

# The Use of Relative Voxel Grey Values in CBCT to Evaluate Radiological Bone Density in the Mandible

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**Abstract** Quality of CBCT images allows for detailed analysis of bone but tissue mineral density can be evaluated with some limitations. The purpose of this study was to investigate the clinical possibility to measure the mandible relative radiological bone density for cortical and trabecular tissue. The CBCT scans were taken with the use of PaxReve3D machine and analyzed by Ez3DPlus software. A modified scale was applied and the ratio of radiological density to measured highest value (HV) was calculated. The relative grey values (GV) of alveolar bone in mandible were measured. Basal cortical reference values (BCRV) of bone density were applied and compared with HVs. Statistically significant very strong positive correlation was observed between relative and rescaled GV for all available data  $r = 0.901$ ;  $p < 0.0001$ . Pearson's correlation coefficient between BCRVs and HVs was found as positive and strong  $r = 0.640$  with  $R^2 = 0.409$ . With the limitations of the study the use of relative grey scale values to evaluate radiological density of mandible is promising and easy to apply method.

**Keywords:** cone beam tomography, bone density, alveolar bone, relative grey values

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## 1. Introduction

The quality of cone beam CT (CBCT) images enables detailed analysis of bone (shape and thickness) but tissue mineral density (TMD) can be evaluated with some limitations [1,2,3]. The assessment of bone mineral density (BMD) or TMD from clinical perspective is important because it accounts for bone quality and may be used to diagnose general bone disease or local anomalies. BMD describes bone quality as the mineral content in the certain volume of bone tissue with all its structures [4]. On the other hand TMD describes mineral contents in the bone matrix only and with three dimensional morphological parameters of trabecular and cortical bone reflects bone mechanical properties [5]. Some studies indicate that TMD can reveal elastic, plastic, and viscoelastic mechanical properties of bone tissue [6,7,8]. However, multiple factors must be considered if reliable values for BMD are expected [9]. The use of calibration curve gives the possibility to compare different CBCT examinations [9]. Another opportunity is the use of relative grey values (GV) or relative values of percentage differences. The latest one is the concept of using cortical bone as a reference object for assessing relative changes of alveolar trabecular bone [10]. The relative grey values were also used in the previous study to overcome the issue of different scanning conditions where maxillary bone quality was evaluated and a modified voxel grey scale was successfully used [11]. The purpose of this study was to investigate the clinical possibility to measure the

mandible relative radiological bone density values and assess the correlation between rescaled and relative GV, in order to evaluate quality of cortical and trabecular alveolus tissue.

## 2. Materials and Methods

The CBCT scans were taken with the use of PaxReve3D machine (Vatech, Seoul, Republic of Korea) and were analyzed by Ez3DPlus (E-Wootech, Seoul, Republic of Korea) software. The radiological density of lingual and vestibular cortical plate and the trabecular bone in anterior and lateral part of the mandible was measured. The study was carried out on 17 people: 11 women and 6 men aged 19 - 73. The total number of measurements was 105, with 41 in frontal part of the mandible and 66 ones in the posterior part. All CBCT scans were made for clinical indications. The density test of cortical plates and the trabecular bone was performed by the Profile tool of the dedicated software. Measurements were made on horizontal cross - section of the mandible using spatial coordinate tool (x - y) positioned on three windows: coronal, saggital and axial (Figure 1).

The alveolus was cut horizontally on the roots level, away from alveolar crest in the interradicular space, where both corticals and trabecular bone was available. In case of the lack of teeth the measurement was taken in edentulous alveolus in the half of its height. On both saggital and coronal cross-sections the coordinates were adjusted in the middle of the interradicular space or edentulous alveolus (Figure 1) with slices thickness

adjusted to 1mm. The Profile tool available in Ez3D software was used to estimate the radiological density of the bone with displayed mean and maximum value of density. Depending on the available bone, every patient had two to five different points of measurements taken in interradicular spaces or edentulous alveolus in both frontal and posterior part of the mandible. In every measurement

point the Profile tool was selected twice: the first one across the alveolus involved both cortical and trabecular bone, the second one with trabecular bone only. Two maximum values for both corticals were read from the first diagram. The density line was drawn from the vestibular to the lingual cortical plate, so the peaks on diagram corresponded accordingly (Figure 2).

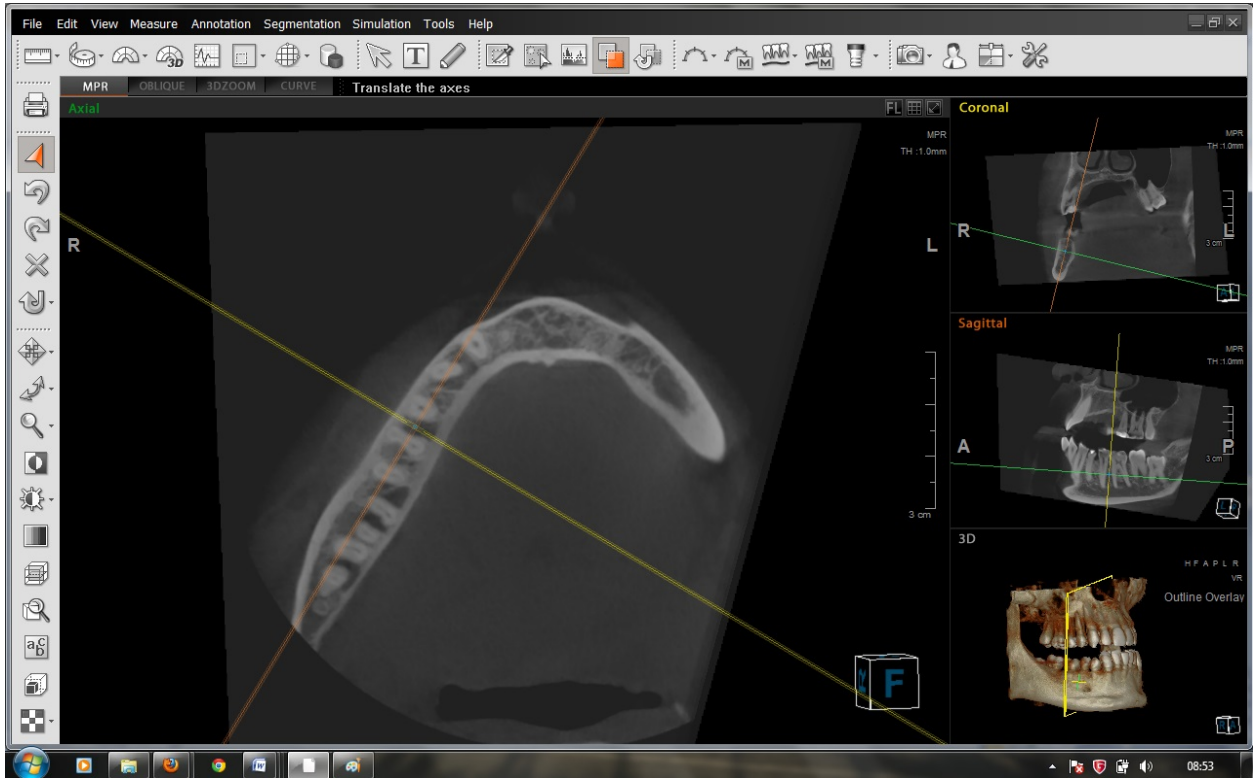


Figure 1. Three pains window, coronal, sagittal and axial view of the measurement place with visible x-y coordinates

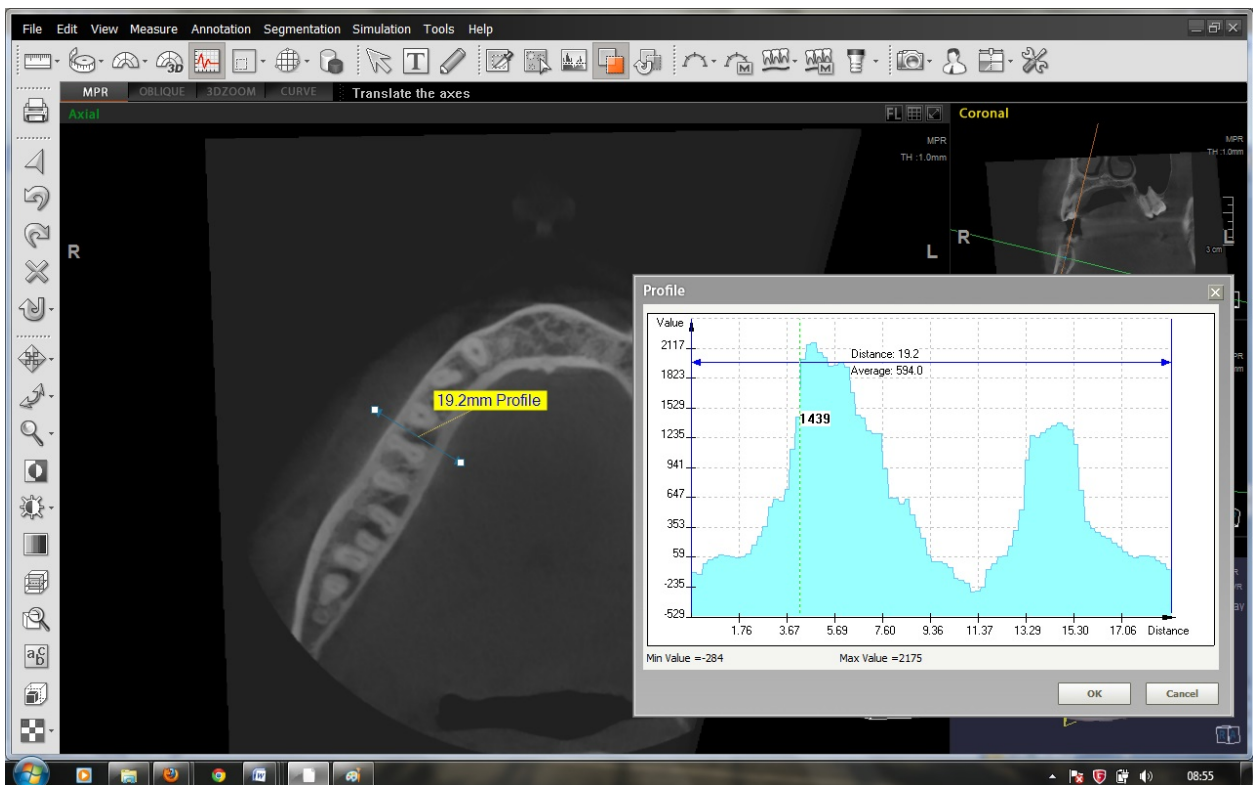


Figure 2. The value of the vestibular and lingual cortical plates measured using Profile tool

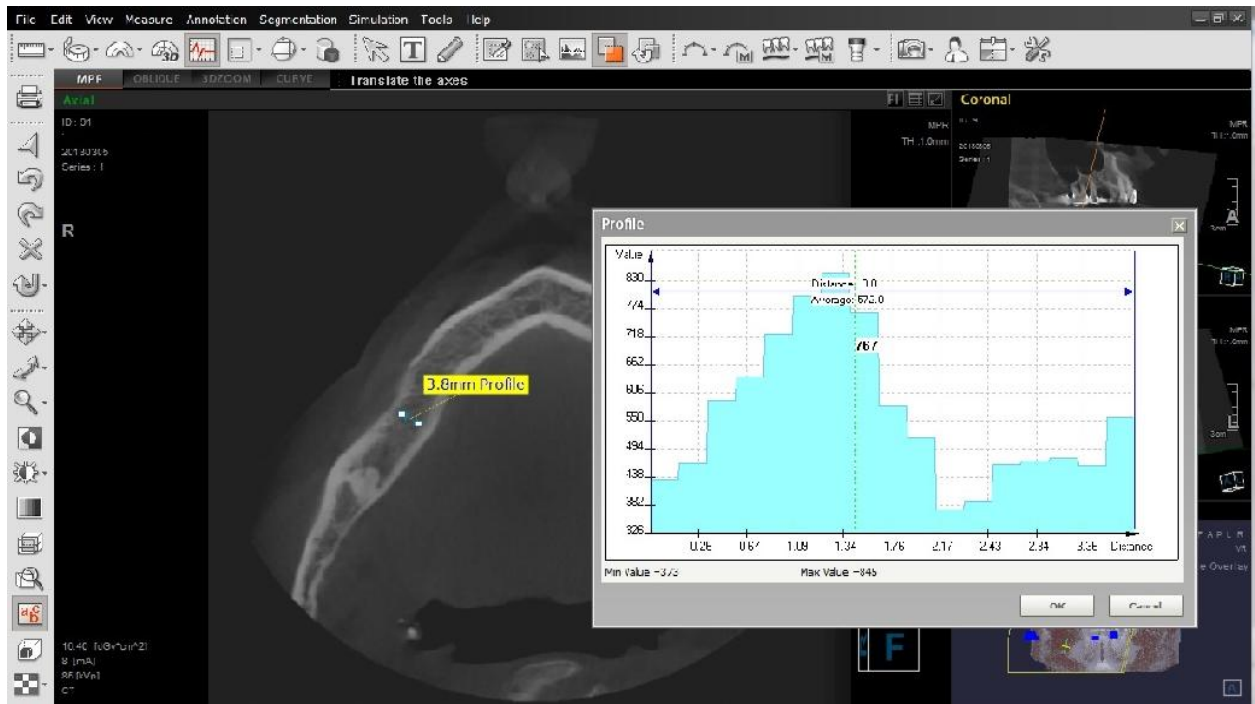


Figure 3. The average value of the trabecular bone measured using Profile tool

To assess the density of the trabecular bone, the average value of trabecular bone was read from the second diagram of the Profile tool (Figure 3).

Every measurement was saved as a screenshot in JPG format (Figure 1, Figure 2, Figure 3) and subsequently, all measured values were saved in the tables. The X - ray exposure settings i.e. the anode current and voltage were presented in the Table 1.

Part of the obtained measurement values was presented in Table 2.

Table 1. Exposure settings

Amperage, anode voltage	Number of scans acquired
8mA,90kV	21
2mA, 90kV	10
8mA, 85kV	24
7mA, 85kV	13
2mA, 85kV	6
5mA, 85kV	17
6mA, 85kV	7

Table 2. The example table with the data of the examined patient

ORIGINAL MEASUREMENTS								RESCALED GREY VALUES			
Tooth	Vestibular cortical plate	Trabecular bone	Lingual cortical plate	Air in the throat(extraoral measurement)	Vestibular cortical plate A (1-x)	Trabecular bone B (2-x)	Lingual cortical plate C (3-x)	The highest value D	Vestibular cortical plate to the highest value A/D	Trabecular bone to the highest value B/D	Lingual cortical plate to the highest value C/D
<i>anterior mandible</i>											
42/43	3406	1702	2773	-1017	4423	2719	3790	<b>4976</b>	0.8888	0.5464	0.7616
32/33	3556	1401	2533	-1017	4573	2418	3550		0.9190	0.4859	0.7134
42/41	3959	2338	2909	-1017	<b>4976</b>	3355	3926		1	0.6742	0.7889
<i>posterior mandible</i>											
45/46	1756	1049	1270	-1017	2773	2066	2287	<b>4976</b>	0.5572	0.4151	0.4596
46/47	2391	578	1430	-1017	3408	1595	2447		0.6848	0.3205	0.4917
34/35	1994	1214	1388	-1017	3011	2231	2405		0.6051	0.4483	0.4833

As GV used in Ez3D software were not compatible with Hounsfield units, a modified scale was used. The value for air was determined as "0". Measurement of radiological density of air was taken in the pharyngeal cavity. The obtained negative GV of the air were subtracted from the values for cortical plates and trabecular bone and that resulted in a new wide rescaled grey scale without negative numbers. The results were collected in columns: A (vestibular cortical plate), B (trabecular bone) and C (lingual cortical plate), as values in the new scale and base for further calculations. For every patient the highest value (HV) from the cortical plate set of data was found, defined as the maximum density of the bone. This number worked as a reference

measurement (D) for each patient. The ratio of radiological density of cortical plates and trabecular bone to D was calculated (described as A/D, B/D and C/D) to create the relative GV. This method allows to reduce potential error coming from different x - ray exposition parameters applied for different patients. The results were grouped in tables, separately for anterior and posterior part of the mandible. Statistical analysis were performed in STATISTICA13. A Pearson's correlation analysis with calculations of linear function slope and intercept was performed. First, a correlation between rescaled GV and relative GV was analyzed for all available data. In the next step the relationship between rescaled and relative GV were analyzed for each location separately **Table 3**.

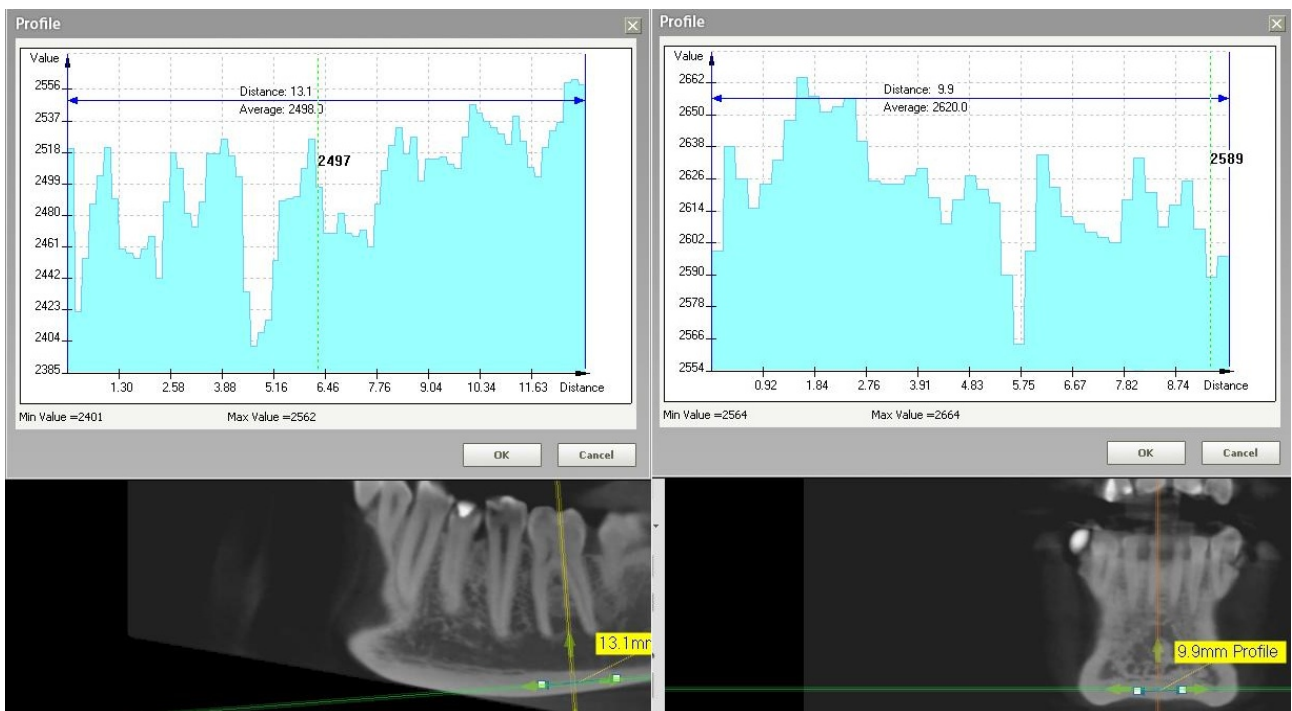
**Table 3. Correlation and linear function fit coefficients for relationship between absolute and transformed data, divided by localization for mandible**

	<i>r</i>	<i>R</i> <sup>2</sup>	<i>a</i>	<i>b</i>	<i>p</i>
Vestibular cortical plate in mandible - anterior	0.888	0.788	0.0001	0.317	< 0.0001
Trabecular bone in mandible - anterior	0.882	0.778	0.0002	0.109	< 0.0001
Lingual cortical plate in mandible - anterior	0.722	0.521	0.0001	0.390	< 0.0001
Vestibular cortical plate in mandible - lateral	0.659	0.434	0.0002	0.310	< 0.0001
Trabecular bone in mandible - lateral	0.865	0.749	0.0002	0.079	< 0.0001
Lingual cortical plate in mandible - lateral	0.657	0.432	0.0002	0.248	< 0.0001
All data	0.901	0.811	0.0002	0.118	< 0.0001

*r* – Pearson's correlation coefficient; *a* – slope; *b* – intercept; *p* – significance.

**Table 4. Mean, standard deviation and p value of the relative bone density for vestibular cortical plate, lingual cortical plate and trabecular bone in anterior and posterior mandible. A/D (Vestibular cortical plate to the highest reading), B/D (Lingual cortical plate to the highest reading), C/D (Trabecular bone to the highest reading)**

	Anterior mandible		Posterior mandible		Student's <i>t</i>
	Range	Mean ± SD	Range	Mean ± SD	
(A/D)	0.4695 – 1.0	0.8381 ± 0.1447	0.56 – 1.0	0.8160 ± 0.1225	<i>P</i> = 0.466
(B/D)	0.6206 – 1.0	0.8528 ± 0.1078	0.2557 – 0.9541	0.7081 ± 0.1176	<i>P</i> < 0.001
Student's <i>t</i>	<i>P</i> = 0.618		<i>P</i> < 0.001		
(C/D)	0.2332 – 0.8399	0.5886 ± 0.1451	0.2332 – 0.6902	0.4304 ± 0.1150	<i>P</i> < 0.001



**Figure 4.** The measurements of basal cortical reference value (BCRV) located along mandibular lower edge below the first molar and in the midline.

Student t test was used to determine the differences in relative bone density between anterior and posterior mandible, for trabecular bone and both corticals. The mean, standard deviation, maximum and minimum value were calculated and the value of  $p$  was applied for each study group [Table 4](#).

Finally, additional three measurements as basal cortical reference values (BCRV) of bone density were made for each patient, along mandible lower edge located in the midline and below the first right and left molar ([Figure 4](#)).

In purpose to check the possibility to replace the HV by the BCRV the multivariate analysis of variance for repeated measures with Post - hoc analysis for multiple comparisons was performed using Bonferroni correction. Additionally  $r$  - Pearson's correlation coefficient between HV and BCRV (only one value chosen from the same location) was also calculated.

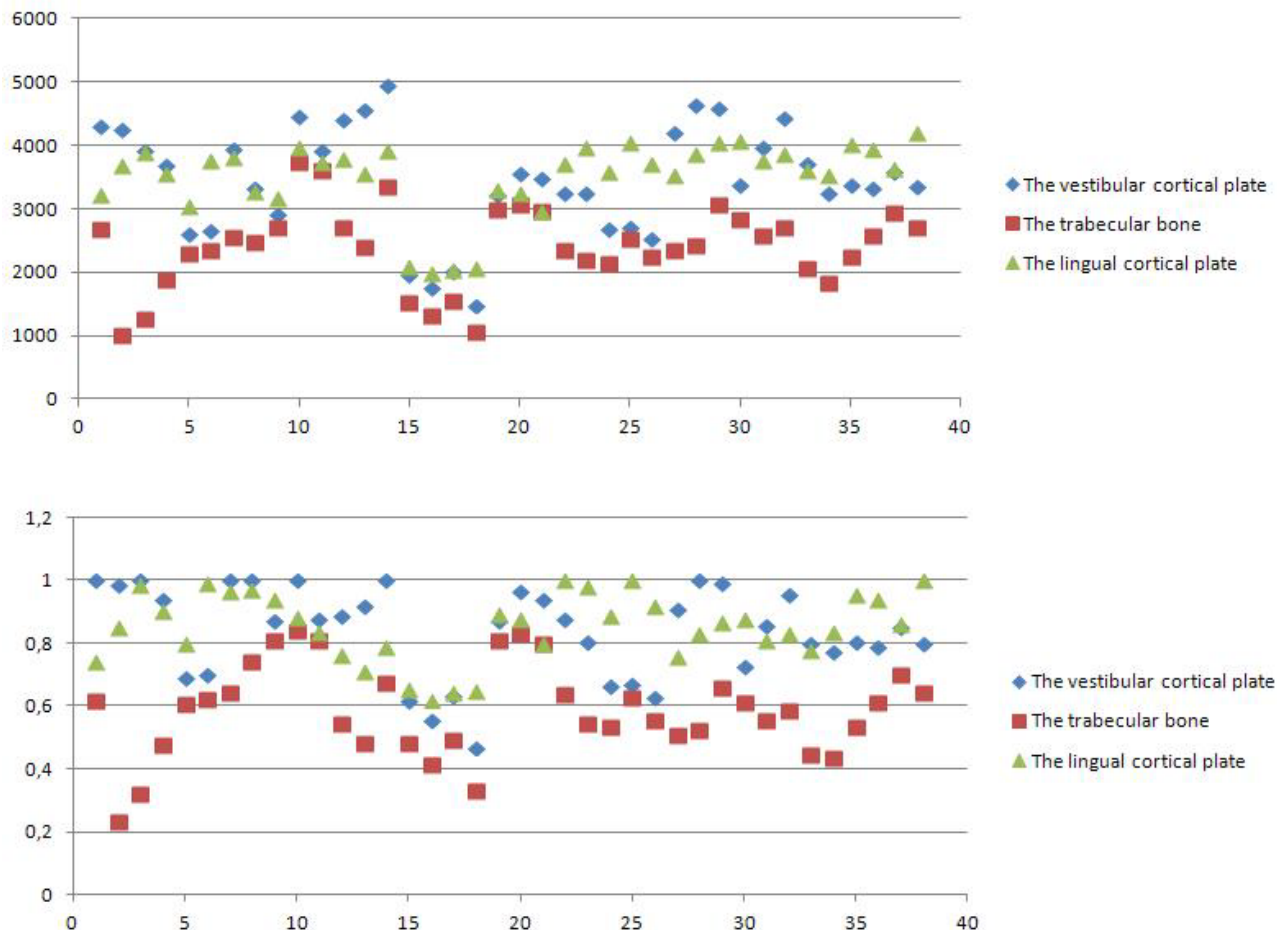
### 3. Results and Discussion

The results in rescaled and relative GVs were grouped separately for anterior and posterior part of the mandible and illustrated by graph points ([Figure 5](#), [Figure 6](#)).

Statistically significant very strong positive correlation was observed between relative and rescaled GV for all available data:  $r = 0.901$ ;  $p < 0.0001$  ([Table 3](#)). Relative GV shared 81% of variability with rescaled GV, as shown by  $R^2$  coefficient, which equaled 0.811 in our study ([Figure 7](#)).

In each of the localizations a statistically significant, positive correlation was observed at  $p < 0.0001$ , however, the strength of the relationship  $r$  varied from 0.657 to 0.888. The  $R^2$  coefficient of determination also varied from 0.432 to 0.788 which indicates slightly better correlations between relative and rescaled GV for anterior mandible. Mean values with standard deviation of relative radiological density of cortical plates and trabecular bone were illustrated in [Table 4](#). The statistically significant difference ( $p < 0.0001$ ) was found between anterior and posterior mandible for lingual cortical plate (approx.18% difference), trabecular bone (approx. 27% difference) and between posterior vestibular and lingual cortical plate (approx.13% difference). The differences were not statistically significant between vestibular and lingual cortical plate for anterior mandible and also for vestibular cortical plate between anterior and posterior mandible. The HVs with BCRVs measured at the lower border of the mandible were illustrated by graph points jointly to enable visual evaluation ([Figure 8](#)).

The results of multivariate analysis of variance were statistically significant:  $F(3;14) = 23.21$ ;  $p < 0.001$ ;  $\eta^2 = 0.83$  ([Table 5](#)) and Post - hoc analysis for multiple comparisons with Bonferroni correction showed that value in region 46 was significantly lower than values for region 36 ( $p < 0.001$ ) and in the midline of the mandible ( $p = 0.028$ ). For this reason the Pearson correlation coefficient between HV and BCRV was used yielding correlation coefficient  $r = 0.640$  with coefficient of determination  $R^2 = 0.409$  [Figure 9](#).



**Figure 5.** The graph in a) rescaled GVs and b) relative GVs illustrated measurements in anterior mandible

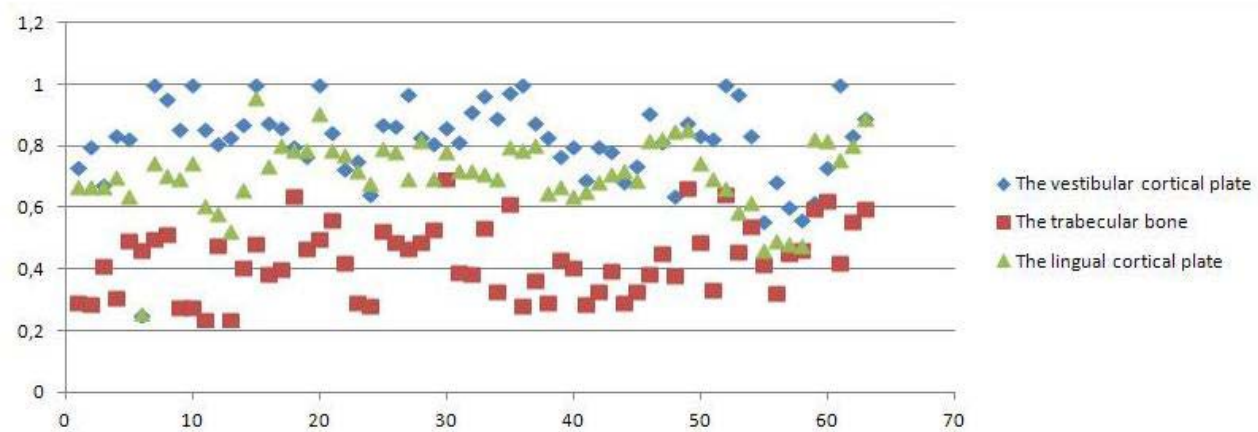
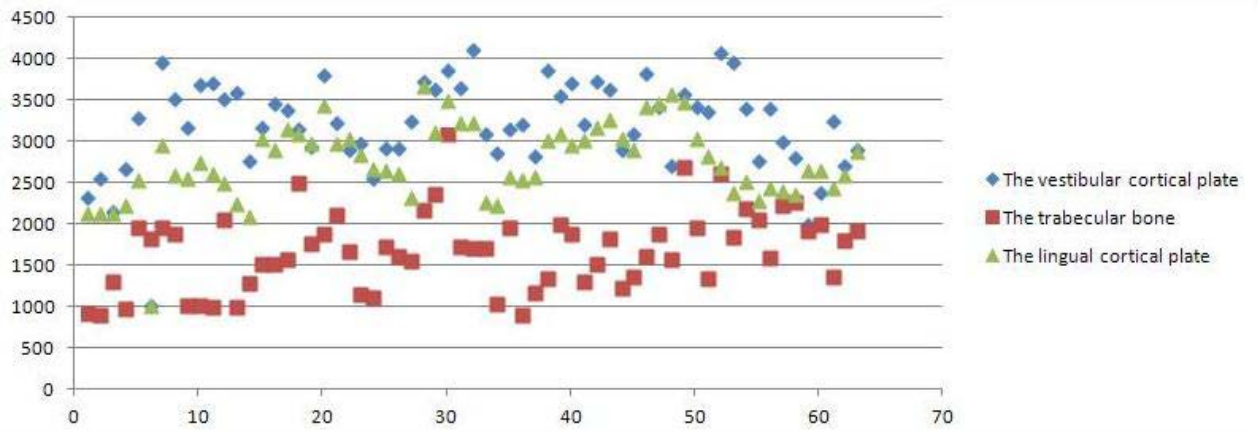


Figure 6. The graph in a) rescaled GVs and b) relative GVs illustrated measurements in posterior mandible.

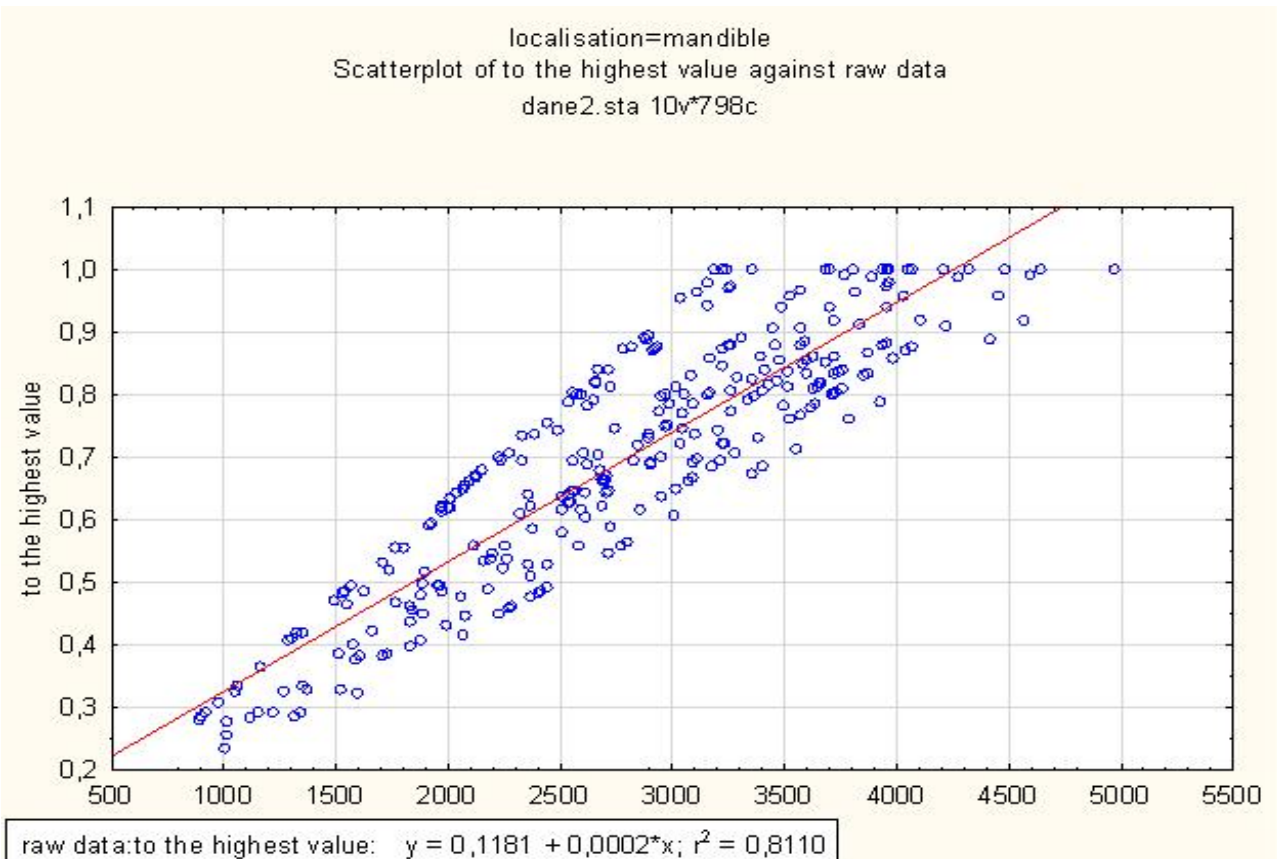


Figure 7. Correlation and linear function fit coefficients for relationship between relative GV and rescaled GV

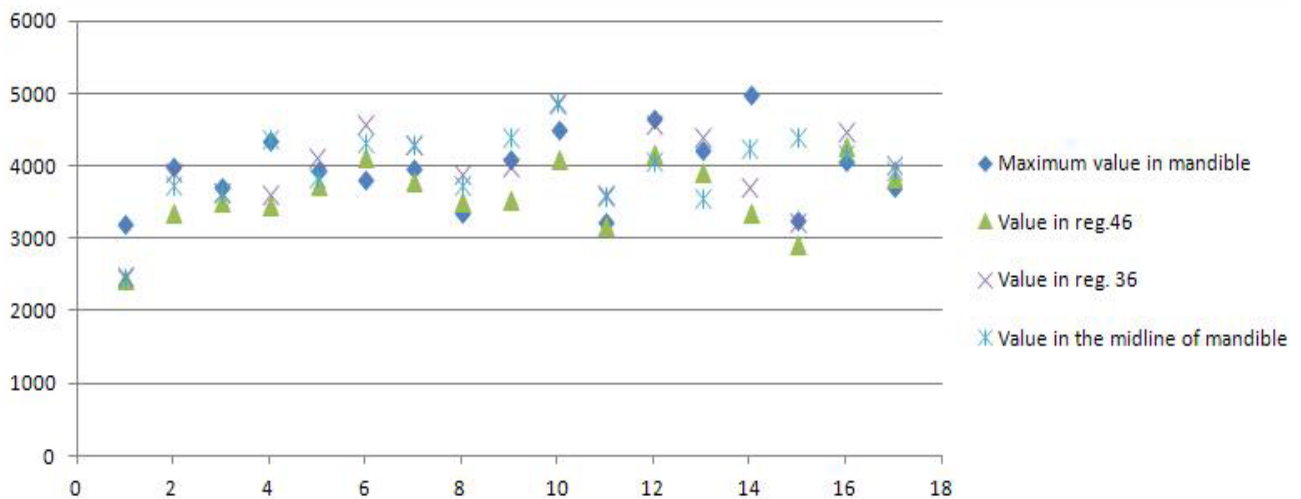


Figure 8. Correlation between maximum value in mandible, value in region 36 and 46 and value in the midline of mandible

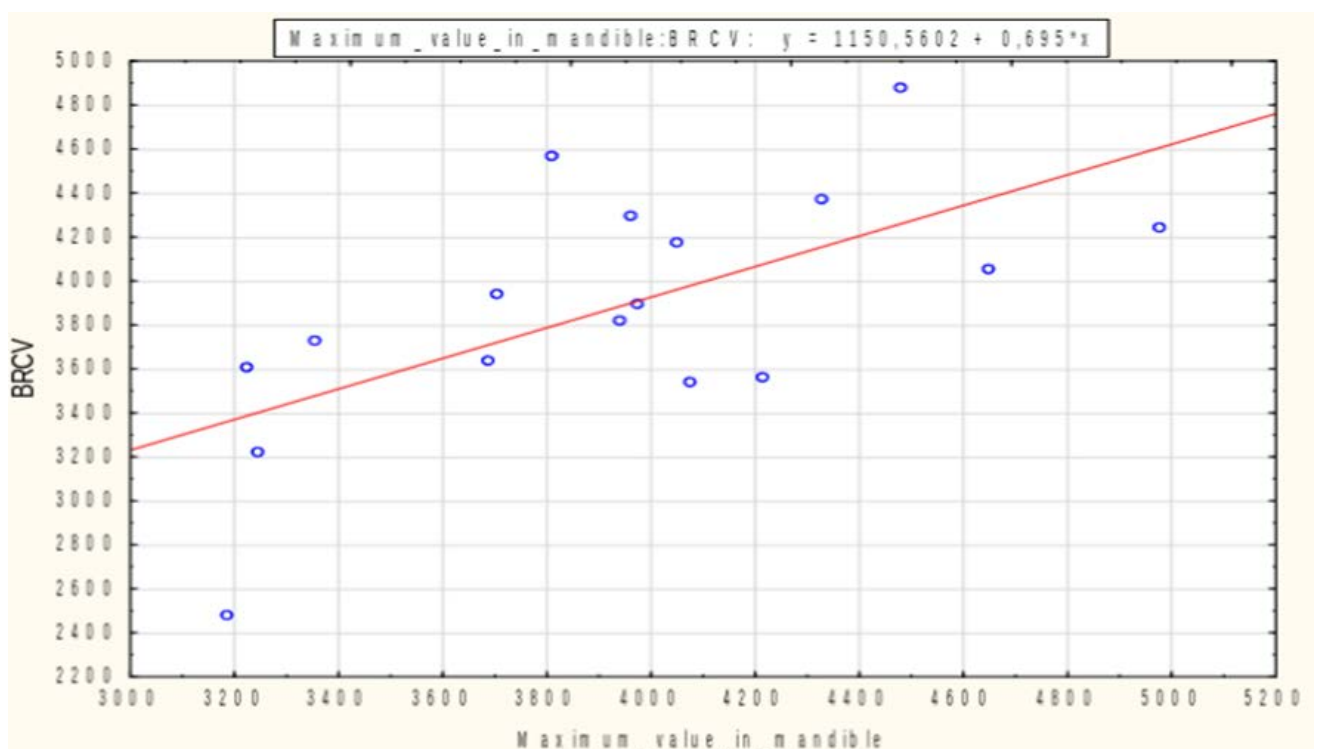


Figure 9 Maximal value in mandible vs. BRCV:  $r=0.640$ ;  $R^2=0.409$ ;  $a=0.695$ ;  $b=1150.56$ ;  $p<0.006$ ;  $r$  – Pearson's correlation coefficient;  $R^2$  – coefficient of determination;  $a$  – slope;  $b$  – intercept;  $p$  – significance.

The measurements of the radiological bone density in the mandible using relative GV scale were used in this study. Understanding bone physiology, function, assessing bone density and their changes in clinical reality is a challenging issue. Increasing CBCT usage for dental purposes gives the possibility to look inside and monitor bone structures not only for local changes but also in a wider perspective. Subtle changes in delicate dental bone structures can be of great importance because of the general health of the patients. Bone quality evaluation is mainly based on its radio density, which is closely related to its structure. Bone structure rich in micro structural connections will result in higher grey values. The literature shows that direct comparison of grey values from different CBCT examination may be charged with significant errors for various reasons [1,2,3,9,12,13,16] still, comparing the relative differences within one study

may have clinical value [10]. Conscious evaluation of numerical value of CBCT image with full awareness of this technique's limitations, is of great value. GVs are well correlated with biomechanical properties of bone [14,15,17]. The results of this research showed that in both anterior and lateral section of the mandible, vestibular and cortical bone have a much higher radiological density than the trabecular one which well reflects mandibular anatomy. Analyzing the received data, it can be noticed that the range of measured values is noticeably wide, starting from 899 to 4976 GV in the modified scale (Figure 5, Figure 6). Looking for the mean of relative GVs for mandibular corticals and for trabecular bone, distinct differences between corticals and trabecular bone density were disclosed. The obtained results of mean relative GVs in anterior part of both mandible compared with maxilla from the other study were on similar level

**Table 4 [11].** In anterior section, vestibular relative mean GV of cortical plate was slightly lower compared with one in maxilla but lingual/palatal cortical relative mean GV for both jaws had close values. Anterior trabecular mean relative GVs were similar with slightly lower level for the mandible. This findings suggest that anterior part of the maxilla has bone density similar to the anterior part of the mandible. For the side section of the mandible, both corticals had similar mean relative GV (with vestibular cortical slightly higher than the lingual one), which were significantly higher than the corresponding relative GV for maxilla. The trabecular mean relative GV was higher than the analogous one in maxilla. For both jaws relative mean GVs for cortical plates were close to each other and nearly twice as high as of the trabecular bone. This is in accordance with well known clinical frailty of lateral part of maxilla. In anterior mandible lingual cortical relative mean GV was higher than the vestibular one, while in posterior mandible it was quite the opposite which information may be useful in planning dental implants. The standard deviation was nearly the same for all three measured groups, ranging from 0.10 to 0.14. Comparisons made between BCRV and HVs (**Figure 7**) showed that alveolar cortical maximum values and basal corticals of the mandible were roughly at the same level therefore multivariate analysis of variance was done. Although the mean BCRV of 46 was significantly lower than the mean for 36 ( $p < 0.001$ ) and in the midline of the mandible ( $p = 0.028$ ), the maximum difference was only about 9% which can be attributed as an error caused by other reasons such as different CBCT artifacts and inconsistencies well described by others [1,2,3,9,12,13,16]. Furthermore, the other three (BCRV in 36, in the midline and HV) differed only slightly with about 1% difference among them (**Table 5**).

**Table 5. ANOVA results for BCRV in region 36, 46 , in the midline of the mandible HV. M - mean; SE - standard error; 95% CI - 95% confidence interval; LL and UL - lower and upper limit of confidence**

	M	SE	95% CI	
			LL	UL
Maximum value in mandible	3932.47	123.82	3669.98	4194.96
Value in reg46	3600.24	115.53	3355.32	3845.15
Value in reg 36	3962.12	140.08	3665.15	4259.08
Value in the midline of mandible	3975.59	129.18	3701.75	4249.43

In order to clarify this issue the Pearson correlation coefficient between HV and BCRV was used yielding correlation coefficient  $r = 0.640$  which can be described as a strong with coefficient of determination  $R^2 = 0.409$  (**Figure 9**). In light of these findings, it can be hypothesized that the concept of using the relative GVs, instead of the original positive/negative GV scale, makes sense, and the use of HV or mandibular BCRV (when is it available) as a reference for calculating relative scale, is promising. Thus, clinical relative bone density evaluation can be introduced

to clinical practice without using artificial minifantom object to allow comparison for different CBCT examinations [9]. The observations from this study are promising but need to be more profound examined before introduced to clinical practice. This paper gives the basic information about relative grey value measurements of dental structures and their usage for bone tissue density comparisons for users who may be interested in evaluating jawbone quality.

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