Radiation Physics and Chemistry 104 (2014) 287–291

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

Radiation dose evaluation of dental cone beam computed tomography using an anthropomorphic adult head phantom

Jay Wu [a,*], Cheng-Ting Shih [b], Chang-hung Ho [c], Yan-Lin Liu [d], Yuan-Jen Chang [e], Max Min Chao [c], Jui-Ting Hsu [f]

[a] Department of Biomedical Imaging and Radiological Science, China Medical University, No. 91, Hsueh-Shih Road, Taichung City 40202, Taiwan, ROC
[b] Department of Biomedical Engineering and Environmental Sciences, National Tsing-Hua University, 101, Section 2, Kuang-Fu Road, Hsinchu City 30013, Taiwan, ROC
[c] Department of Medical Imaging and Radiological Science, Central Taiwan University of Science and Technology, No. 666, Buzih Road, Beitun District, Taichung City 40601, Taiwan, ROC
[d] Institute of Nucelar Engineering and Science, National Tsing-Hua University, 101, Section 2, Kuang-Fu Road, Hsinchu City 30013, Taiwan, ROC
[e] Department of Management Information Systems, Central Taiwan University of Science and Technology, No. 666, Buzih Road, Beitun District, Taichung City 40601, Taiwan, ROC
[f] School of Dentistry, China Medical University, No. 91, Hsueh-Shih Road, Taichung City 40202, Taiwan, ROC

HIGHLIGHTS

- A home-made anthropomorphic adult head phantom was proposed.
- The proposed phantom can be easily built with lower price than the standard Rando phantom.
- The proposed phantom can be used for evaluating the effective dose during dental CBCT scanning.

ARTICLE INFO

Article history:
Received 24 June 2013
Accepted 22 November 2013
Available online 4 December 2013

Keywords:
Dental cone beam computed tomography (CBCT)
Anthropomorphic phantom
Thermoluminescent dosimeters (TLD)

ABSTRACT

Dental cone beam computed tomography (CBCT) provides high-resolution tomographic images and has been gradually used in clinical practice. Thus, it is important to examine the amount of radiation dose resulting from dental CBCT examinations. In this study, we developed an in-house anthropomorphic adult head phantom to evaluate the level of effective dose. The anthropomorphic phantom was made of acrylic and filled with plaster to replace the bony tissue. The contour of the head was extracted from a set of adult computed tomography (CT) images. Different combinations of the scanning parameters of CBCT were applied. Thermoluminescent dosimeters (TLDs) were used to measure the absorbed doses at 19 locations in the head and neck regions. The effective doses measured using the proposed phantom at 65, 75, and 85 kVp in the D-mode were 72.23, 100.31, and 134.29 μSv, respectively. In the I-mode, the effective doses were 108.24, 190.99, and 246.48 μSv, respectively. The maximum percent error between the doses measured by the proposed phantom and the Rando phantom was 14.90%. Therefore, the proposed anthropomorphic adult head phantom is applicable for assessing the radiation dose resulting from clinical dental CBCT.

1. Introduction

Dental cone beam computed tomography (CBCT) can rapidly provide high-resolution cross-sectional images for clinical diagnoses. By using surface and volume rendering, the three-dimensional (3D) structures of the bones and soft tissues in the oral cavity, such as the maxilla and mandible, can be reconstructed (Kuszyk et al., 1996; Cavalcanti et al., 2004; Scarfe et al., 2006). Visualizing these structures by using 2D and 3D images helps dental practitioners accurately and safely perform dental therapies such as orthodontic therapy (Scarfe et al., 2006; Silva et al., 2008), implantation (Ruivo et al., 2009; King et al., 2012), and dentition reconstruction (Qiu et al., 2012; Barone et al., 2013). In addition, dental CBCT images with a large field of view (FOV) are used to diagnose lesions around the oral and sinus cavity (Simon et al., 2006) and guide the reconstruction or reshaping of facial bones (Meng et al., 2012). Because of these applications, dental CBCT has become a vital diagnostic tool in clinical practice. Consequently, it is essential to evaluate the radiation dose of dental CBCT.

* Corresponding author. Tel.: +886 4 22053366x7809; fax: +886 4 22053366.
E-mail address: jwu@mail.cmu.edu.tw (J. Wu).

0969-806X/$ - see front matter
http://dx.doi.org/10.1016/j.radphyschem.2013.11.024

Several measurement tools, such as the dose area product (DAP) meter (Poppe et al., 2007; Lofthag-Hansen et al., 2008; Han et al., 2012), metal-oxide semiconductor field-effect transistor (MOSFET) (Koivisto et al., 2012), and Farmer-type ion chamber (Yu et al., 2010; Batista et al., 2012), have been used to evaluate the dose of dental CBCT. In addition, thermoluminescent dosimeters (TLDs) coupled with an anthropomorphic phantom are an effective tool for measuring dental CBCT radiation doses (Ludlow et al., 2006; Roberts et al., 2009; Qu et al., 2012). TLDs are inserted in the phantom at different locations corresponding to specific organs. The effective dose is calculated based on the TLD readout by applying the conversion factor and the tissue weighting factors. At present, the Alderson Rando anthropomorphic phantom made in accordance with the ICRU-44 standards (ICRU, 1989) is commonly applied in clinical dose evaluations (Ludlow and Ivanovic, 2008). The phantom is shaped to a human torso and sectioned into slabs. Its composition simulates human muscle, bone, air cavities, and other tissues. The tissue-equivalence of the Rando phantom for the beam quality of diagnostic x-rays has been proven (Tsiklakis et al., 2005).

In this study, we proposed a home-made anthropomorphic adult head phantom. The phantom was built by stacking polymethylmethacrylate (PMMA) slabs that were segmented based on actual CT images of the head and neck of a patient. Dental restorative materials were used to fill the bone sites to mimic the bony structures. The proposed phantom was used to measure the x-rays emitted from the CBCT scanner. After comparing our measurements with those of the Rando phantom, we could determine the applicable of the proposed head phantom for evaluating the effective dose during dental CBCT scanning.

2. Materials and methods

2.1. Self-made anthropomorphic phantom

The anthropomorphic phantom built in this study was based on a set of CT images of a 78 years old male patient (170 cm and 68 kg). Two thresholds of −250 HU and 200 HU were applied on these images to segment the contours of the head, air cavity, and bony structures. These contours were then used to guide the laser cutting machine to cut the PMMA slabs automatically. To simulate the bone in our phantom, the plaster–water mixture with a volume ratio of 2:1 was filled into the bony compartments in each PMMA slab. After 4 h of solidification of the mixture in the ambient condition, the PMMA slabs were stacked up and fixed by two PMMA rods across the slabs.

2.2. Dental CBCT scanner

A commercially available dental CBCT scanner (AZ3000, Asahi Roentgen, Japan) was used. It was calibrated for geometric alignment, center of rotation, image resolution, and image uniformity before the study. Four exposure protocols are available in this scanner, including panoramic, temporomandibular joint (TMJ), cephalometric and tomo scans, and two FOVs can be set including the dental mode (D-mode) and the child mode (I-mode). Table 1 shows the specifications of the dental CBCT. Here, we used the tomo scan protocol, which can be at 65, 75, and 85 kVp and D/I mode, to evaluate the radiation doses of the proposed phantom and Rando phantom. The tube current (mA) and the scan time (s) of the scanning protocol were set to 6 mA and 17 s, respectively.

2.3. Dose measurements

TLD chips (TLD-100, LiF: Mg, Ti), having a minimum detection limit of 0.3 mGy and linear dose response between 0.3 and 32 mGy (Bauk et al., 2011), were used to measure the absorbed dose. First, the TLDs were put into a thin PMMA disk and then irradiated against an ion chamber by using 85 kVp and 102 mAs. The field size was 20 × 20 cm^2 to cover the entire disk. The TLDs were read out after 24 h post-irradiation by the RA'94 TLD reader-analyzer (Microlab, Poland). Any TLD with a dose-response variation greater than 5% was excluded from further usage and analysis. The thermoluminescent (TL) signal of the TLD chip was divided by the mean TL signal, and the results were used as calibration factors.

A total amount of 57 TLDs were selected. 19 locations in the anthropomorphic phantom were chosen and listed in Table 2; several small holes were drilled accordingly in the phantom and three TLD chips were inserted in each location. The measurement was repeated three times at each location using the tomo scan protocol with both FOVs and three kVps. The effective doses of the proposed phantom and the Rando phantom were evaluated.

Table 1
Specifications of the dental cone-beam computed tomography operated in two scanning modes.

Specifications	D-mode	I-mode
Filed size (mm)	51 × 51	71 × 71
Voxel size (mm)	0.1 × 0.1 × 0.1	0.155 × 0.155 × 0.155
Tube voltage (kVp)	60–100	
Tube current (mA)	4, 6, 8, 10, and 12	
Focus size (mm)	0.5 × 0.5	
Total filtration	2.8 mm Al	
Scan protocol	Panoramic, TMJ, Cephalometric, Tomo	

Table 2
Locations of TLDs in the self-made adult head phantom and the Rando phantom.

Location	Location	Slab number	
		Self-made	Rando
1	Calvarium posterior	2	5
2	Calvarium anterior	2	5
3	mid brain	2	5
4	Right lens of eye	3	8
5	Left lens of eye	3	8
6	Right cheek	5	11
7	Centre cervical spine	6	12
8	Right parotid	6	12
9	Left parotid	6	12
10	Right ramus	6	12
11	Left ramus	6	12
12	Right submandibular gland	7	14
13	Left submandibular gland	7	14
14	Right mandible body	7	14
15	Left mandible body	7	14
16	Sublingual gland	7	14
17	Right thyroid	9	18
18	Left thyroid	9	18
19	Back of neck	9	18

2.4. Calculating the effective dose of radiation

The readouts of TLDs were converted to the equivalent dose by using the dose response curve (Fig. 1) with r^2 value of 0.993 and the radiation weighting factor ($w_R = 1$). Furthermore, the effective dose (E) (Roberts et al., 2009) was calculated as follows:

$$E = \sum_{T} W_T H_T \quad (1)$$

where T indicates the organ or tissue of interest. W_T denotes the tissue weighting factor for the organ or tissue T. H_T is the tissue