Paediatric organ and effective doses in dental cone beam computed tomography

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Abstract— **Cone beam computed tomography (CBCT) is an x-ray emerging technology with wide applications in the dental and maxillofacial disciplines. Dental CBCT has been associated with higher radiation risk to the patients compared to conventional dental x-ray imaging.**

Several studies have investigated the radiation doses involved in dental CBCT for adults but none has looked into paediatric doses. This study estimates the organ and effective doses to two paediatric tissue-equivalent phantoms using thermoluminescent dosimeters for three dental CBCT units and six imaging protocols. The doses to the thyroid, salivary glands and brain ranged from 0.068mSv to 1.131mSv, 0.708mSv to 2.009mSv and 0.031mSv to 1.584mSv respectively. The skin and red bone marrow have received much lower doses than the other three organs.

The effective doses ranged from 0.022 mSv to 0.081 mSv. The highest effective dose was calculated for the NewTom VG using the dental protocol and the lowest was observed for the Next Generation i-CAT using the 6cm maxilla protocol. The effective doses calculated in this study were much higher than these of panoramic x-ray imaging but lower than conventional CT.

Keywords— **dental cone beam CT, organ dose, effective dose, paediatric**

I. INTRODUCTION

Dental Cone Beam Computed Tomography (CBCT) is a cutting-edge X-ray technology applied in oral and maxillofacial disciplines. The ability of the CBCT systems to provide 3-dimensional (3D) high resolution images with diagnostic reliability resulted in a significant CBCT increase in areas such as orthodontics, endodontics, oral medicine and surgery, periodontics and restorative dentistry [1-6]. The radiation absorbed dose to the patient is two-fold lower than conventional medical CT but three to seven times higher than conventional panoramic imaging [1-2]. Therefore it is of major importance to assess the radiation risk imposed on the patient by performing dental CBCT examination. The radiation risk should also be evaluated for paediatric patients since orthodontics x-ray imaging is primarily carried out on children and teenagers.

Several studies have measured absorbed organ and effective doses for a range of dental CBCT examinations and units using thermoluminescent dosimeters (TLDs) and anthropomorphic phantoms [1-3, 7-10]. Although these studies have measured doses to adult patients for a range of CBCT units and imaging protocols, none has estimated the organ and effective doses to paediatric patients. In addition, for most of the studies the number of TLDs used for measuring the average organ doses was rather limited which might have led to underestimation or overestimation of the organ absorbed and effective dose. For large organs such as the brain or for small organs such as the salivary glands which are positioned along several phantom slices, a large number of TLDs should be placed to ensure that the mean absorbed dose is accurately measured.

The aim of this study is to estimate average organ absorbed and effective doses to two paediatric anthropomorphic phantoms for a range of CBCT units and imaging protocols using a large number of TLDs.

II. METHODS AND MATERIALS

A. Anthropomorphic phantoms

Two tissue-equivalent anthropomorphic phantoms (ATOM Model 702-C and ATOM Model 706-C, Computerized Imaging Systems, Inc, USA) were used in the measurement of radiation absorbed doses. Models 702-C and 706-C simulate an adult female and a 10 year old child respectively. An adult female phantom was used to simulate a teenager as there are no commercially available teenager tissue equivalent anthropomorphic phantoms. The ATOM phantoms are based on ICRP 23 [11] and ICRU 48 [12] and available anatomical data. The tissue simulated in the ATOM phantoms are average bone and soft tissue, cartilage, spinal cord, spinal disks, lung, brain, sinus, trachea and bronchial cavities. The paediatric simulated bone tissues match age related density. The bone tissue is an average of known cortical to trabecular ratios and age based mineral densities.

The ATOM phantoms are available in 25 mm slices and for the purposes of this study the head, neck and shoulders of both phantoms were used as shown in figure 1.

B. Thermoluminescent dosimeters (TLDs)

The dose measurements were performed using thermoluinescent dosimeters chips TLD-100H, LiF:Mg,Cu,P (Harshaw Thermo Fisher Scientific Inc, USA). The TLDs were calibrated free in air against an ionisation chamber with calibration traceable to national standards. The calibration was performed using a conventional diagnostic x-ray tube at 80kV (HVL=3.02 mm Al). A flat energy TLD response was observed from 60 kV to 100 kV. Chips with a reproducibility error of less than 10% were used. The chips were read using an automatic TLD reader (Harshaw 5500, Harshaw Thermo Fisher Scientific Inc, USA). Five TLDs were kept outside the CBCT room to measure the background signal.

Fig. 1 ATOM Models 702-C and 706-C

C. Evaluation of organ and effective doses

Absorbed doses were measured in the brain, salivary glands, thyroid gland, red bone marrow, skin and lungs as these are the most radiosensitive organs in the head, neck and shoulders according to ICRP 103 [13]. Bone surface, oral mucosa and oesophagus are also listed as radiosensitive organs in the ICRP 103 [13]. It was assumed that the bone surface and oesophagus absorbed doses are equal to the red bone marrow and thyroid ones respectively. Multiplying the red bone marrow dose with the bone surface tissue weighting factor (w_T) resulted in an insignificant dose. The oral mucosa is listed as a 'remainder' organ and therefore its contribution to the average 'remainder' dose is insignificant since the rest of the 'remainder' organ doses are zero. Finally, the dose to the oesophagus was assumed to be small since it has to be fractionated over 14-16 slices. Therefore these three organs were not taken into account for the calculation of the effective dose.

For small organs such as the brain, salivary glands, thyroid gland, a uniform irradiation can be assumed and therefore the factors f_i which account for the fraction of the total mass of the specified organ in the phantoms slice i are reduced to unity. For large organs like the skin and the red bone marrow the average doses per slice were fractionated using the f_i values from the Huda *et al* study [14]. The effective dose was calculated as the product of the radiation weighted average organ doses and the relevant ICRP 103 [13] w_T summed over all of the tissues/organs exposed.

Table 1 Location and number of TLDs in the two ATOM phantoms

Organ	ATOM model 706-C		ATOM model 702-C	
	Number of TLDS	Slices	Number of TLDs	Slices
Brain	35	2-6	27	2-7
Right submandibular gland	2	8	2	7
Left submandibular gland	2	8	2	7
Right parotid gland	3	6-7	2	6
Left parotid gland	3	6-7	2	6
Sublingual gland	1	8	1	7
Thyroid gland	5	10	5	9
Red bone marrow	59	2-12	36	2-11
Skin	48	2-12	44	2-11

D. Dental CBCT units and imaging protocols

Table 2 shows the CBCT units and the imaging protocols used in this study while table 3 summarizes the exposure factors. The imaging protocols were the ones most frequently used by the dental practices.

Table 2 Dental CBCT units and Imaging protocols

Organ	Manufacturer	Imaging protocol
NewTom VG	QR s.r.l/AFP Imaging	Dental, Maxillofacial
Next Generation i-CAT	Imaging Sciences International	6 cm mandible, 6 cm maxilla, 10 cm
3D Accuitomo 170	Morita MFG. CORP	4x4 molar mandible

Table 3 Technical factors used in this study

	NewTom VG		Next Generation i-CAT (all protocols)		3D Accuitomo 170	
	702-C	706-C	702-C	706-C	702-C	706-C
kV	110	110	120	120	90	90
mA	2.5	2	5	5	5	3
mAs	8.2 (dental) 15.8 (max)	4.8 (dental) 11.7 (max)	18.5	18.5		
Scan time					17.5	17.5
FOV	9''	9''	6 x16 10x16	6 x16 10x16	4x4	4x4
Voxel size (mm)	0.3	0.3	0.4	0.4		

III. RESULTS

Tables 4 and 5 summarise the organ absorbed doses to the five radiosensitive organs for both phantoms. Figure 2 shows the effective doses for the two phantoms.

Table 4 Organ absorbed doses for the 10 year old phantom

	Red bone marrow (mGy)	Skin (mGy)	Thyroid (mGy)	Salivary glands (mGy)	Brain (mGy)
NewTom VG-Maxillofacial	0.165	0.088	0.197	0.708	1.584
NewTom VG-Dental	0.103	0.052	1.131	1.901	0.381
Next Generation i-CAT-6cm Mandible	0.045	0.030	0.380	1.563	0.077
Next Generation i-CAT-6cm Maxilla	0.086	0.036	0.190	1.021	0.285
Next Generation i-CAT-10 cm	0.090	0.040	0.485	1.678	0.228
3D Accuitomo 170	0.024	0.021	0.217	1.333	0.031
Average (mGy)	0.085	0.044	0.433	1.367	0.431

Table 5 Organ absorbed doses for the teenager phantom

	Red bone marrow (mGy)	Skin (mGy)	Thyroid (mGy)	Salivary glands (mGy)	Brain (mGy)
NewTom VG-Maxillofacial	0.222	0.107	0.107	1.627	1.438
NewTom VG-Dental	0.108	0.063	0.297	1.970	0.228
Next Generation i-CAT-6cm Mandible	0.040	0.025	0.134	1.427	0.047
Next Generation i-CAT-6cm Maxilla	0.058	0.029	0.068	1.084	0128
Next Generation i-CAT-10 cm	0.123	0.052	0.194	1.813	0.167
3D Accuitomo 170	0.038	0.033	0.179	2.009	0.042
Average (mGy)	0.098	0.052	0.163	1.655	0.342

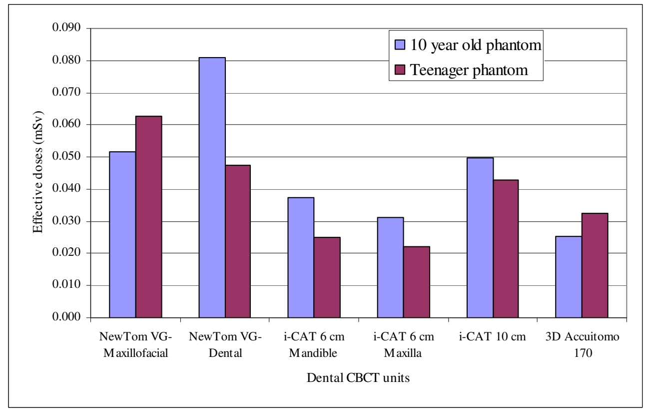

Fig. 2 Effective doses for the 706-C phantom (10 year old) and for the 702-C phantom (teenager)

IV. DISCUSSION

Figure 2 shows that the effective doses range from 0.025 mSv to 0.081 mSv for the 10 year old phantom and from 0.022 mSv to 0.063 mSv for the teenager phantom. The maxilla imaging protocol of the Next Generation i-CAT unit and the 3D Accuitomo give the lowest effective doses for the two phantoms. The highest effective doses for both phantoms were observed for the NewTom VG unit due mainly to its fixed large FOV.

The effective doses for the 10 year old phantom are higher than these of the teenager phantom for most of the CBCT units and imaging protocols. This is mainly due to the positioning of the thyroid, salivary glands and brain with respect to the primary beam. As the 10 year old phantom is smaller in size than the teenager phantom and the beam field sizes on the phantoms are fixed for the same imaging protocols, organs such as the thyroid, salivary glands and brain are more likely to be positioned either in or closer to the primary beam for the 10 year old phantom than for the teenager phantom. For example, there is an almost two-fold difference between effective doses for the NewTom VG-Dental. Comparing the thyroid doses between the two phantoms shows that the dose to the thyroid for the 10 year old phantom is almost four times higher than the one for the teenager phantom due mainly to the field size and positioning. The thyroid gland for the 10 year old (slice 9) was fully covered by the primary beam while the thyroid gland for the teenager phantom (slice 10) was outside the primary beam.

Tables 4 and 5 show that the red bone marrow and skin absorbed doses are lower than the thyroid, salivary glands and brain absorbed doses. For the NewTom VG unit and for the maxillofacial protocol, the brain contributes the most to the effective dose for the 10 year old phantom while for the teenager phantom the salivary glands contribute almost half of the effective dose. For the rest of the imaging protocols and units, the salivary glands contribute the most to the effective dose for the teenager phantom while for the 10 year old phantom there is an almost equal contribution from the salivary glands and thyroid gland to the effective dose.

Hayakawa *et al* [15] have calculated an average effective dose of 9.8 μSv from rotational panoramic radiograph. The average effective dose found in this study was 42 μSv. This study confirms that the effective doses involved in dental CBCT examinations are much higher than these involved in conventional dental x-ray imaging.

The % radiation-induced fatal cancer risk per Sv in a UK population for a 10 year old child is 11% and for a 15 year old is 10% [16]. This study has calculated an average effective dose of 0.046mSv for a 10 year old child and 0.039 mSv for a teenager. The % radiation-induced fatal cancer risk for a 10 year old child undergoing a dental CBCT exam is 0.0004% and for a teenager is 0.00028%.

V. Conclusions

This study has estimated the organ and effective doses to two paediatric tissue-equivalent anthropomorphic phantoms for three dental CBCT units and for six imaging protocols. It was found that the radiation doses to patients are significantly higher than the traditional x-ray imaging.

As children are more radiation sensitive than adults it is essential that the dental CBCT use is fully justified over conventional dental imaging techniques.

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References

1. Roberts JA, Drage NA, Davies J, Thomas DW (2009) Effective dose from cone beam CT examinations in dentistry. The British Journal of Radiology 82:35-40
2. Ludlow JB, Davies-Ludlow LE, Brooks SL and Howerton WB (2006) Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT. Dentomaxillofacial radiology 35:219-226
3. Hirch E, Wolf U, Heinicke F and Silva MAG (2008) Dosimetry of the cone beam computed tomography Veraviewepocs 3D compared with the 3D Accuitomo in different fields of view. Dentomaxillofacial Radiology 37:268-273
4. Guerrero ME, Reinhilde J, Loubele M, Schutyser F, Suetens P and van Steenberghe D (2006) State-of-the-art on cone beam CT imaging for preoperative planning of implant placement. Clinical Oral Investigations 10:1-7
5. Ziegler CM, Woertche R, Brief J, Hassfeld S (2002) Clinical indications for digital volume tomography in oral and maxillofacial surgery
6. Mah J, Enciso R, Jorgensen M (2003) Management of impacted cuspids using 3-D volumetric imaging. J Calif Dent Assoc 31:935-41
7. Ludlow JB, Davies-Ludlow LE, Brooks SL (2003) Dosimetry of two extraoral direct digital imaging devices: NewTom cone beam CT and Orthophos Plus DS panoramic unit. Dentomaxillofacial Radiology 32:229-34
8. Silva MAG, Wolf U, Heinicke F, Bumann A, Visser H and Hirch E (2008) Cone-beam computed tomography for routine orthodontic treatment planning: A radiation dose evaluation. American Journal of Orthodontics and Dentofacial Orthopedics 133:640.e1-e5
9. Hashimoto K, Arai Y, Iwai K, Araki M, Kawashima S, Terakado M (2003) A comparison of a new limited cone beam computed tomography machine for dental use with a multidetector row helical CT machine Oral Surg Oral Med Oral Pathol Oral Radiol Endod 95:371-77
10. Lofthag-Hansen S, Thilander-Klang A, Ekestubbe A, Helmrot E, Gröndahl K (2008) Calculating effective dose on a cone beam computed tomography device: 3D Accuitomo and 3D Accuitomo FPD. Dentomaxillofacial Radiology 37:72-79
11. International Commission on Radiological Protection (1975) ICRP Publication 23: Reference Man: Anatomical, physiological and metabolic characteristics, (1975) Pergammon Press, England
12. International Commission on Radiation Units and Measurements (1992) ICRU Report 48 Phantoms and computational models in therapy, diagnosis and protection.
13. International Commission on Radiological Protection ICRP Publication 103 (2007) Recommendations of the International Commission on Radiological Protection. Annals of the ICRP. Elsevier Ltd.
14. Huda W and Sandison (1984) Estimation of mean organ doses in diagnostic radiology from Rando phantom measurements. Helth Physics 47:463-467
15. Hayakawa Y, Kobayashi N, Kuroyanagi K, Nishizawa K (2001) Paediatric absorbed dose from rotational panoramic radiography. Dentomaxillofacial radiology 30:285-292
16. National Radiological Protection Board (1993) Board Statement on Diagnostic Medical Exposures to Ionising Radiation During Pregnancy and Estimates of Late Radiation Risks to the UK population

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