularly use to provide a non-invasive method for retrieving the geometry of bones and estimating local material properties. CBCT also can be used to determine bone density and bone quality for dental implant placement, bone height and width, distance to anatomical structures such as the mandibular canal and sinuses, and the stability of the implant (Razi et al., 2014). It is commonly known that the mechanical properties of bone are highly dependent on its density. The attenuation of radiation in a material also depends on the density and the chemical composition of the material. In CBCT, the degree of x-ray attenuation is shown by gray scale (voxel value). As such, the gray value in the CBCT image is theoretically equivalent to the density of the material. CBCT manufacturers and software providers commonly present the gray scales in CBCT as the Hounsfield Unit (HU), but it is important to note that the gray value measurements are not the true HUs (Cassetta et al., 2012; Mah et al., 2010; Parsa et al., 2012).

There are findings that report the value from CBCT was not reliable because the values are influenced by device (Arisan et al., 2013; Emadi et al., 2014), positioning (Nackaerts et al., 2011) and exposure factors (Cassetta et al., 2012). Their finding was supported by Kim (2014) which suggest that in order to obtain a reliable density value using a CBCT image, numerous factors must be considered. As the density from gray value of CBCT was affected by multiple factors, researcher had to test the applicability of CBCT gray value for measurement bone density. A study by (Arisan et al., 2013) had found that CBCT generated higher gray density values than CT HU. Reeves et al. (2012) had proposed that the grey levels taken from CBCT scans can be used to derive Hounsfield units in a clinical environment. A study (Nomura et al., 2013) that investigate the stability of voxel values from CBCT in surrounding circumstances that mimics the clinical situations found that correlation was exist between the voxel values from CBCT and the hydroxyapatite contents in the phantom.

As the gold standard for bone density measurement was using DXA, researchers starts to find the correlation between measurement from CBCT and DXA. The early study (Hsu et al., 2012) to evaluate the bone strength of cortical bones using dental CBCT had obtain the results indicated that CBCT is superior to DXA for predicting cortical bone fracture loads. Another study (Shokri et al., 2019) that made assessment to find the correlation between BMD determined by CBCT gray values and BMD determined by DXA was found that a strong correlation was exists. Few studies (Alagl et al., 2017; Barngkgei et al., 2014; Gungor et al., 2016; Hao et al., 2014) support the findings that found the CBCT gray values can defined the changes in the jaw bone density.

2.2.3 Dental radiograph index

The two dimensional (2D) techniques of assessing BMD lack the accuracy to establish density and the images also overlap. In some 2D techniques, it also not able to distinguish between trabecular and cortical bone. The use of 3D techniques had improved the knowledge about oral and maxilla facial in three dimension with reduced radiation dose and higher resolution images and allows the visualization of the structures without superimposition and magnification or distortion (Scarfe et al., 2006). The use of tomography technique to evaluate BMD were recommended by (Barwick et al., 2017; Celenk and Celenk, 2012; Schreiber et al., 2014). In dentistry, the CBCT was used in many clinical applications as its provides a three-dimensional representation of the facial skeleton with minimal distortion and improved image sharpness with minimum radiation dose compared to multi-slice CT. Due to this, the researcher took this opportunity to study the role of dental radiograph to identify the patient with reduced bone density. With the results, the dentist able to alter the treatment plan and refer such patients to the related specialists for treatment. Furthermore, CBCT examination is relatively low cost compared with multi-slice CT.

As an alternative way to measure the bone density in the jaw, researcher proposed the use of radiographic indices using dental radiograph; OPG (Devlin et al., 1998; Drozdzowska et al., 2002; Horner and Devlin, 1998b; Jagelaviciene et al., 2010; Marandi et al., 2010; Nemati et al., 2016b) and CBCT (Gungor et al., 2016; Koh and Kim, 2011; Mostafa et al., 2016; Taalab et al., 2018). Indices such as, mandibular cortical width, inferior mandibular index, superior mandibular index and cortical index was measured. This term was proposed as computed tomography mental index (CTMI), computed tomography mandibular index inferior (CTI I), computed tomography mandibular index superior (CTI S), and computed tomography cortical index (CTCI) on CBCT images and mental index (MI), panoramic mandibular index inferior (PMI I), panoramic mandibular index superior (PMI S) and mandibular cortical index (MCI) for OPG images. CTCI and MCI were qualitative measurement where the inferior cortical edge of the mandible was estimated with observation. The appearance of the inferior cortical edge of the mandible was classified in three categories; C1, C2 and C3, according to its degree of resorption (Klemetti *et al.*, 1994).

There are not many studies conducted to compare the CBCT indices to DXA measurement. Koh and Kim (2011) had made evaluation with four CBCT indices on CBCT images. The subject involved in their study also went to have DXA examination of lumbar spine and femoral neck. The subjects were postmenopausal women, grouped into osteoporotic and normal. Their results show the mean values for all linear measurements were lower in osteoporotic group compared to normal group and only CTI I and CTI S that significantly different between normal and osteoporotic group. Furthermore, significant differences were found between osteoporotic and normal BMD for CTCI, as classification C3 was more frequent in the osteoporotic group and classification of C1 was more frequent in the normal BMD group.

Mostafa et al., (2016) had evaluated one quantitative index (CTMI) and a qualitative index (CTCI) in postmenopausal females. The subjects also had DXA examination and grouped into normal and osteoporotic group based on the result of DXA. They found that the CTI and CTMI was significantly different between osteoporotic group and the normal BMD group. They also found significant positive correlation between CTMI and CTI with lumber spine BMD. Beside the indices, they also did FD measurement and found no significant difference between the two groups and FD also had negative significant correlation with lumbar spine.

Gungor et al. (2016) had conducted the study on subjects who had undergone CBCT for several oral conditions and referred them for DXA examination of the lumbar spine and proximal femur for osteoporosis assessment. The subjects were grouped into normal, osteopenia and osteoporosis. All CBCT linear measurements were significantly lower in osteoporotic patients than in patients with normal BMD and in patients with osteopenia. Other than the CBCT indices, they also made measurement of CBCT values, histogram analysis and fractal dimension analysis and found that the measurements in osteoporosis patients were significantly lower than measurements in osteopenia patients and normal subjects.

Taalab et al., (2018) had evaluated the efficacy of mandibular CBCT in assessing bone quality in postmenopausal women and correlate it to the DXA results was done on twenty-four postmenopausal females age 45 years and above. The researcher grouped the subject into osteoporotic and non-osteoporotic group based on T-score from DXA examination. Three quantitative CBCT indices and average trabecular bone density (from CBCT) were measured and correlated it with T-Score from DXA scan. For average trabecular bone density, each subject was identified with a bone category according to Misch bone density classification. From their result, it was found that there were significant differences between the control and test groups in all CBCT indices. A significant positive correlation between also found between CBCT indices, average trabecular bone density and T-score. They had concluded that CBCT indices and average trabecular bone density can be considered as effective for assessing bone quality and can detect the presence of osteoporosis in post-menopausal women visiting the dental clinic.

Although the use of CBCT had more advantage, the OPG is a routine test that is currently performed to evaluate teeth and jaw in dental practice (especially at the centre that did not have CBCT). There are studies (Dagistan and Bilge, 2010; Gulsahi et al., 2010; Mahl et al., 2008; Marandi et al., 2010; Nemati et al., 2016a) that evaluate the findings in the OPG, correlating them with the early diagnosis of osteoporosis and highlighting the role of the dentist in the early diagnosis of this disease. These studies are usually based on the relationship between osteoporosis and the resorption of the crest of the mandibular residual ridge. These study use qualitative and quantitative radiomorphometric indices for comparing the results obtained by means of OPG and those obtained by DXA. Drozdzowska et al. (2002) reported that the efficacy of the panoramic-based mandibular indices in diagnosing osteoporosis is low to moderate. Gulsahi et al., (2010) reported that the BMD of the jaws was not correlated with either femoral BMD or panoramic radiomorphometric indices.

Panoramic images usually to experience with image superimposition, unequal magnification, and geometric distortion. Therefore, the linear measurements obtained from panoramic images have limitations. Several factors, such as patient positioning and differences in technical equipment, affect the magnification ratio on panoramic radiographs (Pfeiffer et al., 2012). To clarify this, researchers (Alonso et al., 2016; Gomes et al., 2014; Secgin et al., 2019; Tang et al., 2017) had done the study to compare the measurement from CBCT and OPG.

Gomes et al. (2014) had done the study to compare the assessment of mandibular indices on panoramic and CBCT images. The study was done using forty-four CBCT images of postmenopausal female subjects. From CBCT images, the panoramic image was reconstructed. Using the cross-sectional images of CBCT and the reconstructed panoramic images, the mandibular cortical index was evaluated using Klemetti classification. Their results had proved that the mandibular index from CBCT images was comparable to that obtained from panoramic images. Alonso et al., (2016) evaluated the validity of CBCT for assessing mandibular bone quality using the Klemetti classification was revealed that mandibular cortical index from panoramic and reconstructed panoramic images were in agreement and the cross-sectional images from CBCT was not in agreement with panoramic images. However, their result also shows that the changes in the morphology of the mandibular cortex can be detected by CBCT.