ORIGINAL Aichi Gakuin Dent Sci 34 : 1–5, 2021

EVALUATION OF CT VALUES IN DUAL-ENERGY COMPUTED TOMOGRAPHY USING MULTIPLE POROSITY HYDROXYAPATITE BLOCKS

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Synopsis

It has been reported that CT values obtained from dual-energy CT change with different tube voltages. However, only a comparatively low and narrow range of CT values have been evaluated. In the present investigation, we have evaluated changes of CT values obtained from dual-energy CT using hydroxyapatite (HA) blocks with a different vesicle rate.

HA blocks with 4 levels of porosity (0, 30, 55, and 85%) were used in the study. CT images obtained at 80, 100, 120, and 135 kV were reconstructed from dual-energy CT. CT values of HA blocks and the water region were then measured. CT values of images obtained from 120-kV single-energy CT with a soft tissue image reconstruction function were standardized, and they were compared with those obtained from dual-energy CT using the Mann-Whitney U-test and covariance analysis.

CT values of HA blocks increased at the lower tube voltages obtained from dual-energy CT. There were significant differences between CT values from 120-kV single-energy CT with a soft tissue image reconstruction function and the other CT voltage conditions using covariance analysis. Also, the relationship between CT values and HA densities could be regressed using a linear equation, and the correlation coefficient was 0.998 to 0.999 in 120-kV single- and dual- energy CT.

In conclusion, CT values of HA blocks increased at the lower tube voltages obtained from dual-energy CT. The correlation between CT values and HA densities was high for single- and dual-energy CT.

Key words: CT, CT values, dual-energy, hydroxyapatite block

Introduction

Various improvements have been made to multi-detector computed tomography (CT), and dual-energy CT has recently been approved for use in orthopedics[1,2]. Dual-energy CT has also been used to reduce metal artifacts generated by hip prostheses and dental implants[3,4]. It has been reported that CT values obtained from dual-energy CT change with different tube voltages[2].

Also, although the tube voltage is generally 120 kV, a lower tube voltage has recently been used to reduce the effective dose[5].

CT values of lesions in cysts and tumors are generally measured in the oral and maxillofacial region. CT values of cancellous and cortical bones in jaws are measured in patients undergoing dental implant treatment and in those with osteoporosis[6,7]. Changes in CT values may be expected with different tube voltages on oral and maxillofacial examination. It was reported that mean CT values were 4.5×10^2 Hounsfield units (HU) in mandibular cancellous bones and 1184 HU in mandibular cortical bones using a 120-kV tube voltage[7,8]. The range of CT values evaluated in the previous study was between 58.8 and 300.6 HU with a 110-kV tube voltage, being comparatively narrow[2]. Changes of CT values need to be clarified in a wider range for oral and

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Received for publication June 22, 2021
Accepted for publication July 29, 2021

maxillofacial examination.

In the present investigation, we have evaluated changes of CT values obtained from dual-energy CT using hydroxyapatite (HA) blocks with a different vesicle rates.

Materials and Methods

Hydroxyapatite blocks

HA blocks with 4 levels of porosity (0, 30, 55, and 85%, APACERAM, HOYA Technosurgical, Tokyo, Japan) were used in the study (Fig. 1). Each cubic block was 10x10x10 mm. The HA density was $3.16x10^3$ mg/cm^3 for the block with 0% porosity, $2.21x10^3$ mg/cm^3 for 30% porosity, $1.42x10^3$ mg/cm^3 for 55% porosity, and $0.47x10^3$ mg/cm^3 for 85% porosity. The blocks were joined and placed in the center of a foam polystyrene vessel (20x20 cm in height and width), which was filled with water.

Multi-detector computed tomography

A multi-detector CT unit (Aquilion PRIME, Canon Medical Systems, Tochigi, Japan) was used. The tube voltages were set at 80 and 135 kV for dual-energy CT. The tube currents were set at 290 and 50 mA for 80 and 135 kV, respectively. The best images were reconstructed from dual-energy CT, and they corresponded to a 100-kV tube voltage. Subsequently, images obtained with 80, 120, and 135 kV were reconstructed from dual-energy CT. In single-energy CT, the tube voltage and tube current were set at 120 kV and 100 mA, respectively. Two-image reconstruction functions were used for soft tissue and bone images. The images were reconstructed with 1-mm-thick slices at 1-mm intervals (Fig. 2). Dual- and single-energy CT were repeated three times in the same way.

Measurements of CT values

Circular regions of interest (ROIs) with a 0.385-cm^2 area were set on the images of HA blocks and the water region using 3-D visualization and measurement software (OsiriX Imaging Software, Geneva, Switzerland). Measurements of CT values were repeated five times in each region, and they were averaged.

Statistical analysis

CT values of images obtained from 120-kV single-energy CT with the soft tissue image reconstruction function were standardized, and they were compared with those obtained from dual-energy CT using the Mann-Whitney U-test and covariance analysis. Differences were considered significant of $P<0.05$. Also, correlations between CT values and HA densities were analyzed in single- and dual-energy CT.

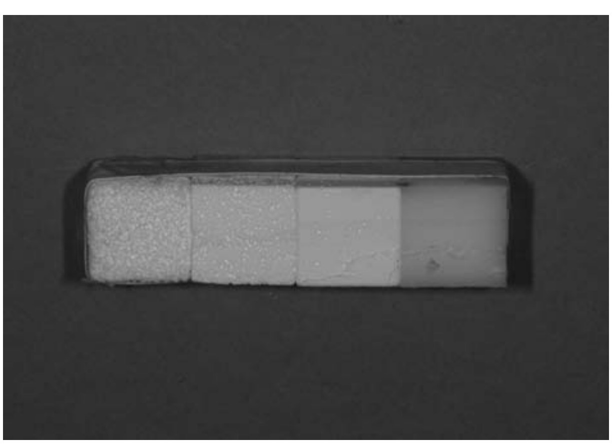

Fig. 1. HA blocks with 4 levels of porosity
Hydroxyapatite blocks with 85%, 55%, 30%, and 0% porosity are shown in order, from the left side.

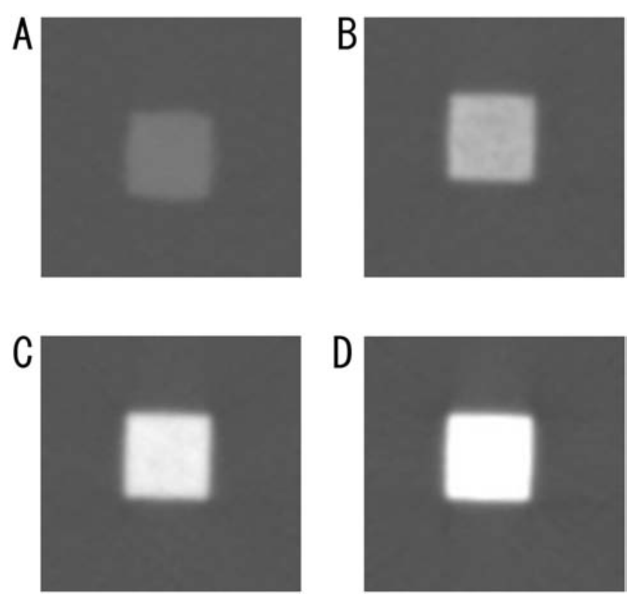

Fig. 2. CT images of HA blocks
A. Block with 85% porosity B. Block with 55% porosity
C. Block with 30% porosity D. Block with 0% porosity

Results

CT values and standard deviations for each tube voltage are shown in Table 1. CT values of HA blocks increased with the lower tube voltages obtained from dual-energy CT. There were significant differences between the CT values of all HA blocks obtained with 120-kV single-energy CT and 80, 100, and 135-kV images obtained by dual-energy CT using soft tissue and bone image reconstruction functions. The CT values of the $0.47x10^3$-mg/cm^3 HA block were not significantly different between 120-kV single- and 120-kV dual-energy CT using the soft tissue image reconstruction function. The CT values of the water region and $0.47x10^3$-mg/cm^3 HA block were not significantly different between soft tissue and bone image reconstruction functions in 120-kV single-energy CT. There were significant differences between CT values of 120-kV single-energy CT with the soft tissue image reconstruction function and the other CT voltage conditions using covariance analysis.

The relationship between CT values and HA densities could be regressed using a linear equation (Figs. 3, 4), and the equation and correlation coefficients are shown in Table 2. The correlation coefficient was 0.999 in 120-kV single-energy CT using the soft tissue image reconstruction function. The range of the correlation coefficient in dual-energy CT was 0.998 to 0.999 using soft tissue and bone image reconstruction functions; the values were very high.

Table 1. CT values and standard deviations at each voltage and with the image reconstruction function

Condition CT	Tube voltage (kV)	Image reconstruction function	HA densities (mg/cm^3) 0	$0.47x10^3$	$1.42x10^3$	$2.12x10^3$	$3.16x10^3$	Covariance analysis
Single	120	soft tissue	0.9 (1.0)	620.1 (15.2)	1644.5 (16.3)	2729.4 (4.0)	3891.4 (2.7)	–
Dual	80	soft tissue	−2.9 (4.1)*	845.5 (15.0)**	2294.7 (24.5)**	3654.2 (7.7)**	5183.8 (7.4)**	<0.01
Dual	100	soft tissue	0.1 (2.7)	720.0 (14.8)**	1929.0 (20.5)**	3136.1 (5.7)**	4454.1 (6.3)**	<0.01
Dual	120	soft tissue	2.7 (2.4)*	627.3 (15.0)	1664.1 (17.6)**	2762.6 (8.9)**	3928.0 (6.9)**	<0.05
Dual	135	soft tissue	4.1 (2.7)**	564.5 (15.0)**	1484.2 (15.9)**	2506.1 (6.7)**	3569.6 (7.8)**	<0.01
Single	120	bone	0.5 (2.3)	616.0 (14.8)	1608.2 (24.3)**	2698.7 (6.7)**	3851.3 (9.4)**	<0.05
Dual	80	bone	0.1 (3.8)	848.6 (17.6)**	2275.3 (29.9)**	3660.6 (6.8)**	5192.7 (12.1)**	<0.01
Dual	100	bone	1.3 (2.8)	721.3 (15.9)**	1910.1 (25.7)**	3142.4 (7.3)**	4463.4 (10.1)**	<0.01
Dual	120	bone	1.9 (3.8)	627.7 (15.0)	1644.9 (23.0)	2767.5 (8.8)**	3937.6 (10.2)**	<0.05
Dual	135	bone	2.3 (4.8)	564.3 (14.9)**	1466.5 (20.8)**	2512.3 (10.5)**	3579.4 (10.8)**	<0.01

The 100 kV image was the best image obtained by dual-energy CT.
CT values obtained by 120-kV single-energy CT with the soft tissue image reconstruction function were standardized.
* : $p<0.05$, * * : $p<0.01$

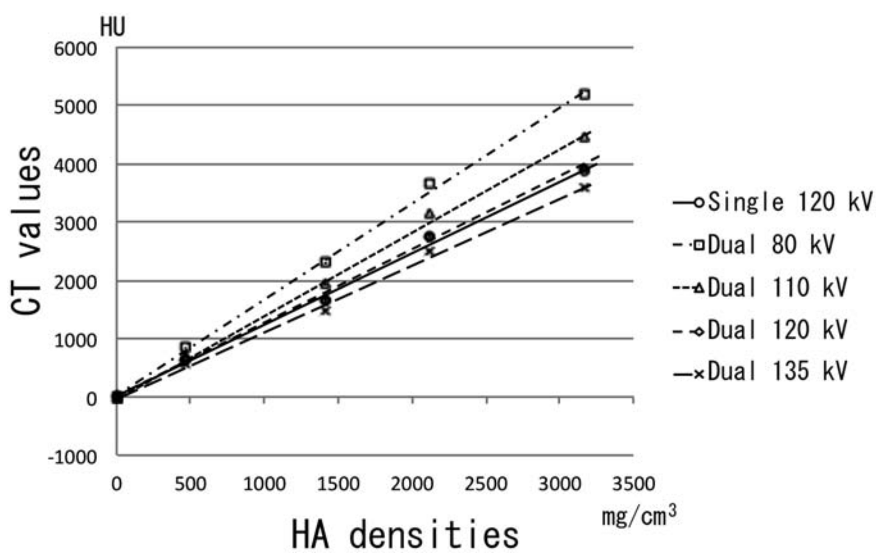

Fig. 3. Correlation between CT values with soft tissue image reconstruction functions and HA densities

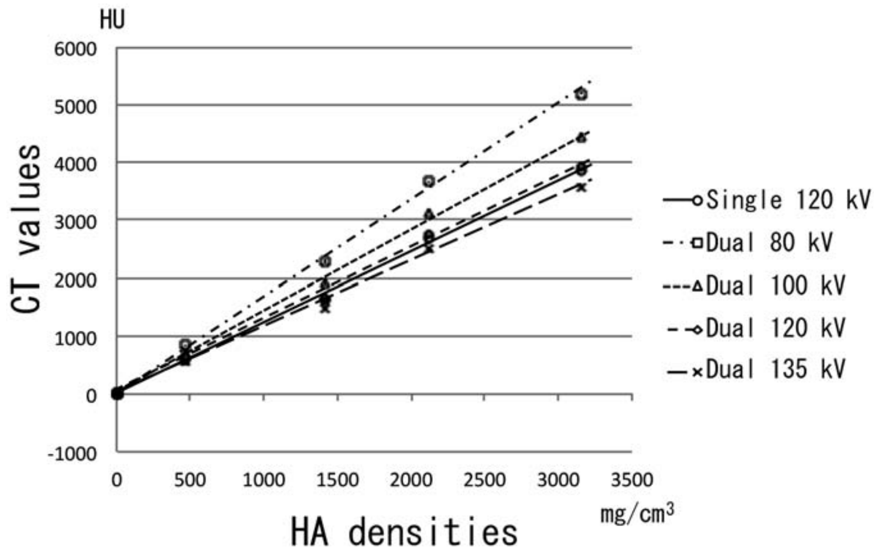

Fig. 4. Correlation between CT values with bone image reconstruction functions and HA densities

Table 2. Linear equation and correlation coefficients between CT values and HA densities at each voltage and with the image reconstruction function

Condition CT	Tube voltage (kV)	Image reconstruction function	Linear equation (y = ax + b) a	b	Correlation coefficient r	P−values
Single	120	soft tissue	1.2379	2.0435	0.999	<0.01
Dual	80	soft tissue	1.6488	30.6570	0.999	<0.01
Dual	100	soft tissue	1.4168	16.1540	0.999	<0.01
Dual	120	soft tissue	1.2498	4.7553	0.999	<0.01
Dual	135	soft tissue	1.1358	3.0404	0.998	<0.01
Single	120	bone	1.2247	−1.2831	0.998	<0.01
Dual	80	bone	1.6508	28.2200	0.999	<0.01
Dual	100	bone	1.4196	12.0580	0.999	<0.01
Dual	120	bone	1.2530	−0.9355	0.998	<0.01
Dual	135	bone	1.1396	9.1705	0.998	<0.01

The 100 kV image was the best image obtained by dual-energy CT.

Discussion

CT is important for imaging-based diagnosis in the oral and maxillofacial region, and CT values are generally measured in the interior of lesions and in cancellous and cortical bones of jaws[6,7]. CT values (Hounsfield units: HU) are defined as follows: the density of air is equal to -1000 HU and that of water is 0 HU, when the tube voltage is set at 120 kV. Resnik et al. classified the cancellous bone density of jaws into five grades using CT values: D1: >1250 HU; D2: 850-1250 HU; D3: 350-850 HU; D4: 150-350 HU; and D5: <150 HU[9]. Although changes of CT values were reported to occur with different tube voltages in a previous study, the range of CT values was comparatively low and narrow[2]. Therefore, studies of changes in CT values caused by different tube voltages are needed to evaluate a wider range, including high CT values.

In the present study, a wider range of densities between 0 and $3.16 x 10^3$ mg/cm^3 HA was evaluated using HA blocks with a different vesicle rate. Tube voltages and tube currents of single- and dual-energy CT in the present study were set to mimic the conditions used generally in our hospital. CT images at 80, 100, 120, and 135 kV were reconstructed from dual-energy CT, and then the CT values obtained from dual-energy CT using soft tissue and bone image reconstruction functions were compared with those obtained from 120-kV single-energy CT using the soft tissue image reconstruction function. CT values of all HA blocks increased at lower tube voltages of dual-energy CT. These results agree with those of a previous study[2]. It was considered that the beam-hardening effect influenced the results.

Garner et al.[2)] reported that noise of images obtained by dual-energy CT was greater than that obtained by single-energy CT. Standard deviations of dual-energy CT using the soft tissue image reconstruction function in $2.12x10^3$ and $3.16x10^3$-mg/cm^3 HA blocks were slightly larger than those of 120-kV single-energy CT. However, standard deviations in $0.47x10^3$ and $1.42x10^3$-mg/cm^3 HA blocks were similar between dual- and single-energy CT. Standard deviations in $0.47x10^3$ and $1.42x10^3$-mg/cm^3 HA blocks were larger than those in $2.12x10^3$ and $3.16x10^3$-mg/cm^3 HA blocks in single- and dual-energy CT. These results may be affected by the irregular porosity of HA blocks.

The relationship between CT values and HA densities could be regressed using a linear equation in all tube voltage images obtained from dual-energy CT, and high correlations between CT values and HA densities were observed. Garner et al.[2)] reported that the development of a mathematic algorithm to use the linear attenuation of bone derived from CT examination at any other voltage would be helpful. In a previous study, HA blocks from 0 to 400 mg/cm^3 were used as the reference to convert CT values to bone mineral densities. HA blocks with a different vesicle rate might be applied as a reference to convert CT values to HA densities for dual-energy CT.

Conclusion

CT values of HA blocks increased with the lower tube voltages obtained from dual-energy CT. The correlation between CT values and HA densities was high for single- and dual-energy CT.

The authors declare to have no conflicts of interest to declare.

Acknowledgement

We would like to thank Mr. Kenichi Gotoh, Mr. Ryo Matsumoto, and Mr. Tsutomu Kuwada of the Department of Radiology and Diagnostic Imaging, Dental Hospital, at the Aichi Gakuin University for their corporation in performing multi-detector CT.

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