Dosimetry of Dental Cone Beam CT and Multi-slice CT in Oral and Maxillofacial Radiology using conversion factors

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A Doctoral Dissertation
Submitted to the Department of Dentistry
and the Graduate School of Yonsei University
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

Hyok Park

June 2013

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June 2013

감사의 글

이 논문이 완성되기까지 부족하기만 한 저에게 끊임없이 세심한 지도와 격려를 아끼지 않으시고 관심을 기울여 주신 박창서 지도 교수님께 깊은 감사의 마음을 올립니다. 아울러 논문의 완성을 위해 아낌없는 조언과 충고를 아끼지 않으신 김기덕 교수님, 이제호 교수님, 이창걸 교수님과 정호걸 교수님께도 진심으로 감사를 드립니다.

논문의 설계와 실험 진행에 많은 도움을 주신 방사선종양학교실 최원훈 교수님과 이정일 강사님께도 감사의 말씀을 전합니다.

언제나 든든하게 곁을 지켜주며 서로 의지하고 있는 정호걸 교수님께 특히 고마움을 전합니다. 선배가 없는 의국에서 많은 업무들을 묵묵히 수행하면서 의국을 든든하게 지키고 있는 황재준 선생님께도 고마움의 인사를 전합니다. 항상 가족과 같은 마음으로 즐겁게 함께 근무하고 있는 방사선과 직원 여러분 모두에게도 감사드립니다.

항상 사랑과 희생으로 힘이 되어 주시고 든든한 후원자이신 부모님께 진심으로 감사드립니다. 자주 찾아 뵙지 못하지만 언제나 반갑고 따뜻하게 맞아 주시는 장인어른과 장모님께도 감사드립니다.

마지막으로 많은 어려움 속에서도 아무런 불평불만없이 나를 늘 반갑게 기다려 주고 내조해 주는 사랑하는 나의 아내 오영선과 예쁜 딸 현이와 씩씩한 아들 환이에게 이 글을 바칩니다.

2013 년 6 월

저 자 씀

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ABSTRACT

Dosimetry of Dental Cone Beam CT and Multi-slice CT in Oral and Maxillofacial Radiology using conversion factors

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Objective: To compare the effective doses between dental cone beam computed tomography (CBCT) and multi-slice computed tomography (MSCT) for the oral and maxillofacial region.

Materials and Methods: VacuDAP® ionization chamber was located in front of the X-ray sources in CBCT units for measuring dose area product (DAP). Measurements are performed in three CBCT units. Dose-length product (DLP) values are acquired from two MSCT units. Effective doses were calculated by conversion factors.

Results: Effective doses of three CBCTs with the similar field of views (FOVs) were 161.9 μSv, 213.6 μSv, and 358.4 μSv, respectively. Effective doses of MSCTs were 1147.2 μSv and 1629.6 μSv. The effective doses of MSCTs are 3.2~10 times more than those of CBCTs.

Conclusions: The effective doses of CBCTs were lower than those of MSCTs, but showed wide ranges depending on units and modes. DAP can be used as an easier and faster way to estimate the patient exposure dose in CBCTs, and can be acceptable to manage it.

Key words: Dosimetry; Effective dose; Dose area product (DAP); Dose length product (DLP); Conversion factor; Cone beam computed tomography (CBCT); Multi-slice computed tomography (MSCT)

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I. Introduction

The amount of background radiation varies with altitude and location, the annual background radiation is about 3 mSv per year.[1] Hence, the amount of radiation received from a radiologic procedure can be expressed in terms of a certain number of days or years of background radiation.[1]

Over the years, a number of terms have been used to describe radiation dose.[1] Confusion can arise through inappropriate use of the terminology to describe radiation doses from clinical procedures to patients.[1]

Dose area product (DAP) is a product of the surface area of the patient that is exposed to radiation at the skin entrance (in cm^2 or m^2) multiplied by the radiation dose at this surface (in Gy).[1] DAP is valuable because radiation-induced bio-effects are directly related to both the magnitude of the radiation dose and the total amount of tissue that is irradiated.[1] Knowledge of DAP and of the location and projection of the x-ray beam allows direct calculation of the effective dose.[1] In clinical practice, tabular data of the conversion factors (in mSv/Gy·㎠) for DAP can yield the effective dose.[1] DAP is considered to be a good tool for estimating the stochastic risk associated with irradiation.[1] Conversion coefficients have been developed for various radiographic projections to provide ways to estimate effective dose from DAP.[1]

The effective dose is obtained by multiplying the radiation dose delivered to each organ by its tissue weighting factor (to account for the carcinogenic sensitivity of each organ) and then by adding those values to get the sum.[1] By using effective dose, the cancer risks and genetic bio-effects can be assessed, regardless of the clinical procedure being performed.[1] Regardless of the location or the amount of tissue being irradiated, effective dose is directly related to the potential risks of radiation-induced cancer and genetic defects.[1] Effective dose is important for all clinical radiologic procedures.[1]

In dental radiology there is still the problem of how to determine the effective dose, which is necessary to compare radiation risk between different examination techniques.[2] The traditional way of determining effective dose is by measuring organ doses using thermoluminescent dosimeters (TLDs), which is a laborious and time-consuming method without standards regarding the number and location of measuring points.[2]

New and less laborious methods for effective dose assessments have been reported by determination of dose–width product (DWP) for panoramic units and DAP for panoramic and other units in dental radiology.[2-5] Measured DAP values can be converted to effective dose and energy imparted using so-called conversion factors.[2] In dental radiology, Helmrot and Alm Carlsson[5] have suggested conversion factors for panoramic radiography and intraoral radiography.[3] Looe et al. reported that the conversion coefficient was related with the kilovoltage.[3]

Cone beam CT (CBCT) is a new modality in dental radiology that has rapidly become popular.[2] It has a high potential for solving many different diagnostic problems in dental radiology and will consequently change the panorama of examinations and exposed age groups.[2] When selecting an appropriate examination technique for each patient for a particular diagnostic task, the ALARA (As Low As Reasonably Achievable) principle should be followed.[2] What they have in common are three-dimensional (3D) imaging and, more importantly, reported lower radiation doses than conventional CT.[2] The reported radiation dose for CBCT is not consistent, as both different dose quantities and different methods have been used.[2]

In conventional CT, the DLP value can be used for estimation of the effective dose.[2] The CBCT units are often compared with conventional CT, mostly because they are both CT scanners and have 3D imaging.[2] But the group of CBCT machines differs more among itself in technique and reproduced volume than compared with the group of conventional CT machines.[2,4]

The aim of this study is to measure the DAP values in three CBCT units and then calculate the effective doses with conversion coefficient equation of voltage dependant, and to compare with the converted effective doses from multi-slice computed tomography (MSCT) for oral and maxillofacial region.

II. Materials and Methods

1. X-ray equipments

Three CBCT units (i-CAT® (Imaging Sciences International, Hatfield, PA), RayScan Symphony® (Ray Co., Gyungi-Do, Korea), and Alphard VEGA® (Asahi Co., Tokyo, JAPAN)) were used to measure the DAP values. DAP values were measured by each provided modes in Alphard VEGA®, such as D, I, P, and C mode.

Two MSCT units (Somatom Sensation 64® and Definition Flash® (Siemens Medical Solutions, Malvern, PA, USA)) were used to measure the DLP values.

The exposure protocols were as shown in Table 1.

Table 1. Exposure protocols.

Protocol			kVp	mA	Second	FOV (cm) (width X height)
CBCT	**i-CAT**	**Facial**	120	5	40	13 X 15
	RayScan Symphony	**Standard**	90	10	20	15 X 18
	Alphard VEGA	**D mode**	80	8	17	5 X 5
		I mode	80	8	17	10 X 10
		P mode	80	5	17	15 X 15
		C mode	80	5	17	18 X 20
64ch MSCT			100	300	7.48	18 X 20
128ch MSCT			100	300	4.56	18 X 20

2. DAP measurements

VacuDAP standard® (VacuTec, RTI Electronics, Dresden, Germany) ionization chamber was located in front of the X-ray sources in each CBCT units. The ionization chamber was connected to the monitor that displayed the measured value.(Figure 1) After exposure, the values were recorded. Effective doses were calculated using the conversion coefficient equation of voltage dependant.[6]

Figure 1. DAP ionization chamber was placed in front of X-ray source of CBCT unit.

3. DLP measurements

After taking facial 3D CT covering whole facial area in two MSCTs, DLP values were displayed on the monitor and recorded in the examination information.(Figure 2) The effective doses were calculated using the conversion coefficient for head CT (2.4 μSv/ mGy · cm).[7]

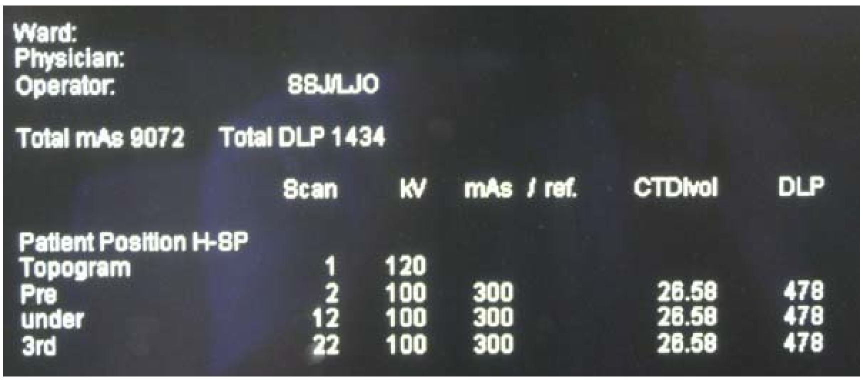

Figure 2. Recorded DLP values of 64ch MSCT after taking facial 3D CT.

III. Results

Measured DAP and DLP values and calculated effective doses are shown in Table 2 and 3.

The effective doses of CBCTs showed wide range by units and modes.

Effective doses of three CBCTs with the similar field of views (FOVs) were 161.9 μSv in RayScan Symphony, 213.6 μSv in i-CAT, and 358.4 μSv in P mode of Alphard VEGA, respectively.

The effective doses of Alphard VEGA were 80.6 μSv in D mode, 272.4 μSv in I mode, 358.4 μSv in P mode, and 433.5 μSv in C mode.

Effective doses of MSCTs with routine facial 3D protocols were quite larger than that in C mode of Alphard VEGA. The FOVs were same in 18 cm width and 20 cm height.

Comparison of effective doses is shown in Figure 3.

Table 2. Measured DAP values and calculated effective doses of CBCTs. [6]

		DAP (μGy・㎡)	DAP (mGy・㎠)	Effective dose (μSv) Conversion coefficient of voltage dependant: E/P_{KA} = 0.00145 x (kV) + 0.01188
i-CAT	**Facial**	114.9	1149	*213.6
RayScan Symphony	**Standard**	113.7	1137	161.9
Alphard VEGA	**D mode**	63.0	630	80.6
	I mode	213.0	2130	272.4
	P mode	280.3	2803	358.4
	C mode	339.0	3390	433.5

* 1149 mGy・㎠ x (0.00145 x [120 kV] + 0.01188) μSv/mGy・㎠ = 213.6 μSv

Table 3. DLP values and converted effective doses of MSCTs.[7]

	DLP (mGy · cm)	Effective dose (μSv)
64ch MSCT	478	*1147.2
128ch MSCT	679	1629.6

* 478 mGy · cm x 2.4 μSv/mGy · cm = 1147.2 μSv

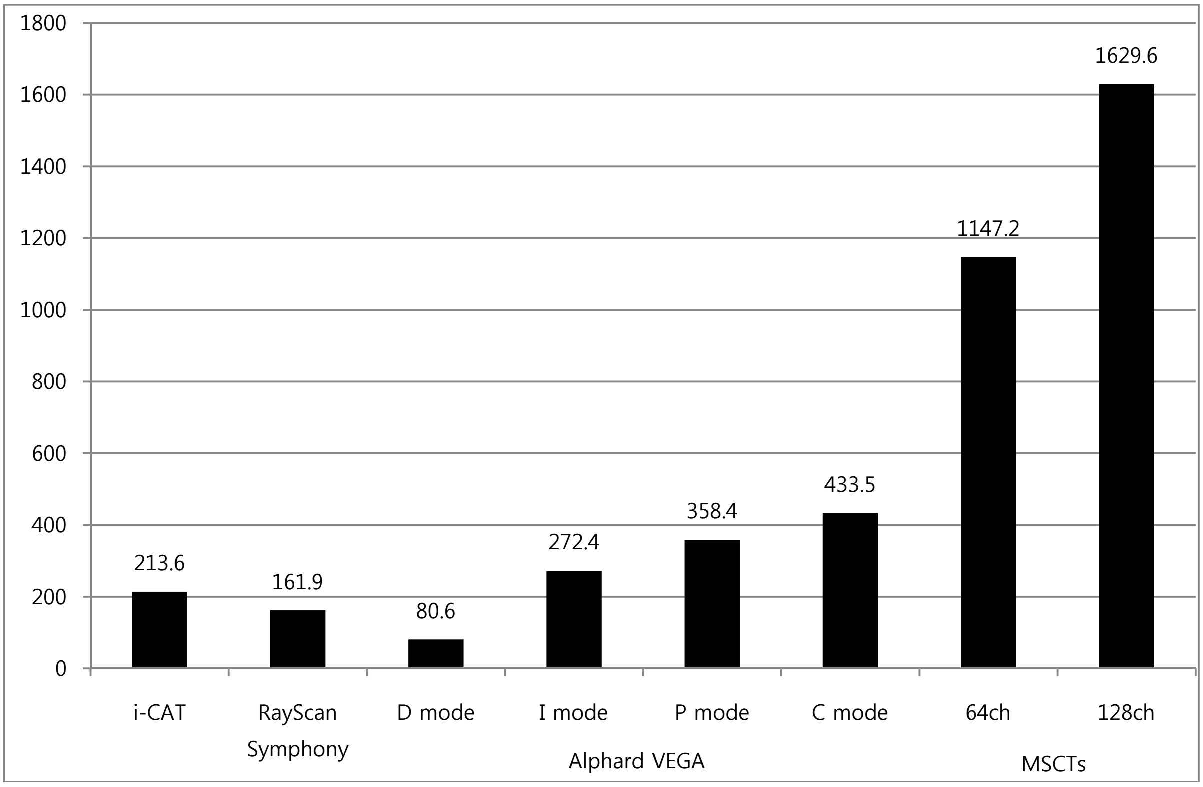

Figure 3. Effective doses of CBCTs and MSCTs.

IV. Discussion

Estimation of effective doses from radiographic examination is essential to develop selection criteria for radiological imaging, based on the risk-benefit analysis of the procedure.[4,8] Typically, these dose estimations are done using TLDs to measure the absorbed dose at various anatomic locations in an anthropomorphometric phantom.[9] Comparing with previous studies, they used different phantoms and used different numbers and positions of TLDs. The results are compared in Table 4.

Table 4. Comparison of effective doses (μSv) of CBCTs and MSCTs in previous studies.

	i-CAT NG	i-CAT Classic	RayScan Symphony	Alphard VEGA	New Tom	CB Mercu Ray	4ch CT	64ch CT	64ch Low-Dose	128ch CT
This Study		213.6	161.9	358.4 (P mode)				1147.2		1629.6
Pauwels (2010)[8]	83				83 (VG)					
Suomalainen (2009)[10]							685	1410		
Ludlow& Ivanovic (2008)[4]	74	69			68 (3G)	569		860	534	
Okano (2009)[11]						510.57	768.88			
Silva (2008)[12]		61.1			56.2 (9000)			429.7		
Davies (2012)[13]	78									
Loubele (2009)[14]		77			30 (3G)		1110			
Ludlow (2006)[4]		193.4								
Roberts (2009)[15]		182.1								
Jeong (2012)[16]	111.6 (KaVo)									

The only way to estimate precisely the absorbed dose for any organ is to use TLDs at as many locations as possible for this organ, because the absorbed dose is an average dose.[8] As reported by Ludlow and co-workers,[4] the reproducibility of the TLD technique can be low.[2] They found significant deviations for specific dosimeter locations, especially apparent in those placed on the skin.[2] Furthermore, the choice of weighting factors for radiation-sensitive organs (e.g. salivary glands) is unclear and the values of these factors have changed with time, and new weighting factors are under consideration.[2]

However, TLD technique has some disadvantages. Annealing time for TLD is very long. TLD chips are very fragile, so should be managed with great care. Choice of numbers and positions of TLDs, phantoms and the field of view (FOV) may have an influence to the results.

Recently, other techniques are introduced to replace TLD such as optically stimulated luminescent dosimeter (OSLD) and DAP.[1,9]

Optically stimulated luminescence dosimeters (OSLDs), composed of carbon-doped aluminum oxide, have been used for personnel dosimetry for more than a decade.[9] The basic principles of dose measurement are similar to that of thermoluminescent dosimeters (TLDs).[9] Like TLDs, energy from the incident photons produces electrons that are trapped at sites of crystal imperfections; however, instead of heating, the dose readout is performed by controlled illumination of the dosimeter with 540-nm light photons.[9] Recently, OSLD nanoDots® (Landauer Inc., Glenwood, IL, USA), a commercially available radiation dosimeter system, was introduced as a convenient alternative to TLD for point dosimetry.[9] OSLD system is more convenient for researchers to handling the chips and have similar results comparing with the TLD system. It is likely that OSLD system will replace TLD system for point dosimetry applications.[9] To replace TLD system, OSLD system need suitable human antromorphometric phantom for positioning OSLD chips into the holes like TLDs. But there is no phantom designed for OSLD chips now. In the future, modified human antromorphometric phantoms of adult male, adult female and child will be provided to apply OSLD system.

DAP can be measured shortly after exposure. So it can be used to manage the patient dose clinically. But some cautions should be given during DAP measurements. First, do not apply pressure on the ionization chamber when locating it in front of the X-ray source. Second, one should know the exact position of X-ray tube in the housing, and then locate the ionization chamber at the center of X-ray beam. Third, the connecting cable should not pull the ionization chamber during exposure. The best way to keep DAP ionization chamber into the best environment is to put the ionization chamber in front of the X-ray tube of CBCT. It can be suggested to the manufacturers for the management and reduction of patient dose.

DAP values can be converted to effective doses with conversion coefficient. In dental radiology, the conversion coefficients are reported in intraoral, panoramic and cephalometric radiography.[3,4,17,18,19] Many researchers are doing their efforts to find the conversion coefficient of CBCTs.[2,6] The reproduced volume, exposure parameters, radiation dose and its distribution, and design differ among the many CBCT brands.[2] Furthermore, the CBCT technique is still developing, both in the size of imaging field and the detector material, which may influence the radiation dose.[2] In previous studies, FOV and kilovoltage revealed to have a great influence to the patient dose. So in this study, three different CBCT units that have different FOVs and exposure protocols are used to compare the influence of FOV and kilovoltage.

Usually, tabular data of conversion coefficients are available to estimate effective dose from SAD for radiography, from DAP for fluoroscopy, or from CT dose index averaged over volume (CTDIvol) or dose-length product (DLP) for CT.[1] The goal is to convert the higher radiation doses delivered to a small portion of the body into an equivalent uniform dose to the entire body that carries the same risk for causing radiation-induced fatal and nonfatal cancers and serious hereditary effects to all generations.[1]

In this study, the conversion coefficient equation was used for calculating the effective doses of CBCTs, which is Batista et al. (2012) suggested. The equation is as follows;

$$\text{Conversion coefficient of voltage dependant } (E/P_{KA}) = 0.00145 \times (kV) + 0.01188$$

E : effective dose, P_{KA} : air kerma area product, kV : kilovoltage

DAP values were measured in i-CAT, RayScan Symphony, and Alphard VEGA. These three units have similar detectors, but have different FOVs and exposure protocols. The calculated effective dose of i-CAT was near to the results of former authors in Table 4. The effective dose of RayScan Symphony was lower than that of i-CAT. It can approve the result that the effective dose of CBCT was influenced by kilovoltage.

The effective doses by modes of Alphard VEGA showed wide range and that by I mode was near to that of i-CAT. In Alphard VEGA, the effective dose of small FOV (D mode) was quite lower than that of large FOV (C mode). It may be the result of beam collimation because the ionization chamber was placed just in front of X-ray source. And also it may approve the effective dose of CBCT was influenced by FOV. A proper FOV of CBCT suitable for the purpose must be chosen to decrease the patient exposure dose in clinical diagnostic use.

DLP values of two MSCTs (64ch and 128ch) were recorded, and the effective doses were calculated by the conversion coefficient of 2.4 μSv/ mGy · cm.[7] The effective doses of MSCTs were 3.2~10 times more than those of CBCTs. The effective doses of CBCTs were much lower than MSCTs in this study, but that of low-dose technique in MSCT[3,16] showed the near value to that by C mode in Alphard VEGA.

As the technology in software and hardware develops more and more, MSCT can acquire good CT images with lesser dose to the patient. In CBCT, new approach such as intermittent X-ray exposure can replace the constant X-ray exposure during the full exposure time for decreasing the patient exposure dose. And the point of compromise between patient exposure dose and image quality should be found.

In the future studies, more convenient way to measure patient dose will be developed, and more correct conversion coefficient tables will be provided, then we can manage patient exposure dose by CBCT quickly and easily. In that progress, DAP can be a good solution. And we can suggest to the manufacturers to equip DAP ionization chamber into their CBCT products for monitoring the patient dose like DLP in MSCT.

V. Conclusion

The effective doses of CBCTs were lower than those of MSCTs, but showed wide ranges depending on units and modes. DAP can be used as an easier and faster way to estimate the patient exposure dose in CBCTs, and can be acceptable to manage it.

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국문요약

구강 악안면 영역에서 변환 인자를 이용한 치과용 콘빔 CT와 다중절편 CT의 선량 측정

박 혁

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연구목적: 구강악안면영역에 이용되는 치과용 콘빔 CT(Cone beam CT, CBCT)와 다중절편 CT(Multi-slice CT, MSCT) 간의 유효선량을 비교하고자 한다.

재료 및 방법:

면적선량(dose area product, DAP)을 측정하기 위하여 VacuDAP® 전리함(ionization chamber)을 CBCT의 X선원 앞에 위치시켰다. 측정에는 3 종류의 CBCT가 사용되었다. 선량길이곱(Dose-length product , DLP) 값을 두 종류의 MSCT에서 획득하였다. 유효선량은 변환인자를 이용하여 환산하였다.

결과:

유사한 조사야(field of view, FOV)를 가진 3 종류 CBCT의 유효선량은 각각 161.9 μSv, 213.6 μSv, 그리고 358.4 μSv이었다. MSCT의 유효선량은 1147.2 μSv과 1629.6 μSv이었다. MSCT의 유효선량이 CBCT보다 3.2~10배 높았다.

결론:

CBCT의 유효선량이 MSCT보다 낮게 나타났으나, 기종과 촬영방법에 따라 넓은 범위를 나타내었다. DAP는 CBCT에서 환자의 선량을 측정하는데 있어 쉽고 빠른 방법으로 이용될 수 있으며, 선량 관리를 위해 이용될 수 있다.

핵심되는 말 : 선량측정; 유효선량; 면적선량; 선량길이곱; 변환인자; 콘빔CT, 다중절편 CT