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Three-dimensional bone microarchitecture assessment of human jaw bone using cone beam CT

콘빔 CT 영상을 이용한 사람 악골의 3차원 골 미세구조 분석

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ABSTRACT

Three-dimensional bone microarchitecture assessment of human jaw bone using cone beam CT

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1. Objective

The purpose of this study was to define the potential usability of cone beam computed tomography (CBCT) in the assessment of trabecular bone microarchitecture.

2. Materials and Methods

Sixty eight cylindrical bone specimens were prepared from 4 pairs of 4 human jaw bone. The specimens were scanned using both micro-CT and CBCT. The voxel sizes of micro-CT and CBCT were 19.37 μm and 100 μm, respectively. With micro-CT, additional reconstruction images with 96.87 μm voxel size were acquired to simulate the CBCT images of 100 μm voxel size. Three-dimensional (3D) morphometric analysis was performed in each set of images and the morphometric parameters were calculated. The correlation of parameters between the micro-CT and the CBCT was evaluated using the linear correlation test.

3. Results

The bone volume (BV), percent bone volume (BV/TV), trabecular separation (Tb.Sp), and degree of anisotropy (DA) of CBCT images showed strong correlations (Pearson correlation coefficient, $r > 0.5$) with those of micro-CT with 19.37 μm voxel size ($P < 0.05$). Although some parameters such as bone surface (BS), bone surface density (BS/TV), trabecular bone pattern factor (Tb.Pf), structural model index (SMI), and trabecular number (Tb.N) showed relatively weak correlation (Pearson correlation coefficient, $r < 0.5$), still, they showed statistically significant linear correlation ($P < 0.05$). Among the 3D morphometric parameters, DA showed the strongest correlation between CBCT and micro-CT with 19.37 μm voxel. The parameters showing linear correlation between CBCT and micro-CT with 19.37 μm voxel were consistent with those between CBCT and micro-CT with 96.87 μm.

4. Conclusion

Most morphometric parameters from CBCT were correlated with those of micro-CT. Parameters showing strong correlation such as BV, BV/TV, Tb.Sp, and DA would be used to evaluate the bone quality using CBCT.

Key words: trabecular bone, bone microarchitecture, micro-CT, cone beam CT

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Contents

I. Introduction

Bone quality is the one of the essential factors in predicting the success rate of implant installation.[1-3] Mechanical competence of bone is constituted with bone mass, structural properties (macro- and micro-architecture), and material properties. This is referred to as bone quality.[4,5] Dental implant is mainly in contact with trabecular bone rather than cortical bone, and trabecular bone directly contributes to implant stability.[1,6] Therefore, the evaluation of the trabecular microarchitecture would provide useful information for implant installation.

Microarchitectural characteristics of trabecular bone have been investigated by examining two-dimensional (2D) histologic sections of bone biopsies, combined with calculation of morphometric parameters using stereological method.[7] However, histologic examination requires the subject to be sacrificed in order to get the bone specimen. Also, this invasive technique allows tissue quantification in only a limited number of bone sections. Besides, the procedure is complex and time-consuming.

The image analyses of trabecular microarchitectures have been used as another technique in bone quality evaluation. For this kind of evaluation, computerized techniques for histomorphometric analysis based on plain radiographs have been adopted.[8,9] Although analysis of structure via tracing 2D radiograph such as fractal analysis has been proven to be efficient in evaluation of bone quality,[10,11] these methods have fundamental limitations in that the three-dimensional (3D) architecture was projected into the 2D plane.

Various analyzing techniques using 3D imaging modalities have been proposed in order to overcome the limitations. A multi-detector computed tomography (MDCT) with a maximum in-plain resolution up to 250 μm is not suitable to evaluate the individual trabeculae, which are less than 200 μm in diameter.[12-15] Among the recent developed CT scanners, micro-CT has been validated as a highly reliable tool to determine the trabecular bone parameters as a new reference method for ex vivo bone studies.[16,17] Despite the high accuracy of micro-CT, it is hardly used in clinical condition. Beside of its high radiation exposure, the subject should be sacrificed to get specimens due to the small field of view. High-resolution magnetic resonance (hr-MR) is one of imaging modalities that can analyze trabecular architecture and properties using high resolution technique of 100 μm to 300 μm voxel.[18,19] The limitations of hr-MR include the relatively long acquisition time, requirement for specialized coils, complex image analysis, and restricted accessibility.[20] For these reasons, there is no precisely suitable method among clinical imaging modalities for analyzing bone microarchitecture.

Cone beam CT (CBCT) was introduced in 1998 and became routine in diagnosis and treatment planning of dental implant and maxillofacial disease. Compared with MDCT, CBCT has decreased radiation exposure.[21] Moreover, CBCT equipment does not occupy large space and costs less for scanning. Many researches to evaluate the bone condition have been conducted using CBCT. However, most of them focused on the bone quantity such as alveolar bone width and height, density of bone, and visibility of anatomical landmarks.[22,23] Morphometric analysis of trabecular bone using CBCT has not been performed, since CBCT has been regarded as a reference method due to its low spatial resolution compared to the micro-CT. Recently, technical development made it possible to increase the spatial resolution of CBCT up to 80-100 μm. With this technical progress, CBCT is now suggested as a modality to analyze the trabecular microarchitecture at implant sites.[24,25] However, there is no consensus in the parameters useful in analysis of trabecular microarchitecture using CBCT.

The aim of this study was to investigate the relationship between 3D morphometric parameters from micro-CT and CBCT images, and to identify the specific parameter reliable in structural analysis using CBCT.

II. Materials and Methods

1) Bone specimens

Four sets of jaw bones were obtained from human cadaver. Using a micro-cutting and grinding system, the 300 CP precision parallel-control EXAKT (Apparatebau GmbH, Norderstedt, Germany), the mandibles and maxillae were cut as consecutive para-sagittal plates of 5 mm thick under continuous water irrigation. The para-sagittal plane was approximately perpendicular to the occlusal plane. Cylindrical specimens, including trabecular bone portion only, were harvested from each plate using a trephine bur of 4.9 mm in internal diameter. A groove was made on the medial surface of each specimen. The extracted bone specimens were maintained in a buffered 10% formalin solution. Figure 1 shows the schema of the procedures. Totally, 68 trabecular bone specimens were harvested.

2) Micro-CT image acquisition

The micro-CT examination of each bone specimen was performed using SkyScan1172 (SkyScan NV, Konich, Belgium). During the image acquisition, the bone specimens were kept moist with wet tissue around in a plastic tube. The specimen was placed on the holder between the X-ray source and the CCD camera, while the whole specimen was comprised in the field of view (FOV). The scanning parameters were set at 80 kV, 100 μA, a rotation step of 0.4° with total 192°

rotation, 0.5 mm aluminum filtration, and a voxel resolution of 19.37 μm. The projection data were then reconstructed using NRecon (ver. 1.6.1.4, Skyscan, Konich, Belgium) and saved as BMP files. The same raw images were reconstructed in 96.87 μm voxel size which was similar to that of CBCT, and then stored.

3) CBCT image acquisition

After the micro-CT examination, CBCT scanning was performed using Alphard Vega (Asahi Roentgen, Kyoto, Japan). The specimens were kept moist in the same way as when it was under micro-CT examination. The scanning protocol used D-mode with 51 mm x 51 mm FOV. The scanning conditions were constant with 360° rotation, 60 kVp tube voltage, 6 mA tube current, and 17 s exposure time for all specimens. The isotropic voxel size was 100 μm. The axial images were stored as DICOM format by the manufacturer's reconstruction software. The images were transformed using a Picture Archiving and Communication System (PiView STAR^{TM} ; INFINITT, Seoul, Korea) as forms of BMP file.

4) Three-dimensional image analysis

The images were segmented to allow the trabecular bone structure quantification using the SkyScan CT analyzer software (CTAn, ver. 1.10, SkyScan NV, Konich, Belgium). The region of interest (ROI) in the axial plane was set as a circular area in the bone specimen. The size of ROI was the same as that of the actual specimen. The height of cylindrical volume of interest (VOI) was determined as 5 mm just below the groove. The fixed threshold value through histogram analysis was applied to binarization of micro-CT image. For binarization of CBCT image, the threshold values were visually determined by an operator to give the most adequate post-processed images with only minimal changes of the trabecular bone from the original images. From the resultant binary images, CBCT and micro-CT images were reconstructed in 3D and the trabecular morphometric parameters were calculated.

The morphometric parameters measured by CTAn software were as followed; bone volume (BV), percent bone volume (BV/TV), bone surface (BS), bone specific surface (BS/BV), bone specific density (BS/TV), trabecular bone pattern factor (Tb.Pf), structure model index (SMI), trabecular thickness (Tb.Th), trabecular number (Tb.N), trabecular separation (Tb.Sp), and degree of anisotropy (DA). The definition of each 3D morphometric parameters are seen in Table 1.

5) Statistical analysis

The mean and standard deviation were calculated for all parameters. Repeated measures ANOVA were applied to compare the differences between the parameters from CBCT, 19.37 μm, and 96.87 μm voxel size micro-CT.

The relationship between the parameters from CBCT and micro-CT images was evaluated by linear correlation analyses. The relationship between the parameters from micro-CT images of 19.37 μm voxel and CBCT images was analyzed using Pearson correlation coefficients. Additionally, the correlation between the parameters from micro-CT images of 96.87 μm voxel and CBCT images was also access to show the relationship between the parameters from CBCT and the reconstructed micro-CT images of similar voxel size to CBCT images.

IBM SPSS Statistics (ver. 21, SPSS Inc., Chicago, IL, USA) was used for all statistical analyses. The significance in correlation was set at the p level below 0.05.

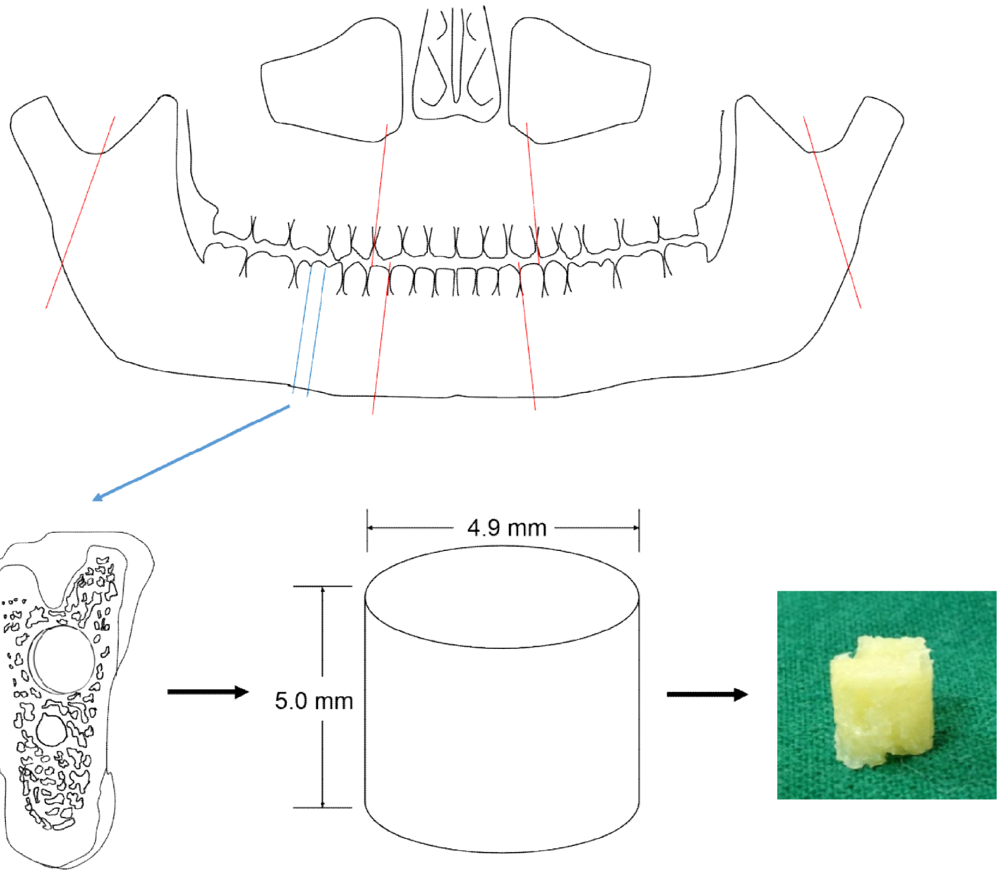


Figure 1. Schema describes the method of preparing bone specimens.

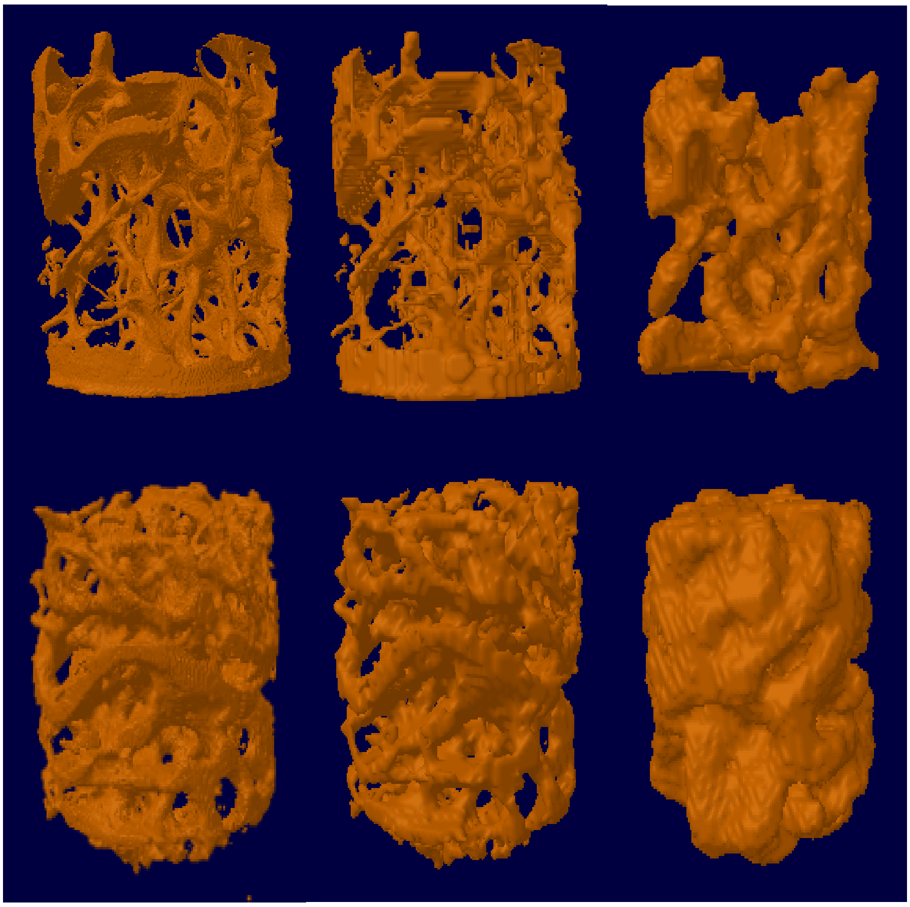


Figure 2. Examples of 3D reconstructions of micro-CT and CBCT data from bone specimens with high and low percent bone volume are seen. Note the prominent merging and thickening of trabeculae in CBCT image.

Table 1. The descriptions of three-dimensional morphometric parameters

Abbreviation (unit)	Parameter name	Definition
TV (mm^3)	Tissue volume	Total volume of the volume-of-interest (VOI). Measured by marching cubes volume model of the VOI
BV (mm^3)	Bone volume	Total volume of binarized objects within the VOI. Measured by marching cubes volume model of the binarized objects
BV/TV (%)	Percent bone volume	The proportion of the VOI occupied by binarized solid objects.
BS (mm^2)	Bone surface	The surface area of all the solid objects within the VOI, measured in 3D. Measured by marching cubes method
BS/BV (mm^{-1})	Bone surface / volume ratio ("specific surface")	The ratio of solid surface to volume measured in 3D within the VOI. Useful basic parameter for characterizing the thickness and complexity of structures.
BS/TV (mm^{-1})	Bone surface density	The ratio of surface area to total volume measured as described above in 3D, within the VOI.
Tb.Pf (mm^{-1})	Trabecular bone pattern factor	Inverse index of connectivity
SMI	Structural model index	Relative prevalence of rods and plates in 3D structure. Involves a measurement of surface convexity
Tb.Th (mm)	Trabecular thickness	True 3D thickness of trabecular bone. Measured by "sphere-fitting" method
Tb.N (mm^{-1})	Trabecular number	The number of traversals across a trabecular or solid structure made per unit length on a random linear path through the VOI.
Tb.Sp (mm)	Trabecular separation	The thickness of the spaces as defined by binarization within the VOI.
DA	Degree of anisotropy	Isotropy is a measure of 3D symmetry or the presence or absence of preferential alignment of structures along a particular directional axis. Measured by mean intercept length (MIL) and Eigen analysis.

III. Results

The mean values of 3D morphometric parameters from micro-CT and CBCT images are seen in Table 2. When micro-CT of 19.37 μm voxel were compared with CBCT, all the values of parameters except SMI showed significant difference ($P<0.05$). Similarly, the differences of mean values came out to be statistically significant in all parameters between micro-CT of 96.87 μm voxel and CBCT. The BV, BV/TV, Tb.Th, and Tb.Sp values were greater in CBCT images compared to micro-CT images. Examples of 3D reconstructed model from each site are seen in Figure 2. Thickening and agglomerating of trabeculae were seen in reconstruction of CBCT images.

The relationship between 3D structural parameters from micro-CT images with 19.37 μm voxel and CBCT are presented in Table 3. All parameters except BS/BV and Tb.Th showed the linear relationships between the two imaging modalities. Among the parameters, the BV, BV/TV, Tb.Sp, and DA from CBCT showed strong correlations (Pearson correlation coefficient, $r > 0.5$, $P<0.05$) with those of micro-CT with 19.37 μm voxel (Figure 3). Although the correlation was weak (Pearson correlation coefficient, $r < 0.5$), the BS, BS/TV, Tb.Pf, SMI, and Tb.N also showed statistically significant linear correlation ($P<0.05$). Among the 3D morphometric parameters, DA, which represent the degree of anisotropy, showed the strongest correlation between the images of CBCT and micro-CT with 19.37 μm voxel ($r = 0.693$, $P <0.05$).

The tendency of parameter correlation in reconstructed micro-CT with 96.87 μm and CBCT was similar to that of micro-CT with 19.37 μm voxel and CBCT. All parameters except the TS, BS/BV, and Tb.Th showed linear correlation relationship (Table 3). The BV, BV/TV, Tb.Sp, and DA revealed strong linear correlation ($r > 0.5$, $P < 0.05$) between the images of micro-CT reconstructed with 96.87 μm voxel size and CBCT (Figure 4). The BS, BS/TV, Tb.Pf, and Tb.N demonstrated intermediate correlation. These values showed slightly higher correlation coefficients than those between 19.37 μm voxel reconstructed micro-CT and CBCT. The DA also showed the strongest relationship ($r = 0.776$).

Table 2. Mean value of morphometric parameters for different imaging protocols

	micro-CT (19.37 μm)	micro-CT (96.87 μm)	CBCT (100 μm)
BV	26.74 ± 11.79	25.66 ± 12.16	72.14 ± 18.81
BV/TV	18.53 ± 8.17	18.15 ± 8.60	49.32 ± 12.86
BS	410.96 ± 135.09	372.54 ± 123.81	234.43 ± 38.36
BS/BV	16.80 ± 4.76	16.33 ± 5.42	3.44 ± 0.85
BS/TV	2.85 ± 0.94	2.63 ± 0.88	1.60 ± 0.26
Tb.Pf	2.68 ± 2.72	1.30 ± 1.90	0.28 ± 0.66
SMI	1.24 ± 0.79	1.42 ± 0.58	1.13 ± 0.70
Tb.Th	0.24 ± 0.07	0.38 ± 0.11	1.17 ± 0.30
Tb.N	0.77 ± 0.27	0.47 ± 0.17	0.43 ± 0.09
Tb.Sp	0.83 ± 0.17	0.95 ± 0.19	1.10 ± 0.26
DA	1.90 ± 0.63	1.87 ± 0.63	1.59 ± 0.37

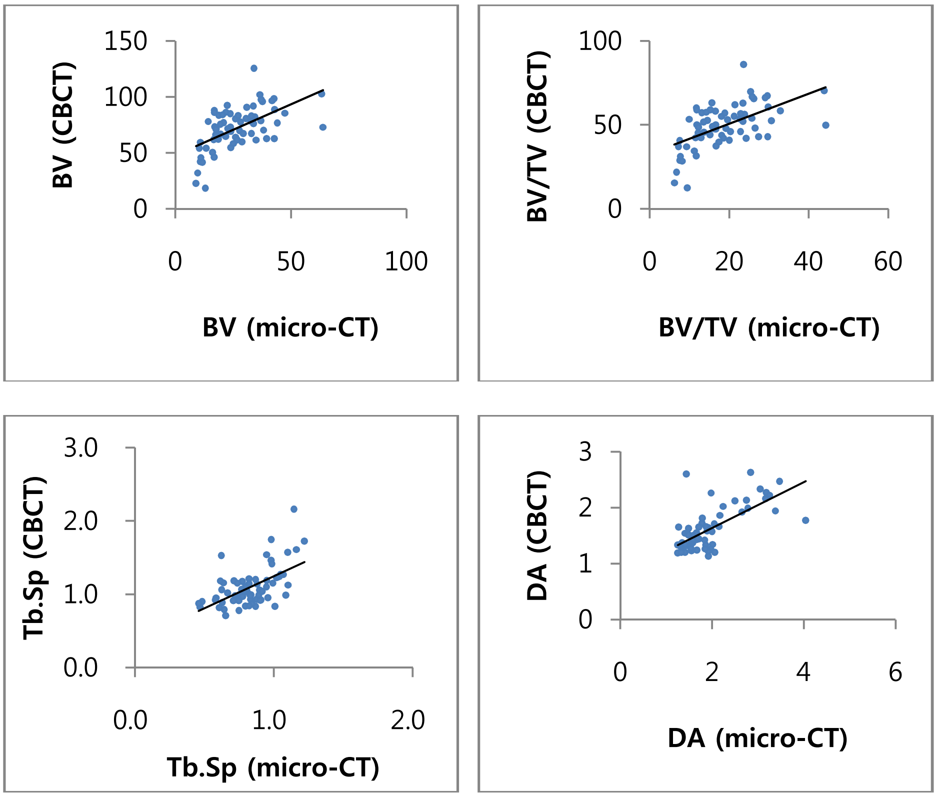
BV: bone volume, BV/TV: percent bone volume, BS: bone surface, BS/BV: bone specific surface, BS/TV: bone specific density, Tb.Pf: trabecular bone pattern factor, SMI: structural model index, Tb.Th: trabecular thickness, Tb.N: trabecular number, Tb.Sp: trabecular separation, DA: degree of anisotropy

Table 3. Pearson correlation coefficient of morphometric parameters between micro-CT and CBCT protocols

	Micro-CT(19.37 um) - CBCT (100 um)	Micro-CT(96.87 um) - CBCT (100 um)
BV	.568*	.538*
BV/TV	.607*	.577*
BS	.268*	.301*
BS/BV	.172	.176
BS/TV	.265*	.301*
Tb.Pf	.295*	.418*
SMI	.266*	.267*
Tb.Th	.051	.123
Tb.N	.253*	.321*
Tb.Sp	.577*	.642*
DA	.693*	.776*

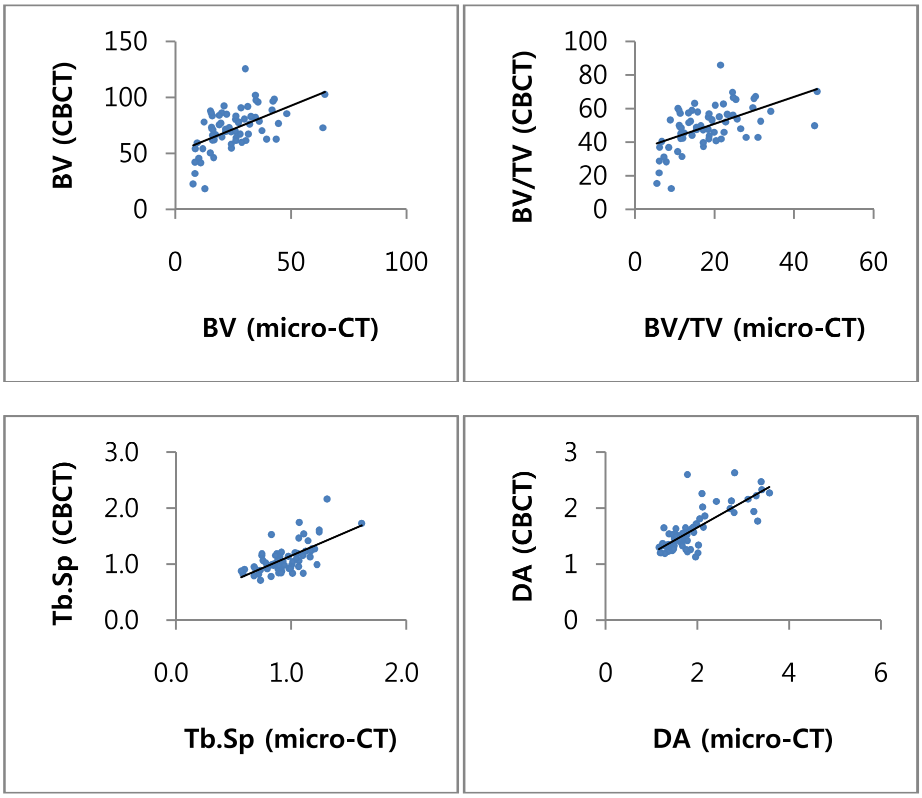
BV: bone volume, BV/TV: percent bone volume, BS: bone surface, BS/BV: bone specific surface, BS/TV: bone specific density, Tb.Pf: trabecular bone pattern factor, SMI: structuremodel index, Tb.Th: trabecular thickness, Tb.N: trabecular number, Tb.Sp: trabecular separation, DA: degree of anisotropy

* Correlation is significant at the 0.05 level (2-tailed).



BV: bone volume, BV/TV: percent bone volume, Tb.Sp: trabecular separation, DA: degree of anisotropy

Figure 3. Scatter plots of parameters show strong correlation between CBCT and micro-CT (19.37 μm).



BV: bone volume, BV/TV: percent bone volume, Tb.Sp: trabecular separation, DA: degree of anisotropy

Figure 4. Scatter plots of parameters show strong correlation between CBCT and micro-CT (96.87 µm).

IV. Discussion

There have been many attempts to evaluate bone quality using CBCT, however they mostly focused on the aspect of bone density.[26,27] Trabecular microarchitecture, as another determinant factor of bone quality, should be also evaluated since trabecular microarchitecture contributes to bone strength as well as bone healing and implant retention.[4,6,28] Recently, there have been some studies to analyze the trabecular microarchitecture around implant sites using CBCT.[12,29,30] However, their studies used the high-resolution image of 80 μm voxel which was not widely used in clinics.[29,31,32] Furthermore, most studies using CBCT were limited to few specific parameters such as BV/TV and Tb.Th.[12,32,33] Among various measurement analysis, the selection of specific parameters that can reveal the accurate structural features of trabecular bone seem to be important. Still, the significant parameters are not in agreement among the studies using CBCT.

In the present study, 3D morphometric parameters using CBCT were compared with those of micro-CT as a gold standard. Through the comparisons, CBCT morphometric analysis showed higher values in BV, BV/TV, and Tb.Th than micro-CT, while it showed lower values in BS, BS/BV, and BS/TV. The parameters of BV, BV/TV, and Tb.Th representing the bone mass increased in CBCT. The values of BS, BS/BV, and BS/TV related with complexity of bone pattern decreased in CBCT. As seen in Figure 2, the reconstructed bone specimen using CBCT images showed thicker trabeculae and agglomerated bone pattern. The possible explanation for this exaggeration of bone mass in CBCT is due to its lower spatial resolution. Several researches showed that decreasing the image resolution resulted in overestimation of some parameters especially Tb.Th.[34-37] Larger voxel size may decrease the accuracy due to the loss or merging of trabeculae. The Tb.Th from CBCT images showed much thicker than the expected value from the micro-CT images reconstructed as almost same as CBCT voxel size. This implies that the actual 3D image resolution is influenced by other factors as well as the voxel size. One of the factors is the amount of noise. CBCT has inevitable limitation due to its high degree of noise which reduces the spatial and contrast resolution. Many studies have applied various filters to reduce the noise on CBCT images; however, no definite method reducing noise critically was defined. In the present study, no additional algorithm was applied except the manufacturer's image processing algorithm.

Many parameters of CBCT morphometric analysis revealed the linear correlation with the parameters of micro-CT analysis, despite the overestimation of some parameters due to image resolution. These findings indicated that both modalities were highly correlated based on the result, although the absolute values were different. The BV, BV/TV, BS, BS/TV, Tb.Pf, SMI, Tb.N, Tb.Sp, and DA showed linear correlation relationships, and among these parameters the DA showed the strongest correlation. There were few reports which compared the parameters of CBCT and micro-CT. For some parameters, the results were in agreement with present study while the others were not. In case of the Tb.Th, Szabo et al.[38] and Ibrahim et al.[29] reported the strong correlation between CBCT and micro-CT contrast to the present study. On the other hand, Van Dessel et al.[31] showed that BV/TV, BS/TV, Tb.Sp, Tb.N, total porosity, and connectivity density had correlation between the two imaging modalities; however, there was no significant correlation in Tb.Th. The results from the current study were consistent with the result of the above study. The studies showing the relationship of parameters from CBCT and micro-CT images hired different parameters to compare and there was no common parameter showing the correlation.

The BV and BV/TV are the parameters associated with the amount of bone, and the BV/TV is the parameter that can represent the density of the bone. Naitoh et al.[12] reported that the BV/TV from CBCT images was highly correlated with CT numbers from MDCT images, suggesting that trabecular bone morphometry could be used to evaluate the density of mandibular trabeular bone. Furthermore, the grayscale values of CBCT images are not reliable to assess the density of bone currently. Take these together, the BV/TV parameter which showed the strong correlation in the present study could be a predictable value to represent the bone density using CBCT in clinic.

The Tb.Pf, an indicator of trabecular connectivity, showed linear correlation between micro-CT and CBCT images. In addition, the SMI, Tb.N and Tb.Sp showed weak correlation between two imaging modalities. The Tb.Pf, SMI and DA are parameters representing the 3D configuration and arrangement of bone. The correlations of these parameters between CBCT and micro-CT images imply that the microarchitectural analysis using CBCT will be a useful method in bone quality evaluation regarding the trabecular bone structure as well as bone density. The DA, degree of anisotropy, is the degree of trabecular polarization in a particular direction. An algorithms based on the measurements of mean intercept length (MIL) in several directions was utilized to determine average orientation of trabeculae in three dimensions. The anisotropy of trabecular bone revealed the relation with the direction of applied stress, therefore DA is one of the predicting factors of mechanical strength of trabecular bone.[39,40] Through few studies on the DA in the jaw bones, it was revealed that the condylar trabecular bone aligned anisotropically coincided with mechanical directions.[41,42] Huh et al.[43] proposed that the DA can be a strong contributor in the prediction of trabecular strength. According to them, the DA behaved independently to other 3D morphometric parameters. Thus, it would contribute to trabecular strength prediction without being interlaced with other factors. In the present study, the strongest correlation was shown in DA between micro-CT and CBCT images. Considering the highly correlated DA between two imaging modalities, CBCT can reproduce the arrangement of trabeculae, despite its large voxel size. Consequently, DA would be a strong predictor for trabecular strength when using CBCT.

The reconstruction image of micro-CT with 96.87 μm voxel size was used to evaluate the relationship between the CBCT and micro-CT at similar voxel size to CBCT. There were some researches that examined the effect of reconstruction voxel size on stereological measures for human cancellous bone.[35 36,44,45] Liu et al.[45] showed that the measurements of HR-pQCT images (82 μm) had stronger correlation with those of micro-CT images with the similar voxel size (80 μm) than the smaller voxel size (25 μm). This tendency was analogous to the present study. The correlation coefficients between CBCT and micro-CT at similar voxel size (96.87 μm) were higher than the coefficients between CBCT and micro-CT at 19.37 μm voxel in most morphometric values. Kim et al.[35] reported that the error in Tb.Th, BS/BV, Tb.N, and Tb.Sp were significantly correlated with increasing in reconstruction voxel size. The tendency was consistent with the differences of values as shown in Table 2. This might originate from the loss or merging of nearby trabeculae as the reconstruction voxel size increase. Despite the fact, in the present study, the parameters correlated between micro-CT with 96.87 μm voxel and CBCT were the same as the parameters correlated between micro-CT with 19.37 μm and CBCT.

Limitations should be recognized in this study. One of the major problems is about the threshold to separate bone trabeculation from marrow space set as the empirical value. Setting the accurate threshold is the major problem in micro-CT morphometric analysis. Archimedes principle is regarded as the best method to determine the threshold.[46] However, applying Archimedes method is a time-consuming procedure and not always practical. Several methods have been developed to determined the threshold, and the parameter values were changed according the different threshold methods.[47] The threshold is often determined visually, or by a software-supplied algorithm. The present study used the global threshold which was set as the value to change bone structure minimally, comparing the scanning images and segmented images visually. The determined threshold may influence the 3D morphometric parameters like other studies revealed.[37, 46] On the other hand, Hara et al.[48] found that differences in value of DA and Tb.N for threshold variation were regligible. Hence, DA values which showed the strong correlation in this study would be more reliable parameter using CBCT analysis. Yet, there is no study about the threshold determination in CBCT imaging. Further research about the method of thresholding for CBCT image segmentation is needed.

Apart from the threshold problem, the noise is another important factor to influence the morphometric analysis using CBCT images. Signal to noise ratio (SNR) plays an important role in determining the capability of an imaging system for depicting delicate anatomical structures. CBCT has a lower SNR than micro-CT and it also shows reduced contrast due to large amount of scatter radiation. Also it is largely susceptible to beam-hardening and edge-aliasing artifacts.[49] With lower spatial resolution, larger amount of noise induced errors in CBCT structural values such as thickening of trabeculae and increasing the percent bone volume.

The present study analyzed human jaw bone, however, it was not the ‘true’ in vivo study. When the study using in vivo model, there may be other possible problems including patient movement artifact and noise produced from surrounding soft tissues.

Previous studies have revealed that 3D microarchitecture parameters using micro-CT images correlated with bone biomechanical strength representing bone quality. The present study demonstrated that the CBCT system using high resolution (100 μm) provided some reliable trabecular bone microarchitectural measurement compared with micro-CT. This indicates the possibility of practical application of CBCT in evaluation of bone quality regarding the microarchitecture of jaw trabecular bone. For the real use of CBCT, further researches are needed. First, the direct correlation between the bone mechanical strength and the morphometric parameters using CBCT images should be evaluated. Second, the definite algorithms to reduce the noise of CBCT have to be developed. Third, the study on the method for determining the threshold in CBCT image and the accuracy of morphometric parameters according to threshold is also needed.

Finally, the clinical study using in vivo model should be performed using CBCT 3D microarchitectural analysis for diagnosis of disease. It is expected that the use of CBCT can reduce the radiation exposure and cost for evaluation of bone quality especially in implant dentistry.

V. Conclusion

This study demonstrated that the 3D morphometric parameters from CBCT images showed correlated relationships with the micro-CT. The result suggests that the method using CBCT offers reliable easy access to the trabecular bone microarchitecture, especially for dental implant installation and bone healing. The parameters showing strong correlation, such as BV, BV/TV, Tb.Sp, and DA, could be used to evaluate the bone quality using CBCT.

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국문요약

콘빔 CT 영상을 이용한 사람 악골의 3차원 골 미세구조 분석

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1. 목적

치과용 콘빔 CT 에서 계측된 악골의 3 차원 미세구조 파라미터와 마이크로 CT 에서 계측된 미세구조 파라미터 사이의 상관관계를 통해 치과용 콘빔 CT 의 생체 내 해면골 미세구조 분석 가능성을 알아보고자 한다.

2. 재료 및 방법

사체로부터 얻어진 각각 4 개의 상하악골에서 여러 부위로부터 채취한, 직경 4.9 mm, 높이 5 mm 인 원기둥 형태의 골시편 68 개를 마이크로 CT 와 콘빔 CT 로 각각 촬영하였다. 마이크로 CT 와 콘빔 CT 영상의 voxel 의 크기는 각각 19.37 μm 와 100 μm 였으며, 마이크로 CT 영상의 경우 reconstruction voxel 크기를 콘빔 CT 와 유사한 96.87 μm 로도 설정하여 골 미세구조 분석을 추가로 시행하였다. Pearson correlation coefficient 를 이용하여 voxel 크기 19.37μm 인 마이크로

CT 와 100 μm 인 콘빔 CT 의 골 미세지표 상관관계를 먼저 분석하고, voxel 크기 96.87 μm 인 마이크로 CT 와 100 μm 인 콘빔 CT 의 골 미세지표 간 상관관계도 추가로 분석하였다.

3. 결과

선형상관분석에서 19.37 μm 로 촬영된 마이크로 CT 영상과 100 μm voxel 크기의 콘빔 CT 영상에서 추출된 3 차원 골 미세구조 파라미터들 중 bone volume (BV), percent bone volume (BV/TV), trabecular separation (Tb.Sp), degree of anisotropy (DA)는 상관계수 (Pearson correlation coefficient, r)가 0.5 이상으로 강한 상관관계를 보였으며, bone surface (BS), bone surface density (BS/TV), trabecular bone pattern factor (Tb.Pf), structural model index (SMI), trabecular number (Tb.N)는 약하지만 유의한 상관관계가 있는 것으로 나타났다. 마이크로 CT 영상의 DA 와 콘빔 CT 영상의 DA 는 상관계수가 0.693 으로 매우 높은 상관관계를 보였다 ($P<0.05$). 그리고, voxel 크기 96.87 μm 인 마이크로 영상과 100μm 인 콘빔 CT 영상에서 추출된 골 미세구조 지표들 사이에서도 같은 파라미터에서 상관관계가 있음이 확인되었으며, 여전히 DA 가 가장 높은 상관관계를 보였다 ($r=0.773$, $P<0.05$).

4. 결론

본 연구에서는 골 미세구조 분석에 gold standard 로 사용되는 마이크로 CT 에서 얻은 미세구조 파라미터와 콘빔 CT 에서 파라미터들이 서로 유의한 상관관계를 보였다. BV, BV/TV, Tb.Sp 와 DA 를 콘빔 CT 를 이용한 생체 내 골질 평가에 사용할 수 있을 것으로 기대한다.

주요어 : 해면골, 골 미세구조, 콘빔 CT, 마이크로 CT
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