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Comparison of effective dose for imaging of mandible between multi-detector CT and cone-beam CT

Dae-Kyo Jeong, Sang-Chul Lee, Kyung-Hoe Huh, Won-Jin Yi*, Min-Suk Heo, Sam-Sun Lee*, Soon-Chul Choi

Department of Oral and Maxillofacial Radiology and Dental Research Institute, School of Dentistry, Seoul National University, Seoul, Korea
**Department of Oral and Maxillofacial Radiology, Dental Research Institute, and BK21 Craniomaxillofacial Life Science, School of Dentistry, Seoul National University, Seoul, Korea*

ABSTRACT

Purpose : The aim of this study was to compare the effective dose for imaging of mandible between multi-detector computed tomography (MDCT) and cone-beam computed tomography (CBCT). An MDCT with low dose technique was also compared with them.

Materials and Methods : Thermoluminescent dosimeter (TLD) chips were placed at 25 organ sites of an anthropomorphic phantom. The mandible of the phantom was exposed using 2 different types of MDCT units (Somatom Sensation 10 for standard-dose MDCT, Somatom Emotion 6 for low-dose MDCT) and 3 different CBCT units (AZ3000CT, Implagraphy, and Kavo 3D eXaM). The radiation absorbed dose was measured and the effective dose was calculated according to the ICRP 2007 report.

Results : The effective dose was the highest for Somatom Sensation 10 (425.84 μSv), followed by AZ3000CT (332.4 μSv), Somatom Emotion 6 (199.38 μSv), and 3D eXaM (111.6 μSv); it was the lowest for Implagraphy (83.09 μSv). The CBCT showed significant variation in dose level with different device.

Conclusion : The effective doses of MDCTs were not significantly different from those of CBCTs for imaging of mandible. The effective dose of MDCT could be markedly decreased by using the low-dose technique. (***Imaging Sci Dent 2012; 42 : 65-70***)

KEY WORDS : Multidetector Computed Tomography; Cone-Beam Computed Tomography; Thermoluminescent Dosimetry; Mandible

Introduction

Radiological examination is essential for the accurate diagnosis and treatment planning for patients with mandibular diseases. Computed tomography (CT) has been a useful tool for examining the mandible and for evaluating adjacent tissues, as well as for detecting possible tumor lesions, inflammatory tissues, or pathologic bony changes.[1]

CT, first introduced by Hounsfield[2] in 1972, improved the quality of radiological diagnosis in various clinical fields, along with the development of computer technology. Not long after the spiral CT first appeared in the early 1990s, multi-detector CT (MDCT) loaded with many detectors began to dominate the market. As a result, radiation doses and exposure times required for image processing have decreased.

In the dental field, the newly developed cone-beam computed tomography (CBCT) presented better resolution with lower exposure to radiation, as compared with conventional CT. Furthermore, CBCT now utilizes state-of-the-art imaging techniques, such as conveying 3-dimensional volumetric information as real images, thereby securing its role as a promising tool for the diagnosis of dentomaxillofacial lesions.[3-5]

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Correspondence to : Prof. Min-Suk Heo
Department of Oral and Maxillofacial Radiology, School of Dentistry, Seoul National University, 28 Yeongeon-dong, Jongno-gu, Seoul 110-744, Korea
Tel) 82-2-2072-3016, Fax) 82-2-744-3919, E-mail) hmslsh@snu.ac.kr

There have been studies on the CBCT dosimetry as well as the usefulness of CBCT in clinical practice. In particular, there has been much interest that CBCT would be more appropriate in the dental area compared with conventional CT because CBCT requires considerably lower doses.[6-8] Chau and Fung[6] documented that of 3 types of diagnostic tools including spiral CT, conventional CT, and CBCT for dental implant prosthesis, spiral CT required the highest dose, while CBCT required the lowest dose. However, MDCT was not evaluated in their study.

Carrafiello et al[9] compared the effective doses between 64-slice MDCT, CBCT, and panoramic units. Although their study concluded that the effective dose of MDCT was 9 times higher than that of CBCT, it left much to be decided since the experiment was performed simply by exposing the X-ray beams on the same anatomical area, without considering the real clinical environment wherein MDCT operates. Meanwhile, Suomalainen et al[10] reported no significant difference in effective dose between MDCT and CBCT. However, they did not consider the actual clinical situations. Kim et al[11] demonstrated that the absorbed and effective doses of CBCT were lower than that of conventional CT. However, their study was performed not with MDCT but with conventional CT, which required a higher dose than MDCT in most cases. Tack et al[12] indicated that low-dose MDCT was the imaging method of choice in patients with suspected chronic sinusitis.

MDCT has always been a secondary option in dental field in spite of its superior image quality due to the high level of x-ray exposure. In the early years of CBCT development, the source of x-rays for CBCT was identical to other dental radiographic equipments, and thus was expected to obtain dependable images with much lower x-ray doses compared with MDCT. However, since early CBCT devices produced significantly higher noise levels than medical CT scanners, recent CBCT units have replaced conventional sources with higher-capacity ones. With the invention of multi-detector CT which obtains its images after only one tube rotation, the dose gap between MDCT and CBCT has been diminished.

The purpose of this study was to compare the effective dose for mandibular imaging between MDCT and CBCT considering the clinical situations.

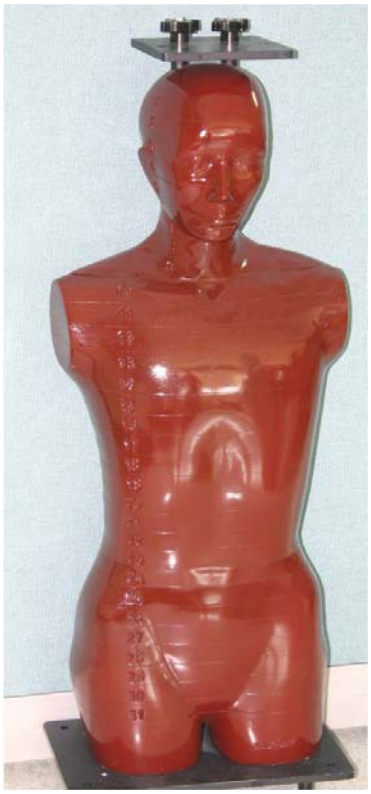

Fig. 1. Alderson radiation therapy phantom.

Fig. 2. Thermoluminescent dosimeter (TLD) chips are inserted into each of the organ structures.

Materials and Methods

An Alderson radiation therapy phantom (Radiologic Support Devices Inc., Long Beach, CA, USA), a human phantom torso structure which included the oral and maxillofacial areas, was used to measure x-ray dose (Fig. 1). The phantom consisted of 32 horizontal sections, each one with a thickness of 2.5 cm, and included the major anatomical

Table 1. Technical factors for MDCT and CBCT imaging of the mandibular area

	Unit	Image detector	Scanning time (s)	mA	mAs	kV	Scan width (cm)	Scan height (cm)	Slice thickness (mm)	CTDI vol † (mGy)	Voxel sizes (mm)
MDCT	Somatom Sensation 10	10-slice detector	8.4	23.8	200	120	body width	5	0.75	21.1	0.6
	Somatom Emotion 6*	6-slice detector	16.04	3.1	50	110	body width	5	0.75	9.82	0.6
CBCT	AZ3000CT, Asahi	Flat panel	17	6	102	85	7.9	7.1	0.2		0.2
	Implagraphy, Vatech	Flat panel	19	3.5	66.5	80	8	5	0.2		0.2
	3D EXAM, Kavo	Flat panel	26.9	1.37	37.07	120	10	5	0.2		0.2

*low-dose technique, † CTDI vol: volume computed tomography dose index

structures of the craniofacial and visceral organs. Each organ structure contained a number of 5 mm-diameter holes that had thermoluminescent dosimeter (TLD) chips installed (Fig. 2). The dosimetry procedure was performed with a TLD chip (TLD-100 Li F chip, Harshaw Chemical Co., Cleveland, OH, USA) and a Harshaw model 3500 TLD reader (Harshaw Chemical Co., Cleveland, OH, USA).

This study evaluated the doses for the following MDCT units: Somatom Sensation 10 (Siemens AG, Erlangen, Germany) and Somatom Emotion 6 (Siemens AG, Erlangen, Germany). Also, three kinds of CBCT units, AZ3000CT (Asahi Roentgen Co., Kyoto, Japan), KaVo 3D eXam (Kavo Dental GmbH, Biberach/Riss, Germany) and Implagraphy (Vatech Co., Yongin, Korea) were used for this study.

The imaging procedures were designed to mimic the real clinical situations. The MDCT image for the standard dose was taken by following the mandible CT protocol adopted by Seoul National University Dental Hospital. Briefly, MDCT was begun by taking a scout view and then focusing on the mandibular area. After the height of the scan was adjusted, by operator-controlled collimation, to cover the mandibular area 5 cm in height, the tube potential, tube current, and rotation time were set at 120 kVp, 23.8 mA and 8.4 seconds, respectively. Low-dose MDCT images were taken by following the mandible protocol adopted by Dankook University Dental Hospital. MDCT was also begun by taking a scout view with a scanning width of 25 × 25 cm and 5 cm in height. Then, the tube potential, tube current, and rotation time were set at 110 kVp, 3.1 mA and 16 seconds, respectively. For CBCT units, AZ3000CT images were taken with a mandibular mode with a FOV of 7.9 × 7.1 cm. The scanning time was 17 seconds. Implagraphy images were taken with a FOV of 8.0 × 5.0 cm, and the total scanning time was 19 seconds. Since there was no mandibular mode in KaVo 3D eXaM, the custom mode was selected in order to set the FOV height for taking the images of mandibular area as with MDCT. The images of both sides were taken with a single scan at a FOV of 10 × 5 cm and the scanning time was 26.9 seconds. Table 1 shows the factors for the equipments.

Table 2. Location of thermoluminescent dosimeter (TLD) chips in the Alderson radiation therapy (ART) phantom. Three TLDs used were used each level

Location	Phantom level
Midbrain	2
Calvarium-right/left: superior	3
Calvarium-right/left: inferior	4
Mandibular ramus-right/left	5
Mandibular body-right/left	6
Submandibular gland-right/left	7
Esophagus	8
Thyroid-right/left	8
Lung-right/left	15
Heart	16
Liver	18
Stomach	21
Kidney-right/left	25
Colon	26
Ovary-right/left	28
Bladder	30

Three TLD chips were installed into each of the 25 tissues or organs, including bilateral organs except for skin (Table 2). After taking images of the mandible region, the chips collected from the phantom were inserted into the TLD reader in order to measure the electronic charges. The mean value of the chips was deduced after removing the outliers, which ranged up to more than double the standard deviation.[13] For bilateral organs, the average value of the 2 organs was adopted. Harshaw calibrated each dosimeter by exposing it to a known quantity of radiation from a Cs-137 source. Dosimeters were analyzed using an automatic hot gas reader and the raw data were recorded. Individual TLD chip sensitivity was obtained and applied as a correction factor to subsequent exposure and reading of each TLD. The standard deviation of calibrated readings from the supplied TLD 100 chips is stated to be less than ±5%. After measuring the electronic charges with the TLD reader,

the chips were initialized, first annealing them in a 400˚C chamber for 1 hour, then cooling them at room temperature, and finally re-annealing them in a 100˚C chamber for 2 hours. The absorbed dose (μGy) was calculated by multiplying the exposed dose (mR) and a correction factor of 8.69 (the exposed dose was obtained by the TLD reader software program).[14-16] The absorbed dose for the whole-body bone marrow was calculated by summing up the individual equivalent doses to the calvarium and the mandible. The determination of these equivalent doses was based on the distribution of active bone marrow throughout the adult body: the mandible contains 1.3% active marrow and the calvarium contains 11.8% active marrow.[4,17] For the calvarium, the average value of 4 sites in the cranial bone was used. Likewise, for the mandible, the average dose value of the mandibular body and ramus was used.

The doses obtained from TLDs at the different positions within the tissues or organs were averaged to express the average tissue-absorbed dose in micrograys (μGy). These values were used to calculate the equivalent dose (H_T) with the following equation: $H_T = \sum W_R \times D_T$, where the equivalent dose (H_T) for a tissue or organ is the product of the radiation weighting factor (W_R) and the average absorbed dose (D_T) measured for the specific tissue or organ. H_T was used to compare the effects of different types of radiation on tissues or organs. Since the radiation weighting factor of x-ray was 1, the values for both the absorbed and equivalent doses were the same, however the unit of measurement was changed from microgray (μGy) to an equivalent unit, the microsievert (μSv).

The effective dose (E) is a dose proposed by the International Commission on Radiological Protection (ICRP) to estimate radiation damage to an exposed population. It is deduced by multiplying actual organ doses by "tissue weighting factors" depending on an individual organ's sensitivity. The effective dose represents the amount of radiation dose that the whole body receives, which also provides information on cancer risk, as compared to other organs receiving different doses. The effective dose (E) is calculated as follows: $E = \sum (W_T \times H_T)$, where E is the product of the ICRP tissue weighting factor (W_T) for the type of tissue or body and the human-equivalent dose for tissue (H_T). The tissue weighting factor represents the contribution that each specific tissue or organ gives to the overall risk of radiation damage. In this study, the ICRP 2007 weighting factors shown in Table 3 were adopted, which included the salivary tissue.

Table 3. Tissue-weighting factors for the calculation of effective dose according to ICRP 2007 recommendations

Tissue	W_T
Bone-marrow (red), Colon, Lung, Stomach	0.12
Breast, Remainder tissues*	0.08
Gonads	0.08
Bladder, Esophagus, Liver, Thyroid	0.04
Bone surface, Brain, Salivary glands, Skin	0.01

*Remainder tissues: Adrenal glands, extrathoracic (ET) region, gall bladder, heart, kidney, lymphatic nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, thymus

Table 4. Absorbed and effective dose (μGy) of exposure for MDCT and CBCT units for mandibular imaging

	MDCT		CBCT		
	Somatom Sensation 10	Somatom Emotion 6*	AZ3000CT Asahi	Implagraphy Vatech	3D eXam Kavo
Brain	423	148	330	166	61
Calvarium	1443	323	1269	728	222
Mandible ramus	5452	4437	5144	1841	1547
Mandible body	10977	5513	9303	1807	2517
Submandibular gland	11082	4339	10747	1857	2661
Esophagus	1855	604	831	281	470
Thyroid	1810	745	776	215	538
Lung	121	52	77	52	77
Heart	76	42	43	23	35
Liver	60	48	48	27	39
Stomach	32	25	27	17	27
Kidney	24	23	24	19	25
Colon	24	25	25	18	26
Ovary	24	27	27	22	25
Bladder	24	20	26	21	23
Effective dose	425.84	199.38*	332.4	83.09	111.6

*low-dose technique

Results

Table 4 shows the absorbed doses for each of the tissues and organs. In the intra-machinery comparisons between all the units, the directly exposed regions, such as the mandible and submandibular gland, showed higher values. In the inter-machinery comparison, Somatom Sensation 10 showed the highest absorbed dose value, especially at the directly exposed regions and their adjacent organs including the mandible ramus, mandible body, and submandibular gland. The lowest value was achieved with Implagraphy which showed the absorbed dose 3-5 times lower than that of Somatom Sensation 10.

The effective doses are presented in Table 4. Of the 5 different units, Somatom Sensation 10 showed the highest value of 425.84 μSv, followed by a value of 332.4 μSv for AZ3000CT, and a value of 199.38 μSv for Somatom Emotion 6. KaVo 3D eXaM and Implagraphy showed similar values of 111.6 and 83.09 μSv, respectively.

Discussion

This study was designed to compare the effective dose for mandibular imaging between CBCT and MDCT units. Since CT images are useful for evaluating the mandibular area, many previous studies have been conducted utilizing conventional or spiral CT.[17] However, the newly developed, cost-effective, and low radiation dose-producing CBCT began to replace conventional CT for mandibular evaluation.[18,19] Since then, most studies have focused on CBCT itself and its comparisons with spiral CT or conventional tomography. Meanwhile, the remarkable progress of MDCT technology has produced commercially available devices with more detectors, allowing for faster scanning times and low-dose exposures compared with conventional CT. However, there have been few studies on comparisons between MDCT and CBCT. Therefore, this study was designed exclusively to compare MDCT and CBCT, according to the scanning protocol for mandible used in clinical examination. Our results were contrary to those of the previous studies that reported that MDCT showed a significantly higher absorbed dose than CBCT.[6,10,19,20]

The effective dose was the highest for Somatom Sensation 10, which was not significantly different from that of AZ3000CT. This value was also 4 times the effective dose of Kavo 3D eXaM, a CBCT device, and 5 times that of Implagraphy, a CBCT unit requiring the lowest effective dose. This implied wide variations of effective doses among CBCT units. Somatom Emotion 6 showed a lower dose than AZ3000CT. The difference in the effective doses between CBCT units was also confirmed by a study by Ludlow et al[21] which reported that dental CBCT units required a higher effective dose than 64-slice MDCT, especially when taken with a high FOV. Of possible factors such as the tube potential, tube current, exposure time and detector sensitivity, the scanning time and tube current would be the most important factors of all the factors suggested by our study.

In this study, the AZ3000CT mandibular mode had a relatively high tube current. The scanning time of Implagraphy was about 19 seconds shorter than that of KaVo 3D exam, and its tube current was the lowest (9.5 mA). These might be the reasons why Impragraphy required such a low effective dose.

Since the pre-set optimal conditions of x-ray dose vary among different units, the total dose cannot be estimated only by tube potential, tube current and scanning time. In image taking, image quality is also an important consideration along with radiation exposure. Although image quality was not evaluated in our study, there has been no argument about the fact that MDCT provided superior image quality compared with CBCT.[22] Mulkens et al[23] showed that with modern technologies, low-dose CT of the sinuses in children yield a good diagnostic image quality with an effective dose comparable to that used for standard radiography.

This study offered the results inconsistent with those of the previous studies that asserted that MDCT requires a higher dose than CBCT. The effective dose of MDCT was lower than that of some CBCT units for imaging of mandible by using the low-dose technique.

There has always been reluctance to use MDCT as the method of choice despite its superior contrast and resolution, as well as precise diagnoses and treatment plans, because there is a putative fear of its seemingly higher radiation exposure. Our study, however, provided direct evidence that MDCT was appropriate for the evaluation of the mandibular area in the dental field.

This study had a limitation due to its small sample size. More experimental data and further studies on clinical comparison of various CT units would be needed to verify our results. The quality control of the low-dose technique should be further validated.[24]

In conclusion, the effective dose of MDCT for imaging of mandible was not significantly different from that of CBCT which showed the highest value. CBCT showed significant variations in dose level among different devices. The effective dose of MDCT could be markedly decreased by using the low-dose technique.

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