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RESEARCH ARTICLE

INFLUENCE OF VOXEL SIZE ON EVALUATION OF TRABECULAR BONE MICROSTRUCTURE ON HUMAN MANDIBLES: A CBCT STUDY

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ABSTRACT

Purpose: The aim of this study was to assess the effect of voxel size on trabecular microstructural evaluation on human cadaver mandible using cone-beam computed tomography (CBCT) images.
Material and Methods: Twenty-two volumes of Interest (VOI) were obtained from human cadaver mandibles scanned in three different voxel sizes using CBCT. Scanning was performed in 0.125 mm (Group 1), 0.2 mm (Group 2) and 0.3 mm (Group 3) voxel sizes. Trabecular thickness (Tb. Th); trabecular separation (Tb. Sp); Bone Volume/Total Volume (BV/TV) values were calculated using plugin BoneJ of the software ImageJ. The results were evaluated statistically in software IBM SPSS Statistics 21.
Results: Tb. Th and Tb. Sp showed significant differences between 0.3 mm and other voxel groups (p=0.000). BV/TV values showed no significant difference between whole groups.
Conclusion: Although microstructural analysis is not the primary aim of CBCT examination, the images offered by this imaging method reveal information on trabecular bone microstructure, which can be a valuable tool for bone quality assessment. A high correlation between values with 0.125 mm and 0.2 mm and a low correlation between values with 0.125 mm and 0.3 mm voxel sizes suggest that; this knowledge is clinically more valuable when voxel size is 0.2 mm or thinner.

Keywords: cone beam computed tomography, trabecular bone, bone density, voxel size

INTRODUCTION

The bone quality can be assessed clinically using a dual-energy X-ray absorptiometry (DXA) device (which is a gold standard for diagnosis of osteoporosis), the Hounsfield scale in tomographic images, and the panoramic mandibular index (PMI) and the fractal analysis (1). Besides, it can be assessed using the nanostructure analysis under a transmission electron microscope (TEM); surface feature analysis under a scanning electron microscope (SEM); two coloured collagen density analysand, and microstructural analysis for different parameters like trabecular thickness (Tb. Th), trabecular spacing (Tb. Sp), bone volume/ total volume(BV/TV) in histological examination or micro-computed tomography (Micro CT) images and mechanical tests like compression, tension, bending, fatigue, creep and the torsion in the laboratory (2-5). Although the techniques applied in the lab show higher accuracy and reliability, they are not applicable in clinics without invasive procedures (6).
Moreover, two-dimensional (2D) clinical techniques provide limited information, which is inadequate for representing a three-dimensional (3D) structure and the Hounsfield scale accepts a nonhomogenous trabecular structure as a homogenous one (7-9).
Clinical 3D microstructural analysis techniques are expected to have high accuracy and easy clinical application. Cone-beam computed tomography

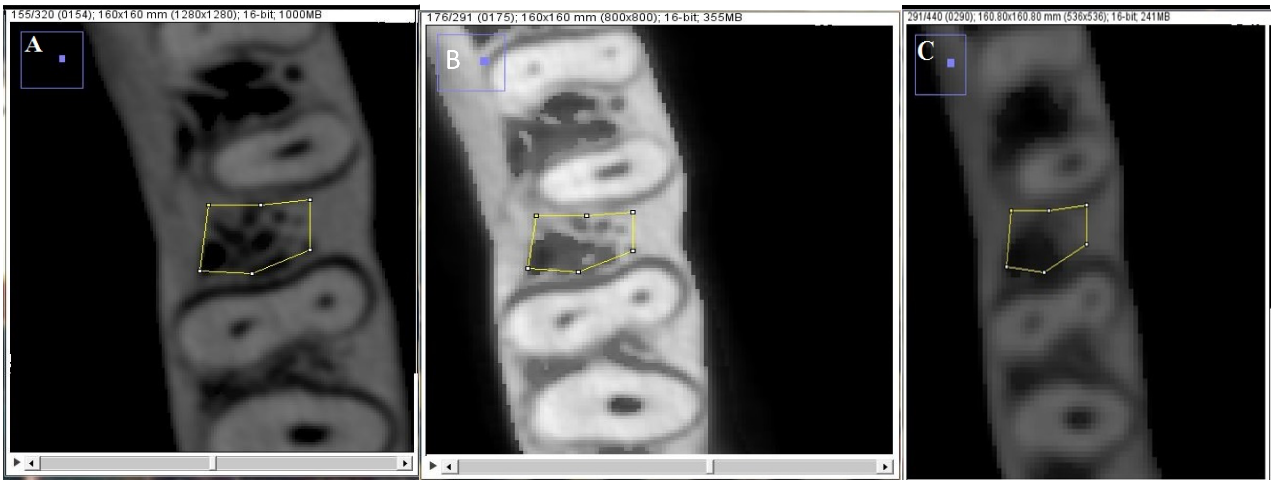

Figure 1. ROIs from exact points in different voxel size and resolutions to form VOIs. 0,125 mm voxel size (a), 0,2 mm voxel size (b), 0,3 mm voxel size (c).

(CBCT) devices are studied for this purpose due to their low radiation doses (10-13) and have been demonstrated to be an alternative for microstructural analysis (7).

In a study, the skulls of three female monkeys (Macaca fascicularis), which were terminated for another research purpose, were scanned using Micro CT as the gold standard and CBCT devices with different resolutions. CBCT images with a resolution of 0.2 mm voxel size had a high correlation in microstructural parameters (Tb. Th, structural model index-SMI) with Micro CT. CBCT images with a low resolution of 0.25 mm voxel size had a low correlation. Results suggested that high-resolution CBCT might provide reliable derived parameters presenting the trabecular bone microstructure (14).

Open-source software ImageJ and its plugin BoneJ are capable and useful for trabecular microstructural analysis in 3D images (15).

Yet being far from providing an osteoporosis diagnosis, microstructural trabecular bone parameters obtained from CBCT images could be used to evaluate bone healing in operation sites, treatment follow-ups, and decisions before some procedures like dental implants. From this point of view aim of this in vitro study is to determine the relationship between microstructural parameters of mandibular trabecular bone and different voxel sizes in CBCT.

MATERIAL AND METHODS

Twenty-two Volumes of Interest (VOIs) were obtained from two human cadaver mandibles scanned in three different voxels using CBCT (KaVo 3D eXam; KaVo Dental, Biberach, Germany). Ethical approval for the study was obtained from the Ethical Committee of Yuzuncu Yil University Faculty of Medicine (Date: 07.02.2017, Decision No: 08).

Scanning performed in 0.125 mm ((Exposure parameters: FOV: 16×13 cm kV: 120 mA: 5Exposure time: 26.9 seconds), 0.2 mm (Exposure parameters: FOV: 16×13 cm kV: 120 mA: 5 Exposure time: 14.7seconds) and 0.3 mm (Exposure parameters: FOV: 16×13 cm kV: 120 mA: 5 Exposure time: 8.9 seconds) voxel sizes. Uncompressed images are exported, avoided data loss, and imported into an open-source image processing software ImageJ (NIH, Maryland, USA).

Regions of interest (ROIs) are set at the same points of a different number of slices for each resolution to form volumes of interest (VOIs) (Figure 1a-c). Several slices are calculated proportionally from several real slices of each resolution and mandible. According to this, for the first mandible, 61, 38 and 25 slices were used for 0.125mm; 0.2mm and 0.3 mm voxel sizes, respectively. These numbers of slices were 50,33, and 21 for the second mandible.

6 posterior (the region between second molars and first molars, first molars and second premolars, second and first premolars of right and left sides) and 5 anterior (the region between right canine and lateral incisor, right lateral and central incisors, central incisors, left central and lateral incisor and left lateral incisor and canine) VOIs are obtained for both mandibles, therefore totally 22 VOIs are set to investigate trabecular parameters. Set VOIs from these calculated slices are then duplicated, and image processing applications like contrast-

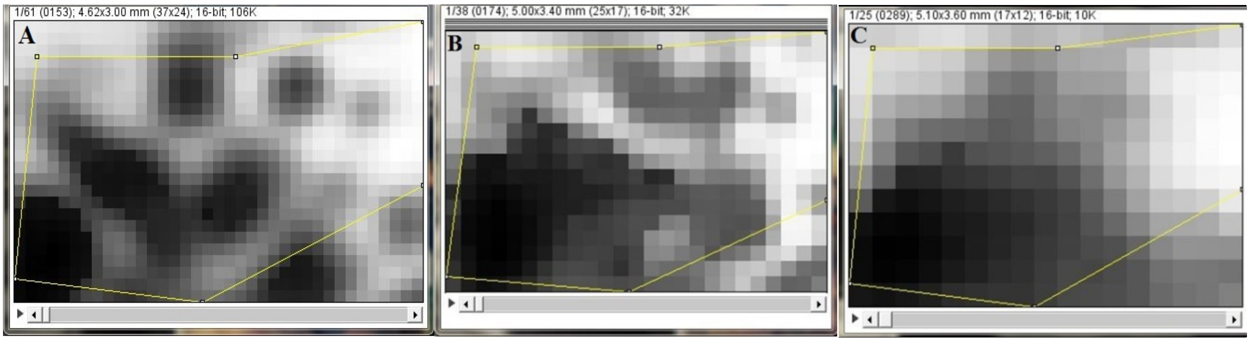

Figure 2. Set VOIs are dublicated and extracted from the main image in different voxel size and resolutions. 0,125 mm voxel size (a), 0,2 mm voxel size (b), 0,3 mm voxel size (c).

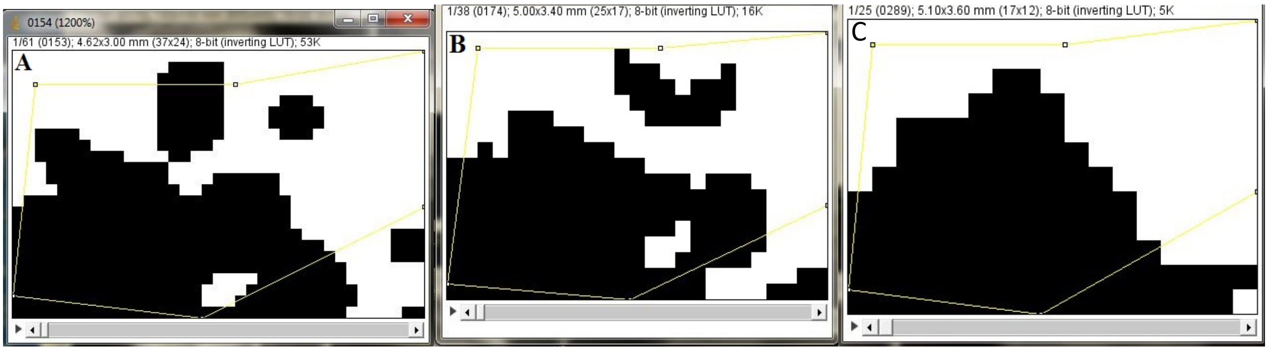

Figure 3. Dublicated VOIs are then converted in to binary image in different voxel size and resolutions. 0,125 mm voxel size (a), 0,2 mm voxel size (b), 0,3 mm voxel size (c).

enhancing, histogram equalization and normalizing are performed as in the microstructural analysis software manual. Processed images converted to binary using filters of ImageJ (Figures 2a-c,3a-c). Binary images are then imported into bone analyzing software BoneJ (London, UK), a plugin of ImageJ, and trabecular parameters. Th, Tb. Sp, BV/TV are saved for each VOI. Statistical analysis was performed using software IBM SPSS Statistics 21(SPSS Inc., Chicago, IL).

RESULTS

Values for each structural parameter in each voxel size for each VOI of each mandible are saved (Tables 1,2).

In the first group with 0.125 mm of voxel size; mean Tb.Th was 0.884 ± 0.244 mm; Tb.Sp was 1.6 ± 0.98 mm; BV/TV was 0.371 ± 0.137 mm. Tb.Th was 1.019 ± 0.306 mm; Tb.Sp was 1.81 ± 0.945 mm; BV/TV was 0.349 ± 0.101 in the second group with 0.2 mm voxel size. And in the third group with 0.3 mm voxel size; Tb.Th. was 1.459 ± 0.307 mm; Tb.Sp. was 2.79 ± 0.998 mm; BV/TV was 0.322 ± 0.089 (Table 3).

One-way ANOVA analysis of SPSS software assessed the general difference between the three voxels sizes for the microstructural parameters. Tukey's test was used for the post-hoc analysis of intergroup in a 95% interval. Trabecular thickness showed a significant difference between the first and third and second and third groups (p=0.000). While in the first and second groups difference in trabecular thickness wasn't statistically significant (p=0.273). Similarly to trabecular thickness, trabecular spacing significantly differed between the first, third, second and third groups (p=0.000). While in the first and second groups difference in trabecular thickness wasn't statistically significant (p=0.479). BV/TV values showed no significant difference between whole groups (Table 4).

Tb. Th, Tb. Sp and BV/TV; varies according to scanning resolutions and voxel sizes in CBCT images. 3D images of VOIs are also investigated for both mandibles in different voxel sizes, and differences in details are demonstrated (Figures 4a-c).

DISCUSSION

According to cortical bone, trabecular bone is the primary anatomical and functional unit of bone metabolism due to the higher turnover rate (16). Therefore investigating features of trabecular bone is an inseparable process in evaluating bone quality.

Table 1. Values for each morphometric parameter in each voxel size and exposure time for each VOI of mandible 1

	0.125mm BV/TV	Tb Th	Tb Sp	0.2mm BV/TV	Tb Th	Tb Sp	0.3mm BV/TV	Tb Th	Tb Sp
46-47	0.345	0.744	1.144	0.323	0.721	1.375	0.345	1.789	2.504
45-46	0.232	0.899	1.291	0.168	0.973	2.066	0.183	1.945	3.434
44-45	0.183	1.019	2.462	0.22	1.333	2.539	0.169	1.873	3.399
43-42	0.581	0.83	0.676	0.4	0.89	1.073	0.303	1.37	2.033
42-41	0.407	0.774	1.022	0.397	0.906	1.036	0.365	1.341	2.258
41-31	0.343	0.599	1.003	0.357	0.688	1.301	0.322	1.041	2.726
31-32	0.425	0.56	0.758	0.43	0.844	1.142	0.337	0.966	2.576
32-33	0.601	0.883	1.024	0.454	1.041	1.137	0.477	1.38	1.579
34-35	0.361	0.904	1.491	0.329	0.882	1.393	0.489	0.961	0.944
35-36	0.396	0.79	0.989	0.272	1.056	1.961	0.276	1.379	3.179
36-37	0.502	0.964	0.976	0.526	0.94	0.952	0.45	1.442	1.63

Table 2. Values for each morphometric parameter in each voxel size and exposure time for each VOI of mandible 2

mand2	0.125mm BV/TV	Tb Th	Tb Sp	0.2mm BV/TV	Tb Th	Tb Sp	0.3mm BV/TV	Tb Th	Tb Sp
46-47	0.262	0.56	1.856	0.345	1.102	2.404	0.345	0.744	1.144
45-46	0.172	0.54	4.194	0.248	0.803	3.554	0.232	0.899	1.291
44-45	0.083	0.521	4.438	0.105	0.531	5	0.183	1.019	2.462
43-42	0.404	1.013	1.378	0.418	1.453	1.616	0.581	0.83	0.676
42-41	0.568	1.334	1.458	0.384	0.842	1.234	0.407	0.774	1.022
41-31	0.437	0.905	1.324	0.405	0.798	1.207	0.343	0.599	1.003
31-32	0.479	1.139	1.464	0.424	1.293	1.962	0.425	0.56	0.758
32-33	0.236	1.432	1.293	0.244	1.914	1.507	0.601	0.883	1.024
34-35	0.378	1.059	1.619	0.391	1.026	1.554	0.361	0.904	1.491
35-36	0.321	0.949	2.228	0.406	0.978	2.242	0.396	0.79	0.989
36-37	0.449	1.031	1.106	0.422	1.396	1.544	0.502	0.964	0.976

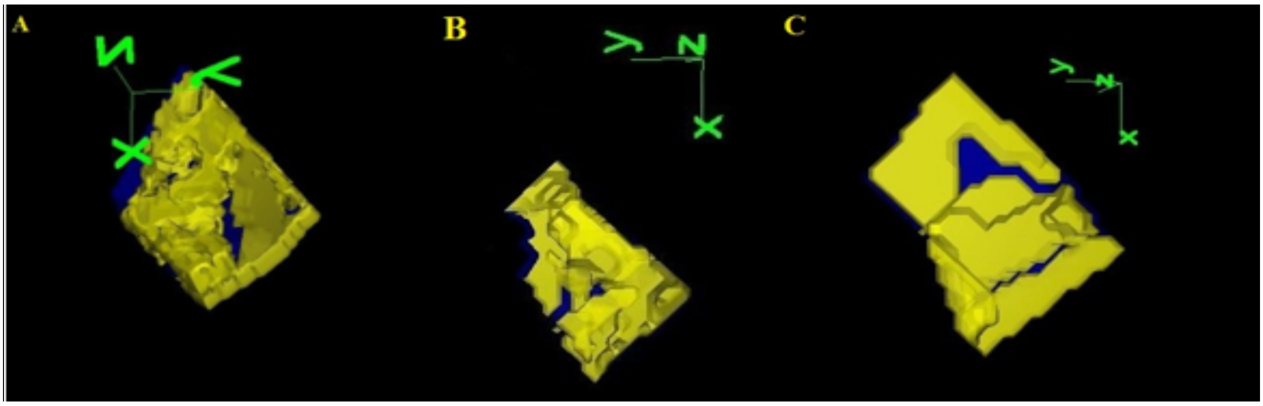

Figure 4. Loss of image detail in 3D images of selected VOIs in different voxel sizes. 0,125 mm voxel size (a), 0,2 mm voxel size (b), 0,3 mm voxel size (c).

BMD values give a lumped view of analyzed bone but are weak in specific knowledge of macro and microstructural parameters of cortical and trabecular bone individually (17).

Table 3. Mean trabecular microarchitectural parameters for each voxel size

Voxel Size (mm)	N	Tb.Th.	Tb.Sp.	BV/TV
0.125	22	0.884 ± 0.244	1.6 ± 0.98	0.371 ± 0.137
0.2	22	1.019 ± 0.306	1.81 ± 0.945	0.349 ± 0.101
0.3	22	1.459 ± 0.307	2.79 ± 0.998	0.322 ±0.089

With successful results on accuracy and reproducibility, micro-ct became a gold standard in the trabecular microstructural analysis (18). However, clinical use of micro-ct is only possible with invasive bone removal procedures, and these procedures do not provide a clinical follow up of the total bone. Microstructural analysis of upper and lower extremities using both micro-ct, multislice computed tomography (MSCT) and CBCT showed that besides the advantages of CBCT, an increase of noise and artefacts in the images as the resolution enhances should be considered. However, it is demonstrated the reliability and validity of CBCT in bone quality assessment, and besides density measurements, microstructural assessment is recommended (19).

Mys et al. investigated microstructural analysis of wrist bone using micro-CT and CBCT after image processing applications. They demonstrated that CBCT had a high potential to visualize and quantify the bone microstructure for musculoskeletal applications. They also stated that besides overestimated values in CBCT images, significant correlations for all microstructural parameters were observed (BV/TV, Tb. Th, Tb. Sp etc.) (6). Supporting their study, microstructural parameters had more overestimated values when voxel sizes went thicker also in our study (Table 3).

Ibrahim et al. found significant correlations between trabecular microstructural parameters of CBCT and micro-CT images. They stated that CBCT datasets could be used to evaluate trabecular bone microstructure at dental implant sites (20).

Blok et al. found Tb. Th significantly higher in the mandible than in the maxilla and in an in vitro study with10 human cadaver skulls using micro-CT. Compared to the anterior, the posterior mandible showed slightly higher trabecular thickness and higher trabecular spacing supporting our data (21).

Table 4. Statistical evaluation of trabecular microarchitectural parameters and different voxel sizes of CBCT

Tukey Post Hoc (p<0.05*)	Tb.Th.	Tb.Sp.	BV/TV
0.125 mm – 0.2 mm	0.273	0.479	0.778
0.125 mm – 0.3 mm	0.000*	0.000*	0.312
0.2 mm – 0.3 mm	0.000*	0.004*	0.708

Supporting present results, in the study, two different CBCT systems with 0.2 mm and 0.25 mm voxel sized resolutions were used to determine microstructural parameters in comparison with gold standard micro-CT and while a weak correlation was found between any derived parameters of CBCT with 0.25 mm voxel size and micro-CT; a strong correlation between CBCT with 0.2 mm resolution and micro-CT suggested that high-resolution CBCT might provide reliable derived parameters presenting the trabecular bone microstructure (14). Therefore since different devices obtained CBCT images with different resolutions, these diversities may not be caused by resolution but by other hardware or software features. The limitation of this study was an insufficient number of species, and this limitation is intended to be tolerated by obtaining several measurements from different locations.

CONCLUSION

Previous studies have shown that CBCT images have the potential for trabecular microstructural evaluation. High correlation is also demonstrated when considering overestimated values of trabecular microstructural parameters in CBCT than those in micro-CT. Overestimated results prevent providing an Osteoporosis diagnosis; however, microstructural trabecular bone parameters using CBCT images should be used to investigate bone healing in operation sites, treatment follow-ups, and decide bone quality before some treatments like treatments dental implants in suitable voxel size and resolution. Besides microstructural analysis is not their first purpose, CBCT images carry knowledge about trabecular bone microstructure; the high correlation between values with 0.125 mm and 0.2 mm and low correlation between values with 0.125 mm and 0.3 mm voxel sizes suggest that; this knowledge is clinically more valuable when voxel size is 0.2 mm or thinner.

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