Influence of CBCT exposure conditions on radiation dose

J. Martin Palomo, DDS, MSD,[a] Pejavar S. Rao, PhD,[b] and Mark G. Hans, DDS, MSD[c]
Cleveland, OH
CASE WESTERN RESERVE UNIVERSITY

Background. Cone-beam computed tomography (CBCT) has been changing the way dental practitioners use imaging. The radiation dose to the patient and how to effectively reduce the dose is still not completely clear to most users of this technology.
Objective. The objective of this study was to quantitate the change in radiation dose when using different CBCT settings.
Methods. A CBCT machine was modified to allow different setting combinations. The variables consisted of 4 different mA choices (2, 5, 10, and 15), 2 kVp choices (100 and 120), and 3 fields of view (6 inches, 9 inches, and 12 inches). A radiation phantom with 10 thermoluminescent dosimeters (TLD) was used to measure radiation dose. One specific setting (15 mA, 120 kVp, and 12-inch FOV) was scanned 3 times to determine consistency.
Results. The CBCT showed less than 5% variance in radiation dose values. An overall reduction in dose of about 0.62 times was achieved by reducing the kVp from 120 to 100. When reducing the field size the dose decreased 5% to 10%, while for organs that escaped the direct beam the reduction was far greater.
Conclusions. A reduction in radiation dose can be achieved by using the lowest exposure settings and narrow collimation. **(Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;105:773-82)**

The first cone-beam computed tomography (CBCT) scanner to receive Food and Drug Administration approval was the NewTom QR-DVT 9000 (Quantitative Radiology Srl, Verona, Italy) in March 2001,[1] and since then there has been a very rapid adoption of this technology, practically revolutionizing dental imaging.

When compared to conventional CT scanners, CBCT machines show 2 major differences in their hardware. First, CBCT uses a low-output fixed anode tube, similar to what is used in dental panoramic x-ray machines. Second, CBCT machines rotate around the patient only once, capturing the data by using a cone-shaped x-ray beam. These changes allow for a less expensive, smaller machine that exposes the patient to approximately 20% of the radiation of a helical CT, and equivalent to the dose from a full-mouth periapical series.[2-9]

There are several different CBCT scanners currently in the market, all using cone-beam CT technology, with some differences. The major difference between the scanners is in the detector used, which can be either an amorphous silicon flat-panel detector, or a combination of image intensifier and charge-coupled device (CCD) camera. Both of these technologies have been proven to be accurate and reliable, and currently provide sufficient resolution for the needs of dental imaging. Another difference is in the choice of parameters like kVp and mA, which can be operator controlled or preset into fixed combinations, depending on the machine.

With such a new technology offered by different manufacturers and little understood by most consumers, some concerns have arisen; probably the most common one has had to do with patient's radiation dose. The CBCT scanner is an x-ray imaging device[1] using ionizing radiation to capture images, and is subject to the same physical principles that apply to any x-ray machine. These principles dictate that decreasing kVp and mA, while maintaining dose time fixed, will result in reduced radiation dose. Another way to reduce radiation dose is by altering collimation and filtration judiciously. In conventional fan-beam CT and CBCT machines, which take numerous x-ray projections, another principle applies, namely that the more projections there are or the longer the machine is actively producing radiation, the higher the radiation dose to the patient. The beam-on time (exposure time) can be reduced by using pulsating technology, making the beam-on time shorter than the scan time (time necessary for a revolution around the patient). This technology allows less radiation to be used to produce an image, and is particularly necessary for a flat-panel detector, in order to avoid inaccurate readings.

Even though radiation has been a major topic of discussion, few publications are currently available on

---

[a] Associate Professor of Orthodontics, Director of the Craniofacial Imaging Center, Case Western Reserve University, School of Dental Medicine.

[b] Assistant Professor of Radiology and General Medical Sciences, Case Western Reserve University.

[c] Professor and Chair of Orthodontics, Case Western Reserve University, School of Dental Medicine.

Received for publication Sep 20, 2007; returned for revision Dec 10, 2007; accepted for publication Dec 11, 2007.
1079-2104/$ - see front matter

doi:10.1016/j.tripleo.2007.12.019

the topic, and no publication at this point shows the differences in radiation dose when choosing different setting combinations.[6-9]

The objective of this paper was to quantify the changes in radiation dose when using different CBCT setting combinations. The complete project also evaluated image quality for each combination measured.[10]

MATERIAL AND METHODS

A CB MercuRay CBCT scanner (Hitachi Medical Systems, Tokyo, Japan) was used for this experiment. In this device, the x-ray source revolves 360 degrees around the patient's head in 9.6 seconds, collecting 288 images. The CB MercuRay has user-controlled variables for tube current and tube voltage. The commercially available options for tube current are 10 and 15 mA, and for tube voltage 100 and 120 kVp. To increase the range of options, Hitachi engineers modified the scanner and added tube currents of 2 and 5 mA. The CB MercuRay already allowed for choosing the field of view (FOV) between 6 inches, 9 inches, and 12 inches, depending on the size of the region of interest (ROI). To evaluate an even greater possible reduction in radiation dose, an optional copper filter (1-mm thick) was also added as a variable in this project (Fig. 1). An image-quality assessment was made in conjunction with the radiation dose project to assess the diagnostic quality of the images taken at different settings.[10]

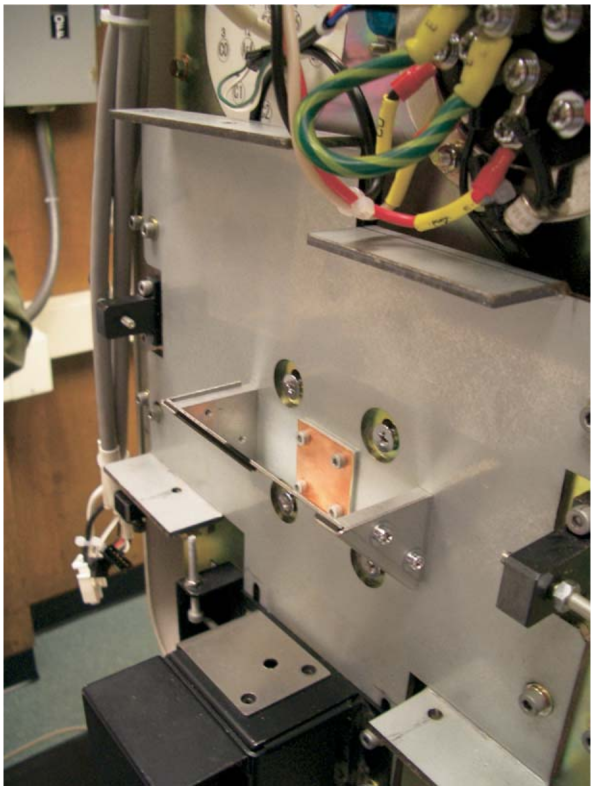

Fig. 1. A copper filter is added to attenuate radiation providing a more homogeneous final x-ray beam, which would result in a "cleaner" image.

With a combination of 4 different mA options, 2 kVp options, presence or absence of a copper filter, and 3 different FOVs, there was a total of 48 possible combinations. Since it was reasonable to assume that radiation doses would be proportional to tube current, a series of observations was first made with the current fixed at 15 mA while varying all the other parameters (12 images). Next, the other parameters were held at 100 kVp, 12-inch FOV, and no filter, and tube current was set at 2, 5, and 10 mA (3 images). These latter observations served not only to indicate how closely the radiation dose was proportional to the set mA values, but also to give exact proportionality constants to enable calculating the expected radiation dose for 2, 5, and 10 mA. Finally, volumes at the setting 15 mA, 120 kVp, 12-inch FOV, and absence of filter were imaged 3 different times in order to assess consistency (3 images). In addition to the normal CBCT settings, the SRAD, a static collection of images was also tested. The SRAD mode has the scanner static while the patient opens his or her mouth, and the scanner's software combines the images taken into a video that shows a radiographic view of the patient's function.

The radiation dose of a ProMax panoramic machine (Planmeca Oy, Helsinki, Finland) and the dose for a full-mouth series using a Planmeca Intra (Planmeca Oy) were also measured to better compare CBCT to more traditional methods (2 images). The settings used for these last measurements were those recommended for an adult male according to manufacturers' recommendations, and used in a routine basis at our university.

The observations were made on a Rando head phantom (The Phantom Laboratory, Salem, NY). The phantom consists of a human skull inside a material that is radiologically equivalent to soft tissue, divided into 10 axial sections (Fig. 2). Radiation dose was determined using thermoluminescent dosimeters (TLD) provided and processed by Landauer (Landauer Inc., Glenwood, IL). A total of 10 TLDs were placed on the esophagus, midline thyroid, right and left mandibular body (bone marrow), right and left submandibular glands, center C spine (bone marrow), mid brain, and on the right and left eyes (surface) (Fig. 3). All TLDs were placed by the same operator to ensure consistency, and were handled with gloves and tweezers to avoid contamination. After exposure, the TLDs were stored separately in individual bags and protected from light and radiation, according to the manufacturer's recommenda-

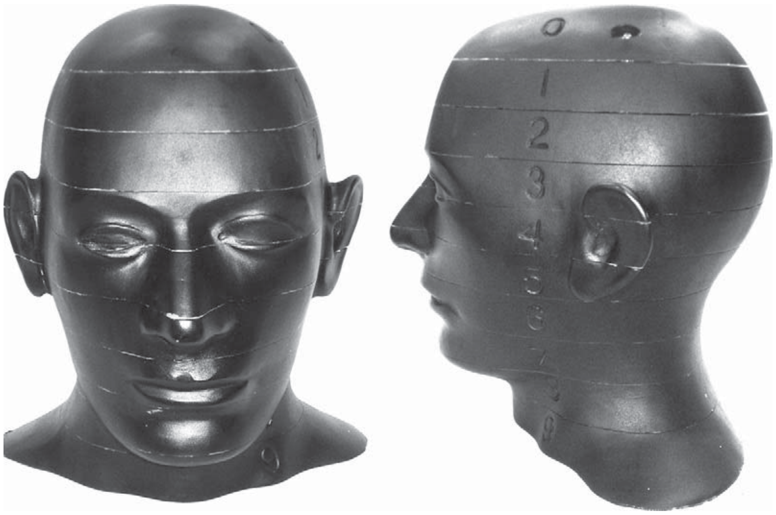

Fig. 2. The Rando Phantom is constructed with a natural human skeleton, which is cast inside a proprietary urethane formulation, designed to have the same absorption as human tissue at the normal exposure levels. The phantom's soft tissue has an effective atomic number and mass density, which simulates muscle tissue with randomly distributed fat.

Fig. 3. A total of 10 thermoluminescent dosimeters (TLD) were used for this project. Besides the 8 shown in this image, there were 2 additional TLDs taped to the phantom's eyes.

tions. Along with all exposed TLDs, a set of unexposed control TLDs was also sent back to Landauer for reading. Landauer reported the results as dose equivalents in millirems. The values were then converted to modern SI units (gray and sievert). The data were entered into a spreadsheet and analyzed for consistency, linearity, and magnitudes relative to one another. The 10 locations listed above were identified as closely as possible with the tissues listed by the International Commission on Radiological Protection (ICRP) in its discussion of effective dose.[11,12] Absorbed doses for additional regions (calvaria and bone surface) were surmised from the measured data, and the effective dose from each CBCT setting was calculated according to the ICRP guidelines and previous literature (Table I).[6-9,11-13]

To avoid possible scatter, the phantom was placed on cardboard boxes and a wood tray, which better supported the phantom's weight (Fig. 4). A leveler was

Table I. TLD location and organs represented, along with tissue weighting factors according to the International Commission on Radiological Protection (ICRP) guidelines in ICRP Publication 60 and in ICRP Publication 103

TLD		*Phantom Level*	*ICRP-identified organ*	*Fraction of total organ irradiated*	*Tissue weighting factor ICRP 60*	*Tissue weighting factor ICRP 103*
1	**Esophagus**	9	Esophagus	0.1	0.05	0.05
2	**Midline thyroid**	8	Thyroid	1	0.05	0.05
3	**Bone - right mandible body**	7	Red bone marrow	0.0065	0.12	0.12
4	**Bone - left mandible body**	7	Red bone marrow	0.0065	0.12	0.12
5	**Right submandibular gland**	7	Salivary glands	0.5	0	0.01
6	**Left submandibular gland**	7	Salivary glands	0.5	0	0.01
7	**Bone - center C spine**	6	Red bone marrow	0.034	0.12	0.12
	Calvaria (mean of TLD 3, 4, and 7)		Red bone marrow	0.118	0.12	0.12
	Right mandible body		Bone surface	0.0065	0.01	0.01
	Left mandible body		Bone surface	0.0065	0.01	0.01
	Center C spine		Bone surface	0.034	0.01	0.01
	Calvaria		Bone surface	0.118	0.01	0.01
8	**Mid brain**	2	Brain	1	0.005	0.01
9	**Left orbital surface**	3	Skin	0.025	0.01	0.01
10	**Right orbital surface**	3	Skin	0.025	0.01	0.01

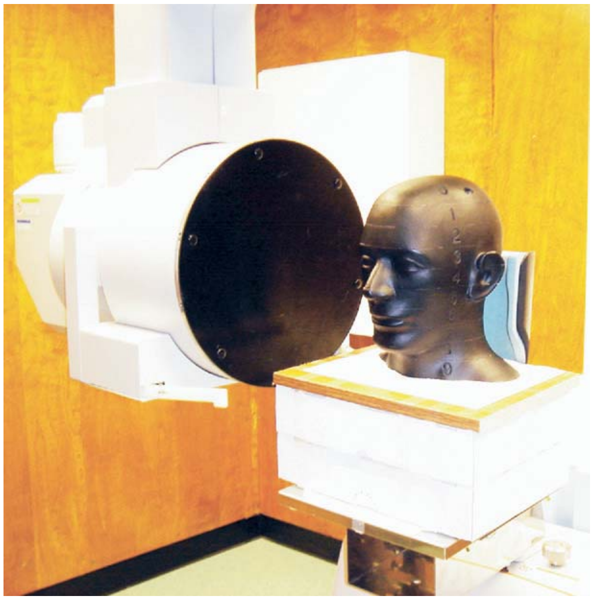
Fig. 4. The phantom ready to be scanned is placed on top of radiolucent and stable base.

used to ensure good positioning, and marks were made on the phantom to allow reproducibility of all 3 fields of view. The region of interest (ROI) for the 12-inch scan was the complete head, the ROI for the 9-inch scan was both dental arches, the condyles, and the nose; and for the 6-inch scan, both arches with anterior soft tissue and as close to capturing the condyles as possible (Fig. 5). The Rando Phantom was scanned only once for each setting combination, the same way that a patient would be scanned for that FOV. Based on previous studies' results, we were confident that all TLDs would be able to capture the dose from a single scan, so more than one scan was not necessary.[6-9,13] Descriptive statistics, ratios, and coefficients of variance were calculated using MS Excel 2003 by a board-certified radiological physicist (P.S.R.).

RESULTS

A total of 21 scans were carried out in this project, namely for 19 CBCT settings, 1 panoramic, and 1 full-mouth series.

Table II shows readings obtained from 3 scans taken under identical conditions. The CBCT machine shows excellent reproducibility; with only 1 exception, the coefficient of variance (CV) for the readings at any 1 site is 5% or less. The 1 exception appears among the readings for esophagus, where the value in trial T2 is much higher than may have been expected. Nevertheless, the mean CV for 10 sets of readings is 4.0% ± 2.7% (Table II).

When reviewing the TLD readings from all 210 TLDs used, we noticed that 3 TLDs showed values too high or too low when compared to what was expected, which was likely due to errors in positioning the relevant TLDs in the phantom. No corrections were made since the impact of the discrepancies on the rest of the observations appeared small enough to be insignificant.

Table III exhibits the linearity of the different mA stations. For the mA values of 2, 5, 10, and 15 mA, one would expect the ratios of the readings to be 2:5:10:15. The means of the observed ratios are 2.7:5.7:9.9:15, and possibly reflect the actual values of the tube currents. It should be noted that if the value for the esophagus in the 15-mA setting had been higher (say 370 instead of 310), the ratios for the esophagus alone

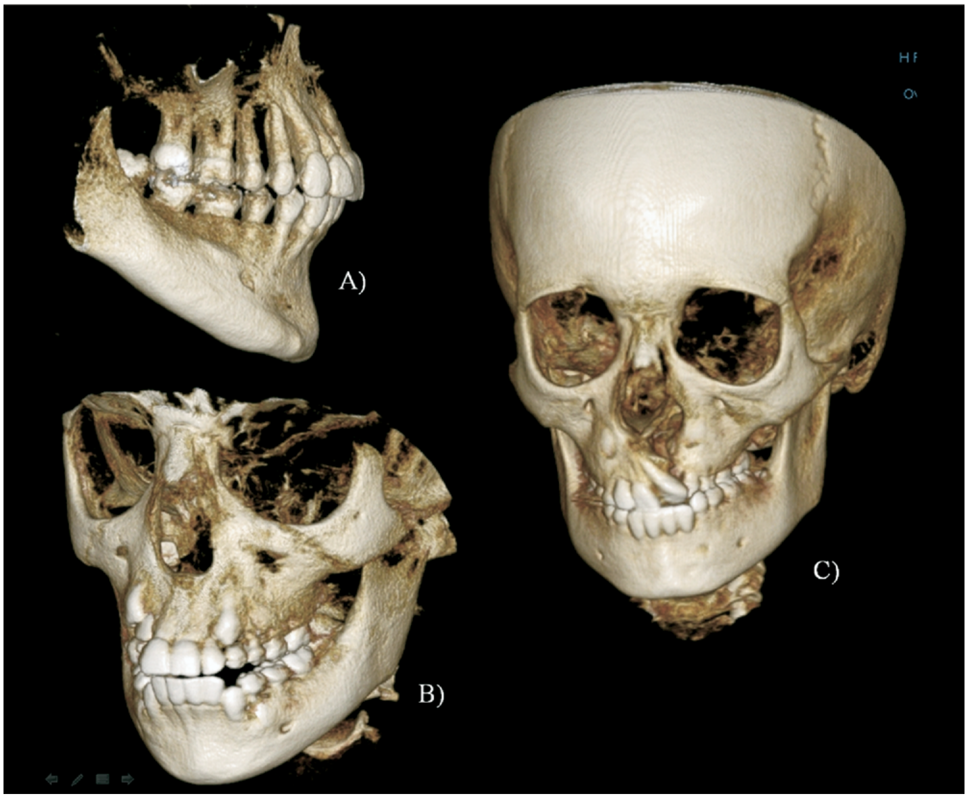

Fig. 5. The 3 fields of view available for the Hitachi CB MercuRay scanner used for this project. **A,** The small field of view (6 inches) usually shows the whole dentition of both arches, and sometimes the condyles. **B,** The medium field of view (9 inches) consistently shows the condyles and most of the mid and lower face. **C,** The large field of view shows most of the craniofacial structures.

Table II. Consistency analysis for the setting of 15 mA, 120kVp, 12″ field of view, and no filter. The phantom was exposed three different times. The correlation between T1 and T3 is 0.99, showing good reproducibility. Consistency between successive scans for the same settings is within 5%, which is satisfactory. The one exception appears to be the dose for "Esophagus". It is likely due to an erroneously high value for the entry in the T2 set

		Dose in milligrays					
		T1	*T2*	*T3*	*Mean*	*SD*	*CV%*
1	**Esophagus**	5.30	6.30	5.30	5.63	0.58	10
2	**Midline thyroid**	8.90	8.20	8.10	8.40	0.44	5
3	**Right mandible body**	6.80	6.80	6.50	6.70	0.17	3
4	**Left mandible body**	6.20	6.50	6.20	6.30	0.17	3
5	**Right submandibular gland**	8.00	7.70	7.20	7.63	0.40	5
6	**Left submandibular gland**	7.40	7.50	7.00	7.30	0.26	4
7	**Center C spine**	6.20	5.80	5.80	5.93	0.23	4
8	**Mid brain**	5.90	6.00	6.20	6.03	0.15	3
9	**Left orbital surface**	11.30	11.30	11.30	11.30	0	0
10	**Right orbital surface**	12.10	12.10	11.40	11.87	0.40	3

would have better matched the ratios for the other sites. However, there would have been little effect on the mean values of the ratios.

Table IV evaluates the effect of interposing a copper filter in the x-ray beam. The presence of the copper filter reduces the radiation dose by a mean ratio of 0.86 ± 0.07, a reduction of approximately 14%. This reduction did not appear to depend on whether the kVp was 100 or 120.

Table III. Ratio of doses at 2, 5 and 10 mA settings to dose at 15 mA setting. The other parameters were fixed at 100 kVp, 12″ field of view, and no filter

		Doses in milligrays				*Ratios*			
		2 mA	*5 mA*	*10 mA*	*15 mA*	*2 mA*	*5 mA*	*10 mA*	*15 mA*
1	**Esophagus**	0.70	1.60	2.30	3.10	0.23	0.52	0.74	1.00
2	**Midline thyroid**	1.00	2.00	3.40	5.50	0.18	0.36	0.62	1.00
3	**Right mandible body**	0.70	1.40	2.60	4.00	0.18	0.35	0.65	1.00
4	**Left mandible body**	0.70	1.40	2.50	3.90	0.18	0.36	0.64	1.00
5	**Right submandibular gland**	0.80	1.80	3.00	4.60	0.17	0.39	0.65	1.00
6	**Left submandibular gland**	0.80	1.70	3.00	4.60	0.17	0.37	0.65	1.00
7	**Center C spine**	0.60	1.30	2.40	3.50	0.17	0.37	0.69	1.00
8	**Mid brain**	0.60	1.30	2.40	3.60	0.17	0.36	0.67	1.00
9	**Left obital surface**	1.20	2.70	4.80	7.40	0.16	0.36	0.65	1.00
10	**Right orbital surface**	1.20	2.80	4.90	7.60	0.16	0.37	0.64	1.00
				Mean ratios		**0.18**	**0.38**	**0.66**	**1.00**
				SD		**0.02**	**0.05**	**0.03**	**0.00**
				Means normalized to 15 mA		**2.7**	**5.7**	**9.9**	**15**

Table IV. Ratios of dose with copper filter to dose without the filter. In the upper set the tube voltage was held at 100 kVp while the field of view varied from 6″ to 9″ to 12″. In the lower set the kVp was 120. In all cases the tube current was fixed at 15 mA

		15.100.06	*15.100.09*	*15.100.12*	*Mean*	*SD*	*CV %*
1	**Esophagus**	0.90	0.93	1.13	**0.99**	**0.12**	**13**
2	**Midline thyroid**	0.79	0.85	0.82	**0.82**	**0.03**	**4**
3	**Right mandible body**	0.82	0.87	0.83	**0.84**	**0.03**	**4**
4	**Left mandible body**	0.81	0.86	0.87	**0.85**	**0.03**	**4**
5	**Right submandibular gland**	0.83	0.84	0.83	**0.83**	**0.01**	**1**
6	**Left submandibular gland**	0.84	0.88	0.85	**0.86**	**0.02**	**3**
7	**Center C spine**	0.96	0.85	0.91	**0.91**	**0.05**	**6**
8	**Mid brain**	1.00	0.78	0.89	**0.89**	**0.11**	**13**
9	**Left orbital surface**	0.68	0.76	0.77	**0.74**	**0.05**	**7**
10	**Right orbital surface**	0.74	0.78	0.78	**0.77**	**0.02**	**3**
		15.120.06	**15.120.09**	**15.120.12**	**Mean**	**SD**	**CV %**
1	**Esophagus**	0.76	0.90	0.90	**0.86**	**0.08**	**9**
2	**Midline thyroid**	0.79	0.83	0.77	**0.80**	**0.03**	**4**
3	**Right mandible body**	0.85	0.84	0.85	**0.84**	**0.01**	**1**
4	**Left mandible body**	0.88	0.87	0.89	**0.88**	**0.01**	**1**
5	**Right submandibular gland**	0.88	0.86	0.82	**0.85**	**0.03**	**4**
6	**Left submandibular gland**	0.85	0.84	0.87	**0.85**	**0.02**	**2**
7	**Center C spine**	1.00	0.89	0.98	**0.96**	**0.06**	**6**
8	**Mid brain**	0.75	1.00	0.93	**0.89**	**0.13**	**14**
9	**Left orbital surface**	0.85	0.75	0.79	**0.80**	**0.05**	**6**
10	**Right orbital surface**	1.48	0.74	0.75	**0.99**	**0.42**	**43**
				Overall Mean:	**0.86**		
				SD:	**0.07**		

Table V shows the effect of reducing the kVp from 120 to 100. The mean ratio of dose at 100 kVp to those at 120 kVp is 0.62 ± 0.05 (a reduction of approximately 38%). This ratio is the same both when the copper filter is present and when it is absent.

Table VI demonstrates how dose changes with the field of view. When reducing the FOV, the dose to tissues that still remain in the beam decreases by about 5% to 10%, presumably because of less scatter contribution. For tissues that escape the direct beam and are therefore affected only by scatter radiation, the reduction is more dramatic.

Table VII and Fig. 6 exhibit the effective dose for every possible setting of the CBCT, as well as for a conventional panoramic and a full-mouth series. The effective dose was determined twice for each case, the first according to ICRP recommendations of 1991 and the second according

Table V. Ratio of dose at 100 kVp to dose at 120 kVp. The first three columns of numerical data pertain to FOV of 6″, 9″ and 12″. The upper set pertains to absence of copper filter (N), the lower to its presence (Y). The tube current in all cases was 15 mA

		15.06.N	*15.09.N*	*15.12.N*	*Mean*	*SD*	*CV*
1	**Esophagus**	0.59	0.71	0.49	**0.60**	**0.11**	**19**
2	**Midline thyroid**	0.62	0.59	0.67	**0.62**	**0.04**	**7**
3	**Right mandible body**	0.58	0.58	0.59	**0.58**	**0.00**	**1**
4	**Left mandible body**	0.62	0.59	0.60	**0.60**	**0.01**	**2**
5	**Right submandibular gland**	0.63	0.63	0.60	**0.62**	**0.02**	**3**
6	**Left submandibular gland**	0.58	0.59	0.61	**0.59**	**0.02**	**3**
7	**Center C spine**	0.59	0.59	0.60	**0.59**	**0.01**	**1**
8	**Mid brain**	0.50	0.64	0.60	**0.58**	**0.07**	**13**
9	**Left orbital surface**	0.94	0.61	0.65	**0.74**	**0.18**	**24**
10	**Right orbital surface**	1.00	0.65	0.63	**0.76**	**0.21**	**28**
		15.06.Y	**15.09.Y**	**15.12.Y**	**Mean**	**SD**	**CV**
1	**Esophagus**	0.69	0.74	0.61	**0.68**	**0.06**	**9**
2	**Midline thyroid**	0.62	0.60	0.71	**0.64**	**0.06**	**9**
3	**Right mandible body**	0.56	0.61	0.57	**0.58**	**0.02**	**4**
4	**Left mandible body**	0.57	0.58	0.59	**0.58**	**0.01**	**2**
5	**Right submandibular gland**	0.59	0.61	0.60	**0.60**	**0.01**	**2**
6	**Left submandibular gland**	0.57	0.62	0.60	**0.60**	**0.03**	**4**
7	**Center C spine**	0.56	0.56	0.56	**0.56**	**0.00**	**0**
8	**Mid brain**	0.67	0.50	0.57	**0.58**	**0.08**	**14**
9	**Left orbital surface**	0.75	0.62	0.64	**0.67**	**0.07**	**10**
10	**Right orbital surface**	0.50	0.68	0.65	**0.61**	**0.10**	**16**
				Overall Mean:	**0.62**		
				SD:	**0.05**		

Table VI. Ratio of dose at 6″ FOV or 9″ FOV to dose at 12″ FOV. Calculations were performed on data for 100 kVp and 120 kVp, with and without copper filter. The tube current was fixed at 15 mA

		100 No Filter		*100 W/Filter*		*120 No Filter*		*120 W/Filter*	
		06/12	*09/12*	*06/12*	*09/12*	*06N/12N*	*09N/12N*	*06/12*	*09/12*
1	**Esophagus**	0.32	0.48	0.26	0.40	0.27	0.33	0.23	0.33
2	**Midline thyroid**	0.85	0.87	0.82	0.91	0.93	1.00	0.95	1.08
3	**Right mandible body**	0.95	0.98	0.94	1.03	0.96	0.99	0.95	0.97
4	**Left mandible body**	0.95	0.95	0.88	0.94	0.92	0.97	0.91	0.95
5	**Right submandibular gland**	0.91	0.98	0.92	1.00	0.87	0.94	0.94	0.98
6	**Left submandibular gland**	0.83	0.93	0.82	0.97	0.88	0.97	0.86	0.94
7	**Center C spine**	0.66	0.94	0.69	0.88	0.67	0.97	0.68	0.88
8	**Mid brain**	0.06	0.25	0.06	0.22	0.07	0.23	0.05	0.25
9	**Left orbital surface**	0.42	0.96	0.37	0.95	0.29	1.03	0.31	0.98
10	**Right orbital surface**	0.30	0.96	0.29	0.97	0.19	0.93	0.37	0.92

to recommendations finalized in 2007.[11,12] Values shown as "measured" were determined from the data obtained with TLDs when the tube current was 15 mA. For almost all the cases where the tube current was 2, 5, or 10 mA, the effective doses were calculated by applying the appropriate ratios deduced in Table III. For 3 of these cases, namely where the kVp was 100, the FOV was 12 inches, and the filter was absent, the TLD data had been collected, and we could determine the effective dose directly. As the table shows, in these cases the differences between the calculated and actual values were very small and not significant, thereby increasing confidence in the accuracy of the scaling factors used.

DISCUSSION

The American Dental Association Council on Scientific Affairs recommends the use of techniques that would reduce the amount of radiation received during dental radiography. Known as the ALARA (As Low As Reasonably Achievable) principle, this includes taking radiographs based on the patient's needs (as determined by the clinician), using the fastest film compatible with

Table VII. Effective doses for all possible CBCT setting combinations, and for a digital panoramic and full mouth series. The column "Meas" corresponds to values determined from measured doses. The column "Calc" corresponds to a mathematical calculation based on the ratios derived in Table 3. Where both actual and calculated values are available, the two are very similar. Calculations are provided using radiation weighting factors in ICRP Publication 60 and ICRP Publication 103

Scan #	*mA*	*kVp*	*FOV*	*Filter*	*Ratio*	*Eff Dose (μSv) ICRP 60*		*Eff Dose (μSv) ICRP 103*	
						Meas	*Calc*	*Meas*	*Calc*
1	15	100	6	Y		265		299	
2	15	100	9	Y		303		344	
3	15	100	12	Y		352		406	
4	15	100	6	N		328		369	
5	15	100	9	N		354		402	
6	15	100	12	N		415		479	
7	15	120	6	Y		440		499	
8	15	120	9	Y		506		575	
9	15	120	12	Y		534		626	
10	15	120	6	N		535		603	
11	15	120	9	N		601		680	
12	15	120	12	N		656		761	
13	10	100	6	Y	**0.66**		175		198
14	10	100	9	Y			200		227
15	10	100	12	Y			232		268
16	10	100	6	N			216		243
17	10	100	9	N			234		266
18	10	100	12	N		264	274	306	316
19	10	120	6	Y			290		329
20	10	120	9	Y			334		380
21	10	120	12	Y			353		413
22	10	120	6	N			353		398
23	10	120	9	N			397		449
24	10	120	12	N			433		502
25	5	100	6	Y	**0.38**		101		114
26	5	100	9	Y			116		131
27	5	100	12	Y			134		155
28	5	100	6	N			125		141
29	5	100	9	N			135		154
30	5	100	12	N		153	158	177	183
31	5	120	6	Y			168		190
32	5	120	9	Y			193		219
33	5	120	12	Y			204		239
34	5	120	6	N			204		230
35	5	120	9	N			229		260
36	5	120	12	N			250		290
37	2	100	6	Y	**0.18**		47		53
38	2	100	9	Y			54		61
39	2	100	12	Y			62		72
40	2	100	6	N			58		65
41	2	100	9	N			63		71
42	2	100	12	N		75	73	86	85
43	2	120	6	Y			78		88
44	2	120	9	Y			90		102
45	2	120	12	Y			94		111
46	2	120	6	N			95		107
47	2	120	9	N			106		120
48	2	120	12	N			116		134
SRAD	10	100	9	Y		125		159	
FMX						115		129	
Pano						20		23	

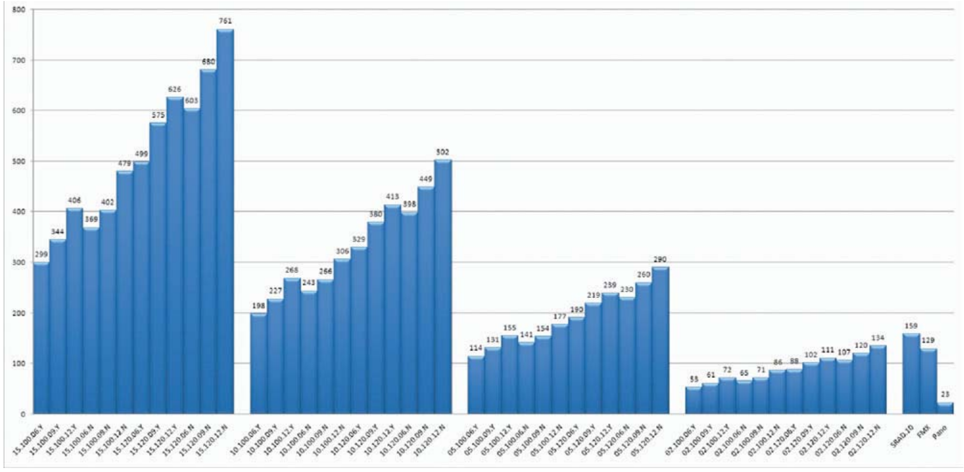

Fig. 6. Graphical display of effective doses for all possible CBCT setting combinations, and for a digital panoramic and full-mouth series following the recommendations published in ICRP Publication 103.

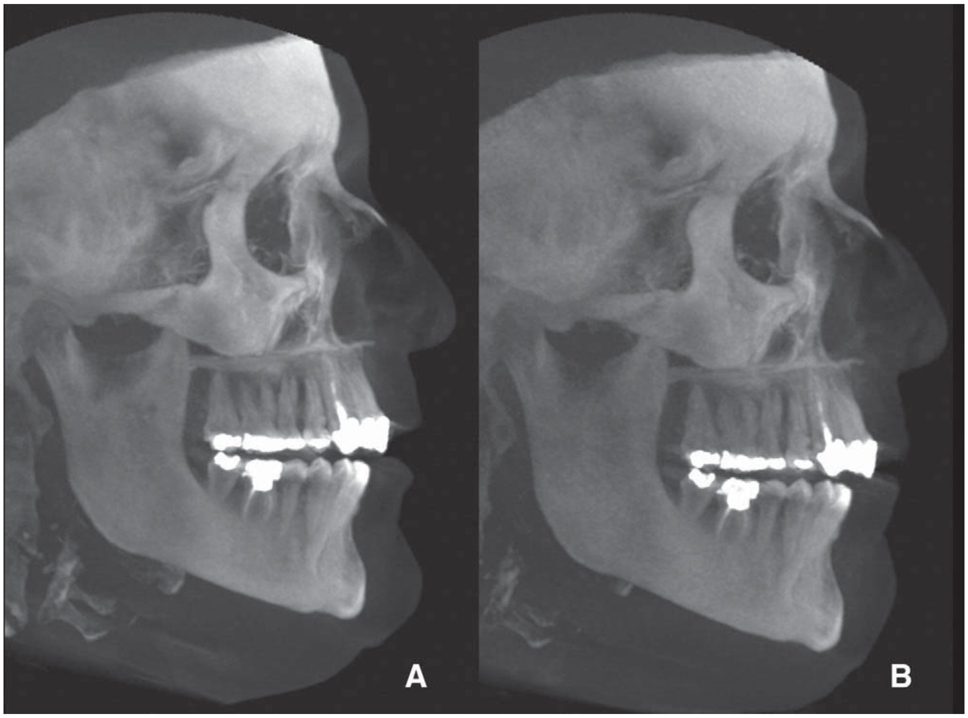

Fig. 7. **A,** A 12-inch image of a fresh cadaver head assigned as the one of highest quality (10 mA, 100 kVp without copper filter) versus (**B**) the same FOV image assigned as the one of poorest quality (2 mA, 100 kVp with copper filter).

the diagnostic task, collimating the beam to a size as close to that of the film as feasible, and using leaded aprons and thyroid shields.[14-16] The patient's needs in this case is the diagnostic information necessary for the clinician to determine the most effective and complete approach to solving the problem. This means that the image acquired should be able to answer the question posed by the clinician. For the purpose of this article, we will consider the definition of appropriate diagnostic quality in an image as that which provides sufficient information to answer all diagnostic questions posed by the clinician. Depending on the procedure that will take place and the diagnostic question, the quality of the image needed will differ. It is a principle of physics that higher settings will provide a "prettier" image, but sometimes even if the image is "grainy," it can serve as an initial screening image or provide basic information like number of teeth, presence of supernumeraries, and so forth, with the advantage of exposing the patient to considerably less radiation dose.

A study parallel to this one was conducted in which a fresh cadaver head, a skull, and an accuracy phantom were scanned for all the same possible setting combinations, in order to determine the image we would acquire if we used the settings tested (Fig. 7).[10] The combination of both studies provided the information needed to determine how low a radiation dose we could use, and still get an image that was of diagnostic quality.

Decreasing the field of view also reduces the patient's radiation dose. The CBCT scanners provide the clinician with different FOVs, a collimation method. The most effective way to determine the FOV is to first determine the ROI, and the choice of FOV should be the smallest option that would capture the ROI.

Even at the highest settings of the CBCT, the radiation dose is well below conservative limits recommended by the National Council on Radiation Protection and Measurements.[11,12,17] Nevertheless, following the ALARA principle, the clinician should be conscious about choosing the most appropriate settings, FOV, and adequate lead protection to avoid any unnecessary radiation dose. At the same time, it is not practical to have 48 different options for settings. Based on the combination of the present study and the study of image quality, it appears that a combination of 1 low setting and 1 high setting will be able to combine practicability with a high range of diagnostic needs. At the present time, the CBCT machine we use has the options of 2 mA and 15 mA. We use the 2 mA in most cases where a 12-inch image is needed, like a craniofacial study performed before orthodontic treatment, and the 15 mA in cases of pathology or when we use the 6-inch FOV to assess bone for implant placement.

CONCLUSIONS

The CBCT tested showed good reproducibility and was able to be modified to provide a wide range of radiation dose levels. Different settings, a copper filter, and 3 collimation choices were tested, and we conclude that a reduction in radiation dose can be achieved by using lower settings and by effectively using the available collimation options.

The authors thank Cynthia McConnaughy for her valuable help, organizational skills, and dedication. Processing of the TLDs was funded in part by Hitachi Medical Systems America, Twinsburg, OH.

REFERENCES

1. Food and Drug Administration. Available at: http://www.fda.gov. Accessed August 13, 2007.
2. Mah J, Hatcher D. Three-dimensional craniofacial imaging. Am J Orthod Dentofacial Orthop 2004;126(3):308-9.
3. Danforth RA, Peck J, Hall P. Cone beam volume tomography: an imaging option for diagnosis of complex mandibular third molar anatomical relationships. J Calif Dent Assoc 2003;31:847-52.
4. Mah J, Hatcher D. Current status and future needs in craniofacial imaging. Orthod Craniofac Res 2003;6(suppl 1):10-6.
5. Sukovic P. Cone beam computed tomography in craniofacial imaging. Orthod Craniofac Res 2003;6(suppl 1):31-6.
6. Ludlow JB, Davies-Ludlow LE, Brooks SL, Howerton WB. Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT. Dentomaxillofac Radiol 2006;35(4):219-26.
7. Mah JK, Danforth RA, Bumann A, Hatcher D. Radiation absorbed in maxillofacial imaging with a new dental computed tomography device. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;96(4):508-13.
8. Schulze D, Heiland M, Thurmann H, Adam G. Radiation exposure during midfacial imaging using 4- and 16-slice computed tomography, cone beam computed tomography systems and conventional radiography. Dentomaxillofac Radiol 2004;33(2):83-6.
9. Ludlow JB, Davies-Ludlow LE, Brooks SL. Dosimetry of two extraoral direct digital imaging devices: NewTom cone beam CT and Orthophos Plus DS panoramic unit. Dentomaxillofac Radiol 2003;32(4):229-34.
10. Kwong J, Palomo JM, Landers MA, Figueroa A, Hans MG. Image quality produced by different CBCT settings. Am J Orthod Dentofac Orthoped 2008;133(1):317-27.
11. International Commission on Radiological Protection. 1990 Recommendations of ICRP. ICRP Publication 60. Ann. ICRP 21(1-3). Oxford: Elsevier Science Ltd.; 1991.
12. Draft document "2005 Recommendations of the International Commission on Radiological Protection". ICRP Publication 103. Available at: http://www.icrp.org. Accessed February 2, 2006.
13. Underhill TE, Chilvarquer I, Kimura K, Langlais RP, McDavid WD, Preece JW, et al. Radiobiologic risk estimation from dental radiology. Part I. Absorbed doses to critical organs. Oral Surg Oral Med Oral Pathol 1988;66(1):111-20.
14. Tsiklakis K, Donta C, Gavala S, Karayianni K, Kamenopoulou V, Hourdakis CJ. Dose reduction in maxillofacial imaging using low dose Cone Beam CT. Eur J Radiol 2005;56:413-7.
15. Brand JW, Gibbs SJ, Edwards M, Katz JO, Lurie AG, White SC. Radiation protection in dentistry. Report No. 145. Bethesda (MD): NCRP Publications; 2003.
16. Mupparapu M. Radiation protection guidelines for the practicing orthodontist. Am J Orthod Dentofacial Orthop 2005;128(2):168-72.; discussion 172.
17. National Council on Radiation Protection and Measurements (NCRP). Limitation of Exposure to Ionizing Radiation. NCRP Report No. 116. Bethesda, MD: NCRP; 1993.

Reprint requests:

J. Martin Palomo DDS, MSD
Case Western Reserve University
School of Dental Medicine
Associate Professor of Orthodontics
10900 Euclid Avene
Cleveland, OH 44106
palomo@case.edu