Normal Value of Cortical and Mandibular Trabecular Bone Density using Cone Beam Computed Tomography (CBCT)

Azhari[1]*, Fahmi O[1], Intan Fariska[1]

1. Department of Dentomaxillofacial Radiology, Faculty of Dentistry, Universitas Padjadjaran, Bandung, Indonesia.

Abstract

Knowing the Mandible bone density is important for dentists as it may affect the treatment plan. The amount of bone mass increases from puberty and reaches its peak around the age of 20-35 years old, but its value is not known for certain. Radiographic modality selected in dentistry to assess mandibular bone density is CBCT because it has a high resolution, accuracy and relatively low dose of radiation dose.

This research used quantitative methods by using design with cross-sectional approach. The population was secondary data of CBCT radiograph from 49 people aged 10-35 years old. The samples were as much as 882 axial, sagittal, and coronal slices with criteria as follows: 4 Region of Interest (ROI) posterior and 2 ROI mandible anterior including trabecular and cortical part. ROI measurement was done by using EZ Implant® software.

The average values of mandible trabecular density were 317.01 (age 10-15); 409.07 (age 16-20); 456.4 (age 21-25); 468.2 (age 26-30); and 464.17 (age 31-35). Whilst average values of cortical density were 722.8 (age 10-15); 752.4 (age 16-20); 789.7 (age 21-25); 794.3 (age 26-30); 800.05 (age 31-35). R value >0.7 from linear regression analysis showed a strong positive linear relationship between the mandible bone density and age on the trabecular and mandible cortical.

There was a relationship between density and mandible bone density increases along with aging period of 10-35 years old.

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Introduction

The process of bone formation occurs rapidly at the puberty age. This process reaches its peak around the age of 20-35 years old and will slowly decrease along with the aging process.[1] Decreases of bone mass starts after the age of 35 years old, which will more decrease after the age of 40 years old, and continue decreasing along with the aging process. Bone density in elderly people is lower than bone density of young adult age. The overall bone mass will decreases thus reducing the thickness and connectivity of trabecular which is a bone quality determinant.[2]

Radiological quality of bone is an important element of preoperative dentistry treatment because its non-invasive nature. Generally uses intraoral and panoramic radiography as they are widely available in many health care services, but the three-dimensional surgical area will directs surgical pre-operative surgical treatment into the use of CBCT. The three-dimensional image of high quality CBCT has high resolution with relatively low dose and affordable cost. The process of evaluating or classifying bone density, gray value of the CT image is quantified as Hounsfield Unit (HU). Hounsfield Unit is a linear transformation of material X-ray attenuation coefficient by water reference. In dentistry, Hounsfield Unit is applied to assess bone quality in the implant placement area, which plays an important role in determining the prognosis of osseointegration.[3]

Lekholm and Zarb were made a bone classification system based on the macrostructure which showed that the morphology and distribution of cortical and trabecular bones determined the bone quality. Following the development of multi-slice CT use

Corresponding author:
Azhari
Department of Dentomaxillofacial Radiology,
Faculty of Dentistry,
Universitas Padjadjaran,
Bandung, Indonesia.
E-mail: azhari@fkg.unpad.ac.id

for preoperative evaluation of bone density in HU, Norton and Gamble were developed a new classification based on the bone HU and correlated this new classification to Lekholm and Zarb classifications. Naitoh, et al. was found that trabecular volume per total of tissue volume obtained from CBCT was highly correlated with HU values from conventional CT image.[31] Although produces the same image, CBCT has a simple geometric configuration and mechanical acquisition.[9]

CBCT operated by using a rotating platform or gantry that contains X-ray sources and detectors. Conical or pyramidal formed radiation sources are transmitted directly into the Region of Interest (ROI), and the remaining beams of attenuation is projected on X-ray detector on the opposite side. The X-ray source and detector rotate around the center of rotation, then stay at the center of the ROI. This rotation center becomes the center of the final image volume obtained. During rotation, multiple sequential planar projection images are obtained when the X-ray source and detector rotate 180 to 360 degrees. These single-projection images are raw primary data consists of basis image, frame image, and raw image.[5]

The resolution and image detail of CBCT determined by the element volume or voxel generated from the volumetric data set. The data set is generated by a series of software algorithms in a reconstruction process. In CBCT image, the voxel dimension depends on the detector pixel size, whilst in CT depending on the slice thickness. The detector resolution is sub millimeter. Therefore theoretically, the CBCT resolution is higher than CT.[5]

Despite the high scattered radiation and the presence of artifacts are disadvantages of CBCT in bone density estimation, numerous studies stated that there was a relation between CT Scan HU and CBCT gray scale thus showed that CBCT voxel value was able to used for bone density estimation. Gray scale is widely applied in determination of lesions and tissue density, but gray scale is not similar among various tools. So far, CBCT manufactures are not providing standard system for gray scale display. However, research conducted by Razi, et al. (2014) showed the relation between CT Scan HU and CBCT gray scale, with R^2 value = 0.997. The CBCT gray scale becomes standard of bone density measurement, thus this tool is recommended because of the low doses and costs than CT Scan.[6]

The CBCT application on dental implant assessment mostly based on linear measurements of bone width and height, as well as bone density.[7] Initial stage of dental implant installation plan is determining the anatomical structure of the jawbone that will supports the properly installed implant. The jawbone quality usually assessed from the density value that represents the jawbone density.[8] CBCT-based density measured by pixel average calculations (including those indicates bone marrow) on the concerned area concerned.[9] The purpose of this study was to determine the normal value of mandibular posterior and anterior density by using CBCT.

Materials and methods

This research was using quantitative methods with cross-sectional design approach. The sample of this study was CBCT radiographs archive with inclusion criteria were no presence of systemic abnormality and having age of 10-35 years old from October 2008 to October 2016.

The sampling criteria of Region of Interest (ROI) measured were 4 posterior regions and 2 anterior regions of the mandibular, each ROI was taken only 3 axial slices, 1 sagittal slice, and 1 coronal slice, where each slice density was able to measured without superimposing with its surrounding structure.

The methods of processing CBCT radiograph data was done by using EZ-Implant® software. Measurement of the density of the mandibular posterior region bone was done in the alveolar bone between P1 & P2, and M1 & M2 teeth on both sides of the jaw. The vertical line was positioned to divided the posterior region of mandibular with parallel orientation with the posterior region of mandibular corpus on the axial view. The vertical line was also positioned parallel to the angulation of alveolar bone on the coronal view, and was positioned in the interdental in parallel position with the roots of teeth on the sagittal view. The density of the cortical bone was measured by positioning the areas on the top, buccal and lingual of alveolar bone with areas of $1mm^2$ on the coronal view as shown in Figure 1.

On the coronal view, the trabecular bone density was measured by using ROI. ROI was placed in the middle of the alveolar bone with areas of 4 mm^2 as shown in Figure 2. On the sagittal view, the trabecular bone density was also measured by using ROI. ROI with areas of 4mm^2 was placed on the apical alveolar bone between 2 teeth. On the axial view, the trabecular bone density was measured by using the Area. The Area feature was placed in the middle of the alveolar bone with areas of 4mm^2. Then the measurement results were recorded from coronal, sagittal, and axial views then taken the average value.

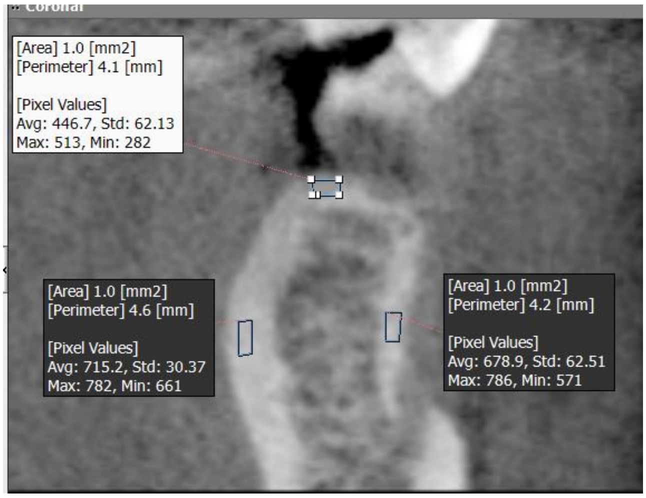

Figure 2. Cortical Density Measurement using Area Feature on Coronal Region.

Figure 3. Trabecular Density Measurement using ROI Feature on Coronal Region.

Results

Total amount of mandibles studied was 36, consisted of 7 mandibles of 10-15 years old sample, 7 mandibles of 16-20 years old sample, 7 mandibles of 21-25 years old sample, 11 mandibles of 26-30 years old sample, and 4 mandibles of 31-35 years old sample.

The average density value of the mandible trabecular was increased linearly along the age (Figure 3). The results of a simple linear regression analysis of the relations between mandible trabecular density and age found the correlation coefficient value (R) = 0.782 indicated that mandible trabecular density has a strong linear relation with age, which means that the density of the mandible trabecular was increased along the age. The value of determination coefficient (R^2)=0.61, indicated that the value of the age explainable variation proportion of mandible trabecular density was 61.1%.

Based on a simple linear regression analysis of the relation between the mandible cortical density with age, the correlation coefficient value (R) = 0.740 indicated that the mandible cortical density has a strong linear relation with age which means that the mandible cortical density increased along with age. Determination coefficient value (R2)=0.548 indicated that the age explainable variation proportion of cortical RB density was 54.8%.

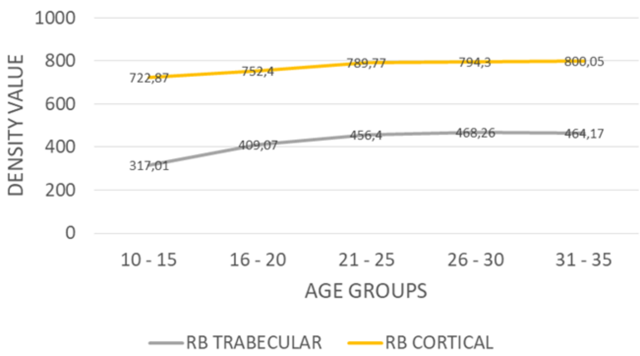

Figure 3. Relation between Age and Mandible Density.

Discussion

Cone Beam Computed Tomography (CBCT) is the development of CT-scan that increasingly used in dentistry fields because of the high resolution, relatively low radiation dose, and lower cost compared to CT scan.[1] CBCT is able to displaying three-dimensional reconstruction of the jaw area and a real-size data set to provide more detailed and accurate information to the observer rather than using two-dimensional image capture techniques.

CBCT is also widely used to assists the implant installation.[10-12] The study of CBCT usage usually aimed to perform dental segmentation,[13-15] or measurement of cortical bone thickness.[16-18]

Several studies have shown that there was a high correlation between dental bone density features measured using CBCT with bone mass density (BMD) obtained from DEXA devices.[19,20] Hua et al. examined the accuracy of fractal analysis and morphometry on CBCT jawbone images to assess bone mass density (BMD) quality obtained from DEXA devices.[20] Segmentation was conducted by using the region growing and thresholding in order to get the objects in the form of jawbone structure. Morphometry or density average value were measured based on the gray level of each CBCT slice. The result obtained was a significant correlation between fractal analysis and BMD whilst morphometry analysis did not having any significant correlation towards BMD.

Mostafa et al. were using fractal dimension (FD) and radiomorphometric indices on the jawbone in CBCT images to calculated its correlation with BMD obtained with DEXA devices.[19] Radiomorphometric indices used were mandibular cortical index (MCI),[21] cortical thickness below the mental foramen (MI),[22] and a panoramic mandibular index (PMI).[23] Gaussian filtering and thresholding was performed on the region of interest (ROI) before the FD measurement of trabecular bone in one coronal slice CBCT image. The research found that there was a high correlation between the measurement results of radiomorphometric indices towards BMD value, but there was no significant correlation between the results of FD measurement value with BMD.

The results obtained by Mostafa et al.[19] was different from Hua et al.[20] because the fractal analysis done by Mostafa et al. only performed in trabecular bone area whilst Hua et al. were also performed on both trabecular and cortical bone, depending on the region of interest (ROI) selected. Differences of bone features used influencing the results of fractal analysis because cortical bone has a higher density than trabecular bone. Hua et al. were also measuring cortical bone density in the jaws by using only gray level values, in contrast with Mostafa et al. which were using an index of standard measurement of the jawbone density.

Hsu et al. were comparing CBCT and DEXA to assess bone strength in the cortical bone of the midshaft of rats femur and tibia.[24] The bone was scanned by using dental CBCT to measure volumetric cortical bone mineral density (vCtBMD) and cross-sectional moment of inertia (cSMI) that were used to obtain bone strength index (BSI).[24] Afterwards, the bone fracturing was performed to measuring the force required as fracture load. Statistical analysis was performed to calculating the correlation between BMD value obtained from DEXA and also from vCtBMD, cSMI, and BSI obtained from CBCT with fracture load value. The results showed that CBCT was providing better fracture load predictions than DEXA and BSI and has a significant correlation with fracture load.

Based on the results of this study, the apparent trend was that the mandibular density pattern tend to showed minimal changes from the age of 25-35 years old or young adult age groups. This was consistent with the study conducted by Sathapana et al. that was reported that the peak density of the jaws was occurring since the age of 20-29 years old which was also classified as young adults group and declined in the age of 40-49 years old.[17]

The increases of bone density was occurred since puberty because it is a growth phase and reached its peak at the age of 25-35 years old, then decreases slowly along with age.[18] Children in the growing periods have more osteoblasts than older people. Mature osteoblasts synthesize bone matrix and regulate bone mineralization. Osteoblasts synthesize alkaline phosphatase, the enzyme that plays an important role in the mineralization process to prepare the alkali atmosphere in the osteoid tissue that formed to make calcium easily deposited on the tissue.[19]

This study stated that the mean value of the trabecular anterior density was higher than the posterior region in all age groups. This result was consistent with research conducted by Norton and Gamble, Zao et al., and Lamia et al. Different with these studies, Shapurian et al. research was found no significant difference between maxillary and mandible posterior density, although the maxillary posterior tend to be having a higher value.[20] The studies have similarities with studies done on the edentulous region.

Compared with the results of Norton and Gamble research, the value range on the results of this study was narrow, possibly means that the distribution of radiopaque and radiolucent patterns in the jawbone of this study sample were more evenly distributed. The results value of this study were closer to the results of research conducted by Zao which also used CBCT, whilst Norton and Gamble were using CT Scan. This might be influenced by the difference of basic principles between CBCT and CT Scan.

Conclusions

The mandible bone density value will increases along with age, starting from the age of 10-25 years old and then remain unchanged until the age of 35 years old.

Declaration of Interest

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