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Thyroid shields for radiation dose reduction during cone beam computed tomography scanning for different oral and maxillofacial regions

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ABSTRACT

Aims: To evaluate the radiation dose level during cone beam computed tomography (CBCT) scanning for the different oral and maxillofacial regions with and without thyroid collar shielding.
Materials and methods: Average tissue-absorbed dose for a DCT PRO CBCT was measured using thermoluminescent dosimeter chips in a phantom with or without applying thyroid collars. Effective organ dose and total effective dose were derived using International Commission on Radiological Protection (ICRP) 2007 recommendations.
Results: The total effective doses for large, middle and small field of view (FOV) were 254.3 μSv, 249.0 μSv and 180.3 μSv, respectively, when no thyroid collar was used. Applying one thyroid collar around the front neck can reduce the total effective doses to 208.5 μSv (18.0% reduction), 149.1 μSv (40.1% reduction) and 110.5 μSv (38.7% reduction), respectively. When two thyroid collars were used around the front and back neck, the total effective doses were reduced to 219.1 μSv (13.8% reduction), 142.0 μSv (43.0% reduction) and 105.5 μSv (41.5% reduction), respectively.
Conclusions: Thyroid collar can reduce the radiation dose during CBCT scanning for the oral and maxillofacial regions. The dose reduction becomes more significant when middle or small FOV is chosen.

1. Introduction

Cone beam computed tomography (CBCT) has been applied in dentistry for more than ten years [1,2]. Compared to multi-slice computed tomography (MSCT), CBCT can provide images of high quality while utilizing cheaper equipments and potentially lower radiation dose [3]. Thus, this technology has been widely applied in diagnosis for oral and maxillofacial lesions [4–8]. Meanwhile, CBCT scanning may inevitably increase the radiation dose delivered to patients. Therefore, concerns about the radiation doses from CBCT scanning occurred [9–11].

Radiation dose should be reduced to a minimum without loss of diagnostic information [12]. Dose minimization is more important to children and young adults, who are more sensitive to radiation. Thyroid gland is one of the most radiosensitive organs and made a large contribution in total effective dose calculation during CBCT scanning for the oral and maxillofacial regions [9]. Thyroid collar was found to reduce radiation doses significantly during CBCT scanning for the oral and maxillofacial regions by using the collars tightly around the front neck of the patient. In this study, the CBCT NewTom 9000 was employed. This unit is one of the first generation CBCTs and provides supine position for patient (Qu et al., unpublished results).

Nowadays, most of CBCT units can provide different field of view (FOV) for scanning. By reducing the FOV, the radiation dose can be reduced [13,14]. Meanwhile, most of CBCT units employ a seat or standing method to position the patient. Then, the question is whether the thyroid collar is still effective when the patient is in an upright position, and the FOV is reduced to a certain size during scanning. The aim of the present study was therefore to evaluate the radiation dose level during CBCT scanning for the different oral and maxillofacial regions with thyroid collars for a phantom in an upright position.

2. Materials and methods

2.1. CBCT scanner

A DCT PRO (VATECH, Yongin-Si, Korea) CBCT scanner was employed in this study. The machine uses a cone-shaped X-ray beam centered on an area detector made from complementary metal oxide semiconductor transistor. Three FOVs are

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Table 1
Locations of TLD dosemeter chips as utilized by Ludlow to determine effective dose.

TLD ID	Phantom location	Rando level
1	Calvarium anterior	2
2	Calvarium right	2
3	Calvarium posterior	2
4	Mid brain	2
5	Pituitary	3
6	Right orbit	4
7	Left orbit	4
8	Right lens of eye	3
9	Left lens of eye	3
10	Left cheek	5
11	Right parotid	6
12	Left parotid	6
13	Right ramus	6
14	Center cervical spine	6
15	Left back of neck	7
16	Right mandible body	7
17	Left mandible body	7
18	Right submandibular gland	7
19	Left submandibular gland	7
20	Thyroid	9
21	Esophagus	9

available: 20 cm × 19 cm, 16 cm × 10 cm and 16 cm × 7 cm (diameter × height). The large FOV (20 cm × 19 cm) can include the entire oral and maxillofacial regions while the middle FOV (16 cm × 10 cm) can include both the maxilla and mandible. In this study, the small FOV (16 cm × 7 cm) was specially adjusted for the scanning of mandible. The scanning time was 15 s with a tube voltage of 90 kV and tube current of 7 mA.

2.2. Phantom

An anthropomorphic adult human male phantom (ART-210, Radiology Support Devices, Inc., Long Beach, CA, USA) was used in this study. The phantom was with tissue equivalent X-ray attenuating characteristics and closely conforms to the International Commission on Radiation Units and Measurements specifications [15].

2.3. Thyroid collar shielding technique

The CBCT scan was performed with applying 0.35 mm Pb thyroid collar (model HRNG-I, Beijing Huaren Health Science & Technology Developing Co., Ltd., Beijing, China) around the neck surface of the phantom. To obtain a maximum protection, scans with two collars placed around the front and back neck surface were carried out as well. Thus, for each FOV setting, three scans were completed:

1. without collar around the neck;
2. with one collar tightly around the front neck;
3. with two collars tightly around the front and back neck.

The placement of thyroid collars on the phantom was shown in Fig. 1.

2.4. Absorbed dose measurement

The absorbed doses were measured using thermoluminescent dosimeter (TLD) chips (LiF:Mg, Cu, P). Before the study, all dosimeters were calibrated using Co-60 source. Three chips were positioned at each of 21 locations within the head and neck region of the phantom. The method presented by Ludlow et al. [11] was used to position the TLD chips (Table 1). Prior to loading, the TLDs were annealed at 240 °C for 10 min and then cooled immediately to ambient temperature. All TLDs were read within 90 min after each exposure using a BR2000D reader (Beijing Bochuangte Science & Technology Development Co., Ltd., Beijing, China). The consistency of dose measurement by the TLD system has been evaluated in the previous study [13].

During each scanning, 6 non-irradiated TLDs were kept outside the scanning room to measure the background radiation dose, which was subtracted from the measured dose values later on. To ensure that even small radiation doses could be measured, the phantom was exposed five times during each examination protocol without changing the phantom position. It was assumed that the radiation dose delivered on each exposure was the same when the CBCT machine is well-maintained. Measured values from TLDs at different positions within a tissue or organ were divided by five to express the average tissue-absorbed dose per examination in micro-gray (μGy).

Table 2
Estimated percentage of tissue irradiated and TLDs used to calculate mean absorbed dose to a tissue or organ.

	Fraction irradiated (%)		TLD ID
	Large and middle FOV	Small FOV for mandible	
Bone marrow	16.5	5	
Mandible	1.3	1.3	13, 16, 17
Calvaria	11.8	2	1, 2, 3
Cervical spine	3.4	1.7	14
Thyroid	100	100	20
Esophagus	10	10	21
Skin	5	2	8, 9, 10, 15
Bone surface	16.5	5	
Mandible	1.3	1.3	13, 16, 17
Calvaria	11.8	2	1, 2, 3
Cervical spine	3.4	1.7	14
Salivary glands	100	100	
Parotid	100	100	11, 12
Submandibular	100	100	18, 19
Brain	100	20	4, 5
Remainder			
Lymphatic nodes	5	5	11–14, 16–19, 21
Muscle	5	5	11–14, 16–19, 21
Extrathoracic airway	100	100	6, 7, 11–14, 16–19, 21
Oral mucosa	100	100	11–13, 16–19

2.5. Effective dose calculation

As suggested by Roberts et al. [16], the average absorbed dose and the percentage of a tissue or organ irradiated in an examination (Table 2) were used to calculate the radiation weighted dose (H_T) in micro-sievert (μSv).

Using the 2007 International Commission on Radiological Protection (ICRP) [17] recommended tissue weights (bone marrow: 0.12; thyroid: 0.04; esophagus: 0.04; skin: 0.01; bone surface: 0.01; salivary glands: 0.01; brain: 0.01; remainder tissues/organs: 0.12), the effective organ dose (μSv) was calculated as the product of the equivalent dose and the relevant ICRP tissue weighting factor (w_T). The total effective dose was summed over all the effective organ doses (*i.e.* $E = \sum w_T \times H_T$).

2.6. Statistical analysis

Effective organ doses and the total effective doses resulting from each protocol were assessed statistically using one-way ANOVA. A significant difference was considered when $p < 0.05$.

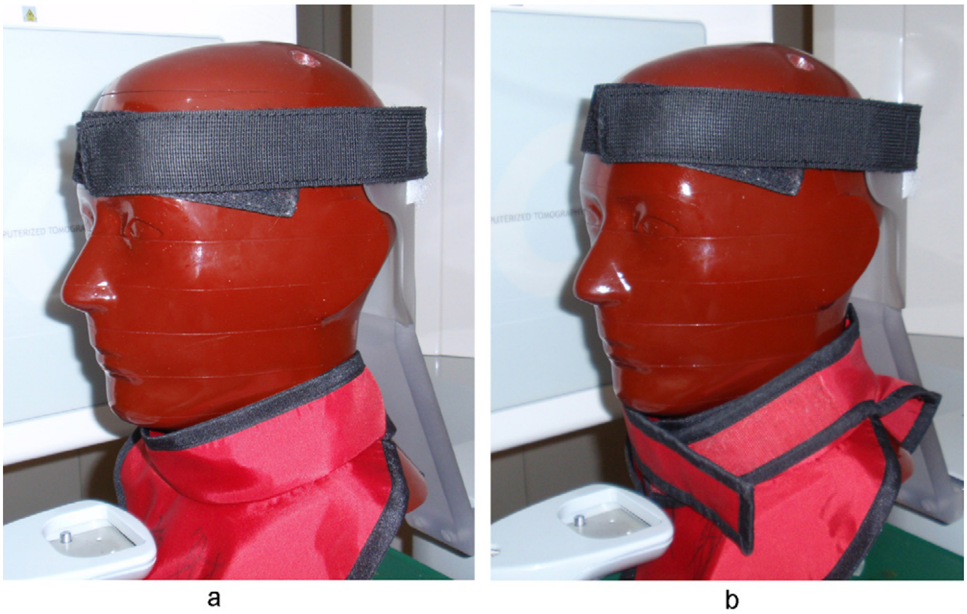

Fig. 1. The placement of thyroid collars. (a) With one collar tightly around the front neck and (b) with two collars tightly around the front and back neck.

3. Results

Fig. 2 shows the images acquired from DCT PRO CBCT scans with three FOVs. The total effective doses for large, middle and small FOV were 254.3 μSv, 249.0 μSv and 180.3 μSv, respectively, when no thyroid collar was used. However, when one thyroid collar was tightly around on the front neck, the total effective doses were reduced to 208.5 μSv (18.0% reduction), 149.1 μSv (40.1% reduction) and 110.5 μSv (38.7% reduction), respectively. With applying two thyroid collars tightly around the front and back neck, the total effective doses could be respectively reduced to 219.1 μSv (13.8% reduction), 142.0 μSv (43.0% reduction) and 105.5 μSv (41.5% reduction).

As displayed in Table 3, by the use of thyroid collar, the effective organ doses for thyroid gland and esophagus can be significantly reduced to a low level ($p < 0.05$). Fig. 3 shows the effective organ dose contribution to the calculation of total effective dose for each FOV scanning.

4. Discussion

Reducing the size of the FOV is an available option that can reduce radiation dose without loss of CBCT image quality. To comply with the requirement for different diagnostic tasks, most of the nowadays CBCT scanners can provide different FOVs for scanning. The DCT PRO CBCT scanner is such a unit and can provide three FOVs. The present study has examined radiation doses (via a phantom) during the DCT PRO CBCT scanning for different oral and maxillofacial regions. The total effective dose becomes lower when scanning with a smaller FOV. On the other hand, the same percentage of an irradiated tissue or organ was used when calculating the total effective dose for the large and middle FOV examinations (Table 2), the calculated total effective dose with large FOV may be underestimated.

According to the Biological Effects of Ionizing Radiation VII report, *Health Risks from Exposure to Low Levels of Ionizing Radiation*, thyroid gland is particularly radiosensitive with stochastic effects that specifically include the induction of thyroid carcinoma [18]. In the CBCT scanning for oral and maxillofacial regions, thyroid gland is often irradiated.

Thyroid collar can resist some X-ray delivered to the neck tissue and organs. In a previous study, the thyroid collars could result in a significant reduction on the effective organ doses for thyroid gland and esophagus (Qu et al., unpublished results). This is also confirmed by the present study. Therefore, thyroid shielding is strongly recommended during CBCT scanning for the oral and maxillofacial regions. Since there is no significant difference on radiation dose reduction between the scan with one collar on the front neck and that with two collars on both the front and back neck, the use of one thyroid collar on

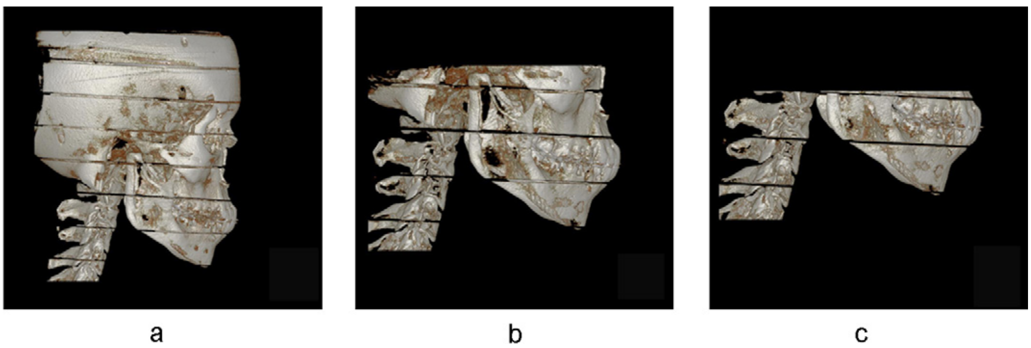

Fig. 2. The 3-D images acquired by DCT PRO with 3 sizes of field of view (FOV). (a) Large FOV, 20 cm × 19 cm; (b) middle FOV, 16 cm × 10 cm and (c) small FOV for mandible, 16 cm × 7 cm.

Table 3
Effective organ dose and total effective dose (μSv) for the different scanning protocols of the DCT PRO.

	FOV (cm)								
	20 × 19			16 × 10			16 × 7		
	1	2	3	1	2	3	1	2	3
Bone marrow	46.9	48.8	50.0	20.4	17.9	16.9	9.1	10.1	10.1
Thyroid	75.8	25.0*	29.1*	108.0	30.7*	29.6*	94.4	27.8*	27.8*
Esophagus	5.7	1.9*	2.0*	6.6	2.1*	1.9*	6.0	2.3*	2.3*
Skin	1.6	1.8	1.8	1.1	1.0	0.8	0.2	0.3	0.3
Bone Surface	12.6	13.1	13.4	5.5	4.8	4.5	2.4	2.7	2.7
Salivary glands	32.1	33.2	36.2	37.8	32.8	29.6	22.8	21.8	19.1
Brain	17.4	18.6	18.5	2.9	2.7	2.5	0.2	0.2	0.2
Reminder	62.2	66.1	68.1	66.7	57.1	56.2	45.2	45.3	43.0
Total	254.3	208.5	219.1	249.0	149.1*	142.0*	180.3	110.5*	105.5*

Shielding methods: 1 without collar around the neck; 2 with one collar tightly around the front neck; 3 with two collars tightly around the front and back neck.
* $p < 0.05$.

the front neck is recommended during CBCT scanning of the head.

Furthermore, applying thyroid collars can result in larger reduction on the total effective dose in CBCT scanning with middle or small FOV than that with large FOV. The reason was that in CBCT scanning with middle or small FOV, the effective organ doses of thyroid gland contribute much more in the calculation of the total effective dose (Fig. 3). Thus, when CBCT scanning is carried out with middle or small FOV, the protection for thyroid gland becomes more important.

Although the radiation dose was significantly reduced by the use of thyroid collars, the total effective dose for middle FOV (149.1 μSv) was still higher than that for small FOV (110.5 μSv). Thus, according to the ALARA (as low as reasonably achievable) principle, the small FOV should be selected on the premise that the examination interest could be included.

A significant dose reduction of esophagus was also observed in the present study when applying thyroid collar. However, the total amount of the dose reduced was very small. This limits its contribution to the effective dose calculation and results in a minimal clinical significance.

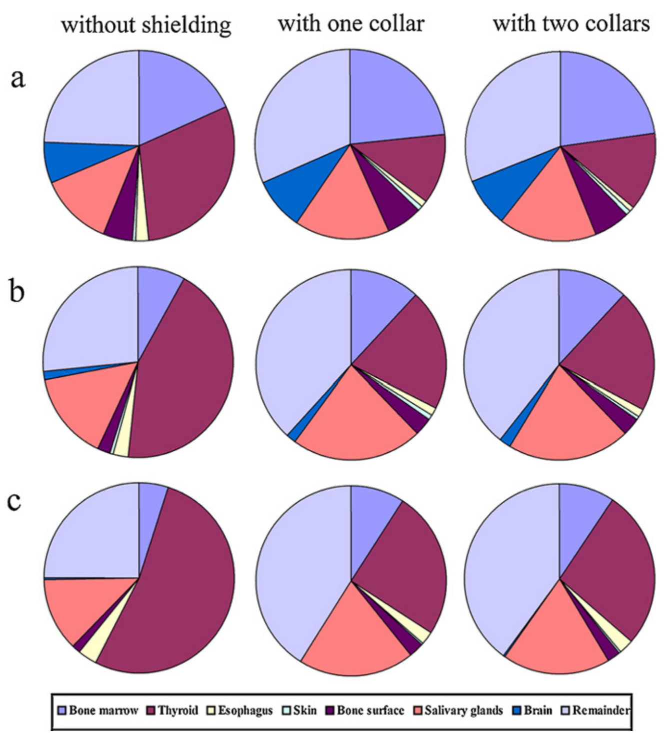

Fig. 3. Contribution of irradiated organs to the calculation of the total effective dose. (a) Large FOV, 20 cm × 19 cm; (b) middle FOV, 16 cm × 10 cm and (c) small FOV for mandible, 16 cm × 7 cm.

Since the application of thyroid collars may sometimes affect the image quality of mandible, in order to avoid this effect, the patients may be asked to lift their chin to ensure the inferior border of the mandible parallel to the horizontal plane during CBCT scanning.

5. Conclusions

In the present study, application of thyroid collar can reduce radiation dose during CBCT scanning for the oral and maxillofacial regions. The dose reduction becomes more significant when small or middle FOV is selected for scanning.

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