Image quality produced by different cone-beam computed tomography settings

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Introduction: The aim of this study was to evaluate image quality at different cone-beam computed tomography settings and 3 fields of view. **Methods:** A Hitachi CB MercuRay (Hitachi Medical Systems, Tokyo, Japan) was modified to allow different setting combinations. The variables consisted of 4 milliampere settings (2, 5, 10, and 15 mA), 2 kilovolt (peak) settings (100 and 120 kV[p]), presence or absence of a copper filter, and 3 fields of view (6, 9, and 12 in). Thirty-two scans were taken on a cadaver head and 16 scans on a dry skull. The groups were divided by field of view, and the images were ranked by at least 30 judges. Diagnostic quality was addressed in a questionnaire. Descriptive statistics and rankings were calculated with Excel 2003 (Microsoft, Redmond, Wash) and the Friedman and Wilcoxon signed rank tests with SPSS software (version 14.0.1; SPSS, Chicago, Ill). **Results:** The presence or absence of a filter showed significant differences ($P < .006$) in 2 pairs of the 9-in field of view. Variation in kilovolt (peak) settings showed significant differences ($P < .006$) in the 6-in 5-mA images with a filter. Altering the milliampere settings showed significant differences ($P < .008$) in the 6- and 12-in groups. The 9-in group showed significant differences between 2 mA and 10 and 15 mA. Overall, the 6-, 9-, and 12-in images had diagnostic quality 56%, 99%, and 99% of the time, respectively. **Conclusions:** Presence or absence of a filter and the kilovolt (peak) setting did not affect overall image quality. Images taken at lower milliampere settings showed good diagnostic quality. (Am J Orthod Dentofacial Orthop 2008;133:317-27)

Cone-beam computed tomography (CBCT) has been used for its capability of providing reliable information compared with conventional methods.[1] CBCT provides excellent tissue contrast, eliminates blurring and overlapping of adjacent teeth, and offers orthogonal views by eliminating projection effects.[2] Additional advantages of CBCT include reduced cost and significantly reduced radiation exposure relative to medical CT.

Although CB technology can produce volumetric images with up to 4 times less radiation than conventional CT, the resulting effective radiation depends on the settings—kilovoltage (peak) (kV[p]) and milliamperage (mA).[3,4] The American Dental Association's Council on Scientific Affairs recommends techniques to reduce the amount of radiation received during dental radiography. Known as the "as low as reasonably achievable" principle, this includes taking radiographs based on the patient's needs (determined by examination), using the fastest film compatible with the diagnostic task, collimating the beam to a size as close to that of the film as feasible, and using lead aprons and thyroid shields. An accepted ratio between exposure and image quality needs to be reached to use this principle.

Image quality in traditional radiography was defined by Curry et al[5] as "the ability to record each point in the object as a point on the film." The definition of image quality for CT images is not as accurately defined but has been described as the visibility of diagnostically important structures in the CT image. The quality of CBCT images has yet to be evaluated; however, the quality of CT images has been evaluated. Previous studies showed that lower settings in medical-grade CT units can achieve image quality comparable to higher settings.[6-10] Sohaib et al[6] evaluated the quality of maxillary sinus CT images in 40 patients with a constant kilovolt (peak) and varying the milliamperage. Although the judges noticed increased graininess, they found no significant differences in image quality between the groups with high and low settings.[6] Two studies evaluated the image quality of intracranial scans. Cohnen et al[7] evaluated image quality with many

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Table I. Hitachi CB MercuRay operator settings

FOV (in)	6	9		12
mA	2	5	10	15
kV(p)	100		120	
Hardware filter-copper filter	Present		Absent	
Reconstruction algorithm	Soft*		Hard	

*Kept constant for all images captured.

combinations of milliamperage and kilovolt (peak) settings, and Gündogdu et al[8] evaluated the quality of 240 images keeping the kilovolt (peak) constant and varying the milliamperage. Both studies showed that scans taken at higher settings had similar image quality, whereas scans at lower settings had unacceptable image quality. Two studies with dental CT evaluated image quality in scans of the mandible. Rustemeyer et al[9] evaluated the quality of 16 images with constant kilovolt (peak) and varying milliamperage, and found no significant differences in the visibility of mandibular structures. Bianchi et al[10] evaluated 28 images with constant kilovolt (peak) and changing milliamperage, and found that images captured at low settings were significantly different from those at mid to high settings. The literature showed that there is no single way to analyze image quality; more than 1 setting was rarely isolated to study the image quality effects of different settings and rarely was a reliability analysis included.

In this descriptive study, we sought to compare the quality of images captured using the CB MercuRay CBCT (Hitachi Medical Systems, Tokyo, Japan) unit. We defined image quality as the ability of the image to answer our diagnostic questions. Many CBCT images of a cadaver head and skull were captured at various operator settings. The images were divided into 3 groups based on the field of view (FOV) (6, 9, and 12 in) and used in a subjective test of image quality. The objective of this study was to evaluate image quality at various CBCT settings for 3 FOVs. The null hypothesis was that there is no difference in image quality in each FOV, and, if there is a difference, it would make no difference on the diagnostic ability of the images.

MATERIAL AND METHODS

The Institutional Review Board of Case Western Reserve University in Cleveland, Ohio, approved the experimental protocol. The CB MercuRay CBCT has user-controlled variables that can affect image quality. These settings include milliamperage, kilovolt (peak), FOV, hardware filter, and reconstruction algorithm (Table I). By varying milliamperage, kilovolt (peak), FOV, presence of absence of a filter, we captured 48 images. Thirty-two images of a fresh human cadaver head and 16 images of a dry skull were captured. A fresh cadaver head was chosen for its similarity to a living person as well as to exhibit image quality for a subject with dental work. Images of the cadaver head were captured in the 6- and 12-in FOV. The skull was chosen to demonstrate how images would look in an ideal situation. Images of the skull were captured in the 9-in FOV. The cadaver head was not used for the 9-in FOV because the condyles and the dentition could not be imaged simultaneously, and 1 purpose of this study was to evaluate the diagnostic capabilities of CBCT technology. The dimensions of the FOV were 6-, 9-, and 12-in spheres, but the size refers to raw data. The data analyzed after primary reconstruction have the edges trimmed, and the final sphere sizes become 4, 6, and 8 in; this is why it is sometimes difficult to have both condyles when using the medium size.

The selection criteria for the cadaver head were as follows: no chemical preservation to maintain the integrity of the soft tissues, most natural teeth present, and minimal full-coverage restorations. The skull was selected from the Hamann-Todd collection based on having most of the dentition, no restorations, and undamaged condyles.

Cadavers were screened by an author (J.C.K.), and a minimal oral examination was done. When the inclusion criteria were satisfied, the head was acquired with the goal of reproducing a natural head position. A scout image was taken to validate the findings of the oral examination. The cadaver head was stored in a cold room at approximately 32°F between periods of image acquisition. The positions of the cadaver head and skull were standardized by using cross-hair projections from the CB MercuRay device in the frontal and lateral positions. All images were captured within 1 week to prevent deterioration of the cadaver.

The CB Works software (version 2.0; Cybermed, Seoul, Korea) was used with the CB MercuRay device to reconstruct and segment the volumes. The images were segmented after standardizing the window levels and widths. Three groups of 16 images were made based on the FOV. Specific images were made to represent each FOV based on the manufacturer's recommended settings. The 6-in FOV was designed to capture only the dentition, and the images taken in this FOV were made to resemble bite-wing radiographs. The 9-in FOV was designed to capture the dentition and the condyles; these images were made to resemble panoramic radiographs. The 12-in FOV was designed to capture the entire face; these images were made to resemble lateral cephalograms. Each image was identified by a serial number that consisted of milliamper-

Table II. Ranks for 6-in images (bite-wing)

6-in image settings	15* 100† 06Y‡	15 120 06Y	15 100 06N	10 100 06Y	10 120 06Y	05 120 06Y	05 120 06N	10 120 06N	15 120 06N	10 100 06N	05 100 06N	05 100 06Y	02 120 06N	02 100 06N	02 120 06Y	02 100 06Y
Overall rank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Mean rank	4.12	3.74	3.50	3.38	2.53	2.21	2.00	1.56	1.24	0.41	−1.09	−1.59	−4.62	−5.62	−5.79	−5.97
SD	3.08	3.59	4.73	3.47	3.65	4.18	3.98	4.20	4.09	4.62	3.43	3.20	2.81	3.35	2.61	2.71
Median	5	4.5	5	3	3	2.5	3	2	2	1	−2	−3	−5	−7	−6	−7
Maximum	8	8	8	8	8	8	8	8	8	8	8	6	2	6	6	3
Minimum	−4	−4	−8	−2	−6	−5	−5	−7	−8	−8	−8	−7	−8	−8	−8	−8
% diagnostic	82	76	88	82	71	74	76	79	85	79	62	59	41	38	32	38

*mA value (2, 5, 10, or 15 mA).
†kV(p) value (100 or 120 kV[p]).
‡Presence or absence of copper filter (*N,* no; *Y*, yes).

age, kilovolt (peak), FOV, and filter settings, respectively.

All images were printed on glossy photo paper for ease of simultaneous viewing. The 12-in images were printed directly from CB Works with a Codonics Horizon printer (Codonics, Middleburg Heights, Ohio). The 6- and 9-in images were exported from CB Works, converted to 16-bit grayscale TIFF images with Adobe Photoshop CS2 (Adobe Systems, San Jose, Calif), and printed on an Epson Stylus Photo R300 printer (Epson America, Long Beach, Calif), with Epson premium glossy photo paper and ink. Serial numbers were coded and labeled on the backs of the images so that the judges were unaware of the settings used to acquire the images.

The judges were chosen from faculty and residents at the School of Dental Medicine at Case Western Reserve University based on the following criteria: experienced in viewing the images and no visual impairment. The judges were asked only to examine the images they use daily. The lateral cephalograms were viewed only by orthodontists and oral surgeons; the panoramic views were viewed by orthodontists, oral surgeons, and general clinicians; and the bite-wings were viewed only by general clinicians. An experienced oral maxillofacial radiologist judged all 3 groups of images. Each group of images was evaluated by at least 30 judges. The evaluators were asked to rank the images from best to worst overall image quality using a technique called "Q-sorting."[11] Each image in the set was assigned a rank from 1 through 16, with 1 representing the best-quality image and 16 the poorest-quality image. The ranks were recorded by an author (J.C.K.) and a research assistant while the judge filled out a short survey.

The survey addressed the inclusion criteria and the diagnostic quality of each image. Specifically, the clinician was asked whether each image (in the order it was ranked) was of diagnostic quality. For the bite-wing images, the clinicians were asked whether the images were of diagnostic quality to be used an adjunct for a periodontal diagnosis (ie, were the bone levels and structures of the periodontium adequately visible?). For the panoramic images, the clinicians were asked whether the images were of diagnostic quality for a general screening (ie, was the image of diagnostic quality to view bone levels, frank caries, condyles, sinuses, trabeculation, and pathology?). For the lateral cephalogram images, the clinicians were asked whether the images were of diagnostic quality to make an orthodontic diagnosis (ie, was the image of diagnostic quality to view the relative positions of the jaws to the cranial base, and the teeth in relation to their respective jaws?).

The rank and diagnosis data were transferred to an Excel 2003 (Microsoft, Redmond, Wash) spreadsheet. To minimize skewing, the ranks were recoded from 1 through 16 to a scale from +8 through −8 (excluding zero).

Statistical analysis

Descriptive statistics were calculated (Tables II-IV) and used to depict the clinicians' image preferences. The data were transferred to the SPSS software for further analysis to compare the effect of filter, kilovolt (peak), and milliamperage settings. To test for the effect of a specific setting, other settings were kept constant, and the mean ranks of images were compared. The Friedman test was used to test image-quality differences in groups of images larger than 2, whereas the Wilcoxon signed rank tests were used for pairwise comparisons. The alpha value was set at 0.05, and the Bonferroni adjustment was applied for multiple comparisons. The data for diagnostic quality were recorded as the percentage of clinicians who thought that the image was of diagnostic quality.

Table III. Ranks for 9-in images (panoramic)

9-in image settings	*05** *120†* *09Y‡*	*15* *120* *09Y*	*15* *100* *09N*	*15* *120* *09N*	*15* *100* *09Y*	*10* *120* *09N*	*05* *100* *09Y*	*02* *100* *09Y*	*10* *100* *09N*	*10* *120* *09Y*	*02* *120* *09Y*	*05* *100* *09N*	*10* *100* *09Y*	*05* *120* *09N*	*02* *120* *09N*	*02* *100* *09N*
Overall rank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Mean rank	2.77	2.20	0.90	0.80	0.77	0.73	0.67	0.53	0.50	0.43	−0.63	−1.20	−1.33	−1.50	−1.77	−3.87
SD	4.95	4.53	5.66	4.95	4.82	4.53	4.72	4.45	5.59	4.21	5.31	5.55	5.08	4.87	3.78	4.61
Median	4.5	3	1.5	2	1	1.5	0.5	1	0.5	1.5	−2.5	−3	−1.5	−2.5	−1.5	−6
Maximum	8	8	8	8	8	7	8	8	8	6	8	8	7	8	4	8
Minimum	−7	−8	−8	−8	−7	−7	−8	−8	−8	−7	−8	−8	−8	−8	−7	−8
% diagnostic	93	93	97	100	87	93	93	93	90	97	93	87	90	93	93	90

*mA value (2, 5, 10, or 15 mA).
†kV(p) value (100 or 120 kV[p]).
‡Presence or absence of copper filter (*N,* no; *Y*, yes).

Table IV. Ranks for 12-in images (lateral cephalograms)

12-in image settings	*10** *100†* *12N‡*	*10* *100* *12Y*	*10* *120* *12Y*	*10* *120* *12N*	*15* *100* *12N*	*15* *120* *12N*	*15* *100* *12Y*	*05* *100* *12N*	*15* *120* *12Y*	*05* *120* *12N*	*05* *100* *12Y*	*02* *120* *12N*	*05* *120* *12Y*	*02* *100* *12N*	*02* *120* *12Y*	*02* *100* *12Y*
Overall rank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Mean rank	2.63	2.47	2.00	1.97	1.83	1.80	1.63	0.87	0.10	−0.47	−0.83	−1.57	−2.77	−3.00	−3.13	−3.53
SD	5.20	4.01	3.60	4.92	5.87	5.55	4.13	3.76	4.84	4.23	4.95	4.76	4.04	5.38	4.87	3.46
Median	3.5	3	2	3	4	3	2	1	0	−1	−2	−3	−4	−5	−5	−4.5
Maximum	8	8	8	8	8	8	7	8	8	7	7	6	7	6	8	5
Minimum	−8	−7	−6	−7	−8	−8	−5	−6	−8	−7	−8	−8	−8	−8	−8	−8
% diagnostic	100	100	100	100	100	93	100	100	100	100	100	100	97	100	97	97

*mA value (2, 5, 10, or 15 mA).
†kV(p) value (100 or 120 kV[p]).
‡Presence or absence of copper filter (*N,* no; *Y*, yes).

A reliability study was conducted 1 month after the first sitting, and 10 clinicians per group were randomly chosen to repeat the Q-sort and diagnosis survey. Intrarater reliability was tested by using Kendall coefficient of concordance, which applies to rank ordinal data. The Kendall coefficient of concordance ranges from 0 (no concordance) to 1 and can be converted to a Spearman correlation.

RESULTS

The 6-in bite-wing images were rated by 37 judges, 3 of whom were excluded for visual acuity problems. The 15-mA images were ranked the highest followed by the 10-, 5-, and 2-mA images. The image of best quality had a mean score of 4.12 (SD 3.08) (Fig 1, *A*), and the image of poorest quality had a mean score of −5.97 (SD 2.71) (Fig 1, *B*). The maximum and minimum ranks for each image showed variations in ranking between judges, and the greatest variation had a range of +8 to −8. The lowest diagnostic quality image (2 mA, 120 kV[p], with the filter) was considered diagnostic 32% of the time. The most diagnostic quality image (15 mA, 100 kV[p], without a filter) was considered diagnostic 88% of the time.

The 9-in panoramic images were judged by 34 clinicians, 3 of whom were excluded for visual acuity problems, and 1 for inability to detect a difference between the images. The image captured at 5 mA, 120 kV(p), with a filter was rated as the best image. However, the setting of 15 mA was generally most preferred, and the 2-mA films were least favored. The image of best quality had a mean score of 2.77 (SD 4.95) (Fig 2, *A*), and the image of poorest quality had a mean score of −3.87 (SD 4.61) (Fig 2, *B*). The maximum and minimum ranks for each image showed variations in ranking, and 10 images showed a range of +8 to −8. The 2 images rated least diagnostic were deemed diagnostic 87% of the time. The most diagnostic image (15 mA, 120 kV[p] with the filter) was considered diagnostic 100% of the time.

The 12-in images were examined by 30 clinicians. The 10-mA images were most preferred followed by the 15-, 5-, and 2-mA images. The image of best quality had a mean rank of 2.63 (SD 5.20) (Fig 3, *A*), and the image

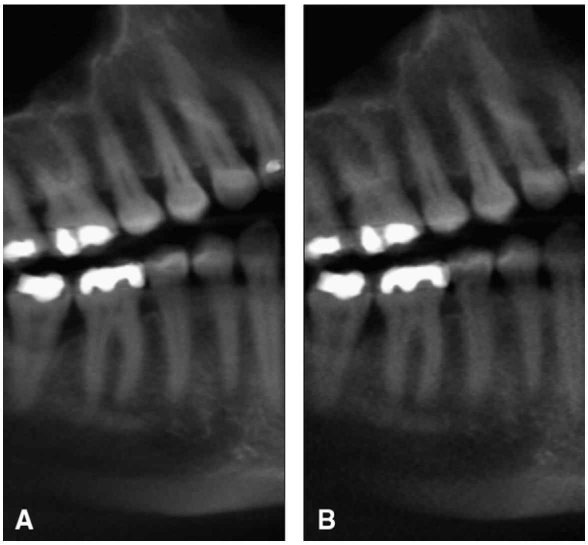

Fig 1. A, 6-in image of highest quality (15 mA, 100 kV[p], with copper filter); **B,** 6-in image of poorest quality (2 mA, 100 kV[p], with copper filter).

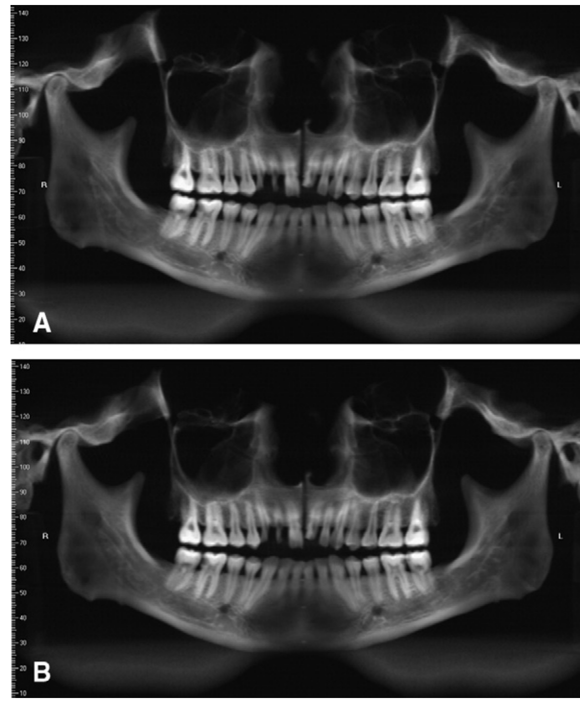

Fig 2. A, 9-in image of highest quality (5 mA, 100 kV[p], with copper filter); **B,** 9-in image of poorest quality (2 mA, 100 kV[p], without filter).

of poorest quality had a mean rank of −3.53 (SD 3.46) (Fig 3, *B*). The standard deviations were fairly high and consistent between the 16 images, but the mean image quality scores were low. There was considerable variation in ranking between judges, and the greatest variation had a range of +8 to −8. The least diagnostic image (15 mA, 120 kV[p], without filter) was considered diagnostic 93% of the time. Twelve images were rated as the most diagnostic 100% of the time.

When isolating the presence or the absence of a filter, significant differences were found (P <.006) only in the 9-in FOV (Table V). When significant differences were found, images captured with the filter were preferred. Overall, the presence of the copper filter did not affect the quality of the CBCT images.

When kilovolt (peak) was varied, 1 significant difference (P <.006) was found in the 6-in FOV (Table VI). In general, the quality of images captured at 100 kV(p) was the same as that of the images captured at 120 kV(p).

For the 6-in images, the effect of varying milliamperage showed significant differences (P <.05) in the following subgroups of images: 100 kV(p) without filter, 100 kV(p) with filter, 120 kV(p) with filter, and 120 kV(p) without filter. Further tests in each group showed significant differences (P <.008) in each subgroup (Table VII). For the 9-in images, the variation of milliamperage showed significant differences in image quality (P <.05) in the 100 kV(p) without filter and the 120 kV(p) with filter groups. Further tests showed significant differences (P <.008) in the 100 kV(p) without filter group (Table VIII). For the 12-in images, the change in milliamperage settings showed significant differences (P <.05) in the following subgroups of images: 100 kV(p) without filter, 100 kV(p) with filter, 120 kV(p) with filter, and 120 kV(p) without filter. Further tests showed significant differences (P <.008) in each subgroup (Table IX). When a significant difference was found, the image captured at the higher milliamperage setting was always preferred.

The Kendall coefficient of concordance (W) was calculated and averaged across the 10 judges. The average W values were 0.888, 0.567, and 0.653 for the 6-, 9-, and 12-in rankings, respectively. The coefficients of concordance were converted to Spearman correlations of 0.78, 0.13, and 0.31, respectively, for these groups. The judges showed a high level of agreement between the 2 time points when ranking the 6-in images, their agreement was low between the 2 time points for the 9- and 12-in images.

DISCUSSION

Image quality is essentially a descriptor of the subjective interpretation of visual data and does not have a simple analytical definition. The quality of an image can be related only to a specific medical task, and the image should convey enough information to

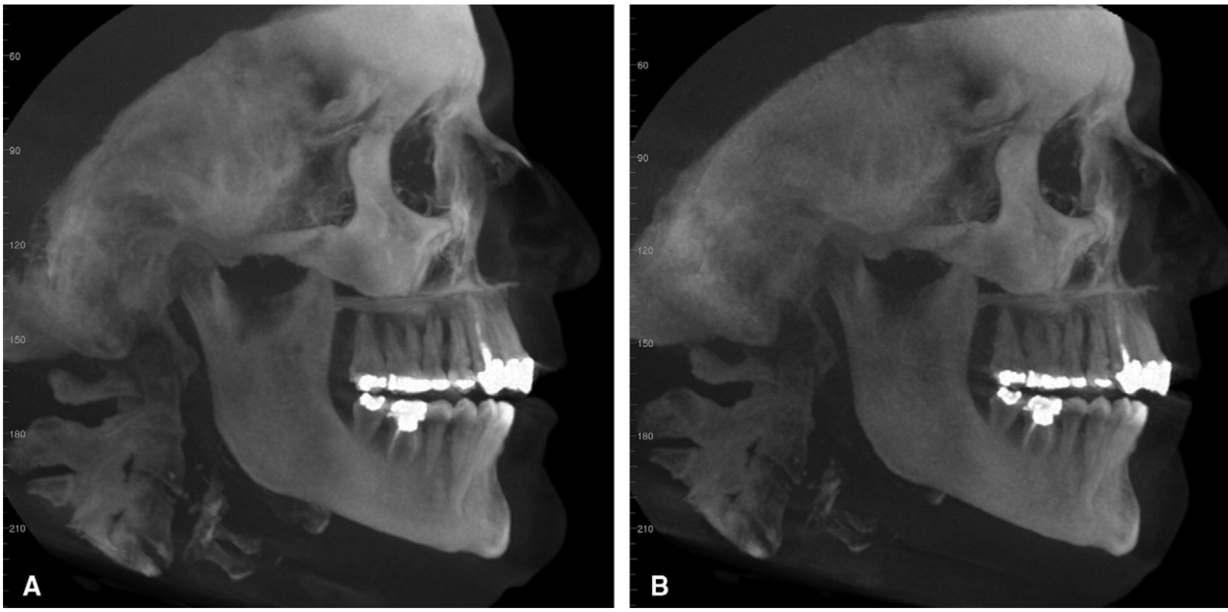

Fig 3. A, 12-in image of highest quality (10 mA, 100 kV[p], without copper filter); **B,** 12-in image of poorest quality (2 mA, 100 kV[p], with copper filter).

Table V. Effect of filter vs no filter on image quality (the mean rank [μ] and standard deviations were compared for images taken with a filter and without a filter)

FOV	*mA*	*kV(p)*	*No filter* μ ± *SD*	*Filter* μ ± *SD*	P *value**
6	2	100	−5.62 ± 3.35	−5.97 ± 2.71	.523
		120	−4.62 ± 2.81	−5.79 ± 2.61	.034
	5	100	−1.09 ± 3.43	−1.59 ± 3.20	.655
		120	2.00 ± 3.98	2.21 ± 4.18	.797
	10	100	0.41 ± 4.62	3.38 ± 3.47	.012
		120	1.56 ± 4.20	2.53 ± 3.65	0.333
	15	100	3.50 ± 4.73	4.12 ± 3.08	.637
		120	1.24 ± 4.09	3.74 ± 3.59	.015
9	2	100	−3.87 ± 4.61	0.53 ± 4.45	.006†
		120	−1.77 ± 3.78	−0.63 ± 5.31	.393
	5	100	−1.20 ± 5.55	0.67 ± 4.72	.240
		120	−1.50 ± 4.87	2.77 ± 4.95	.004†
	10	100	0.50 ± 5.59	−1.33 ± 5.08	.187
		120	0.73 ± 4.53	0.43 ± 4.21	.918
	15	100	0.90 ± 5.66	0.77 ± 4.82	.861
		120	0.80 ± 4.95	2.20 ± 4.53	.257
12	2	100	−3.00 ± 5.38	−3.53 ± 3.46	.861
		120	−1.57 ± 4.76	−3.13 ± 4.87	.216
	5	100	0.87 ± 3.76	−0.83 ± 4.95	.103
		120	−0.47 ±4.23	−2.77 ± 4.04	.071
	10	100	2.63 ± 5.20	2.47 ± 4.01	.749
		120	1.97 ± 4.92	2.00 ± 3.60	.984
	15	100	1.83 ± 5.87	1.63 ± 4.13	.734
		120	1.80 ± 5.55	0.10 ± 4.84	.110

*Based on Wilcoxon signed rank test; †$P < .006$ after Bonferroni adjustment.

Table VI. Effect of 100 vs 120 kV(p) on image quality (mean rank [μ] and standard deviations were compared for images taken with at 100 kV(p) and 120 kV(p))

FOV	*mA*	*Filter*	*100 kV(p)* μ ± *SD*	*120 kV(p)* μ ± *SD*	P *value**
6	2	N	−5.62 ± 3.35	−4.62 ± 2.81	.126
		Y	−5.97 ± 2.71	−5.79 ± 2.61	.556
	5	N	−1.09 ± 3.43	2.00 ± 3.98	.007
		Y	−1.59 ± 3.20	2.21 ± 4.18	.001†
	10	N	0.41 ± 4.62	1.56 ± 4.20	.461
		Y	3.38 ± 3.47	2.53 ± 3.65	.337
	15	N	3.50 ± 4.73	1.24 ± 4.09	.012
		Y	4.12 ± 3.08	3.74 ± 3.59	.292
9	2	N	−3.87 ± 4.61	−1.77 ± 3.78	.059
		Y	0.53 ± 4.45	−0.63 ± 5.31	.398
	5	N	−1.20 ± 5.55	−1.50 ± 4.87	.967
		Y	0.67 ± 4.72	2.77 ± 4.95	.147
	10	N	0.50 ± 5.59	0.73 ± 4.53	.805
		Y	−1.33 ± 5.08	0.43 ± 4.21	.101
	15	N	0.90 ± 5.66	0.80 ± 4.95	.967
		Y	0.77 ± 4.82	2.20 ± 4.53	.180
12	2	N	−3.00 ± 5.38	−1.57 ± 4.76	.177
		Y	−3.53 ± 3.46	−3.13 ± 4.87	.893
	5	N	0.87 ± 3.76	−0.47 ± 4.23	.317
		Y	−0.83 ± 4.95	−2.77 ± 4.04	.181
	10	N	2.63 ± 5.20	1.97 ± 4.92	.523
		Y	2.47 ± 4.01	2.00 ± 3.60	.509
	15	N	1.83 ± 5.87	1.80 ± 5.55	.789
		Y	1.63 ± 4.13	0.10 ± 4.84	.232

*Based on Wilcoxon signed rank test; †P <.006 after Bonferroni adjustment.

allow a medical decision to be made with an acceptable degree of certainty.

Previous studies showed that low settings used in medical CT machines can achieve comparable image quality in medical head and neck imaging as higher settings.[6-8] Other studies comparing dental CT images also showed that low settings can produce images without loss of quality.[9,10] Our study suggests that, depending on the FOV, CBCT images captured at lower settings are comparable with those at higher settings and maintain adequate diagnostic image quality.

Differences in image quality were found in the 6-in group when the milliamperage setting was varied. The 6-in FOV has the smallest voxel size and the highest resolution. However, high resolution does not necessarily imply high image quality. Voxel size, milliamperage, and image quality are intimately related. The milliamperage setting controls the number of photons released by the x-ray tube and subsequently the number of photons that reach the detector voxels. If the number of photons released is kept constant (by holding the milliamperage setting and capture time constant), and the size of the voxel on the detector is changed, the number of photons that strike each voxel will change (Fig 4). In this case, smaller voxels are struck by fewer photons, and larger voxels are struck by more photons. When more photons strike each voxel, more information is generated for each voxel, thus contributing to a difference in image quality.[5] The difference in number of photons can cause a blurry or grainy image. When voxel size is decreased, more photons are required to increase the photon-per-voxel count if the image quality is to remain the same. In our study, images in each FOV were compared. The comparison of image quality between FOVs was not a focus of our study.

In the 9-in group, variations of milliamperage did not have a great effect on image quality. Few significant differences were detected, and the standard deviations and ranges in the maximum and minimum rankings suggest that the differences are not clinically significant. The 6-in images were constructed similarly yet showed considerable differences, suggesting that soft tissues might play a role in image quality. Theoretically, the skull is more likely to produce a consistent image because only high-density structures are present. The lack of soft tissue leads to less attenuation of the x-ray photons by objects such as soft tissues. CBCT produces higher amounts of scattered radiation, thus negatively affecting image quality.[12] Scattered radiation affects

Table VII. Effect of varying mA on image quality for 6-in FOV (mean rank [μ] and standard deviations were compared for images taken at different mA values)

kV(p)	*Filter*	mA_1	$\mu_1 \pm SD$	mA_2	$\mu_2 \pm SD$	P *value**
100	No	2	−5.62 ± 3.35	5	1.09 ± 3.43	.000†
		2	−5.62 ± 3.35	10	0.41 ± 4.62	.000†
		2	−5.62 ± 3.35	15	3.50 ± 4.73	.000†
		5	−1.09 ± 3.43	10	0.41 ± 4.62	.187
		5	−1.09 ± 3.43	15	3.50 ± 4.73	.000†
		10	0.41 ± 4.62	15	3.50 ± 4.73	.002†
	Yes	2	−5.97 ± 2.71	5	−1.59 ± 3.20	.000†
		2	−5.97 ± 2.71	10	3.38 ± 3.47	.000†
		2	−5.97 ± 2.71	15	4.12 ± 3.08	.000†
		5	−1.59 ± 3.20	10	3.38 ± 3.47	.000†
		5	−1.59 ± 3.20	15	4.12 ± 3.08	.000†
		10	3.38 ± 3.47	15	4.12 ± 3.08	.296
120	No	2	−4.62 ± 2.81	5	2.00 ± 3.98	.000†
		2	−4.62 ± 2.81	10	1.56 ± 4.20	.000†
		2	−4.62 ± 2.81	15	1.24 ± 4.09	.000†
		5	2.00 ± 3.98	10	1.56 ± 4.20	.625
		5	2.00 ± 3.98	15	1.24 ± 4.09	.532
		10	1.56 ± 4.20	15	1.24 ± 4.09	.790
	Yes	2	−5.79 ± 2.61	5	2.21 ± 4.18	.000†
		2	−5.79 ± 2.61	10	2.53 ± 3.65	.000†
		2	−5.79 ± 2.61	15	3.74 ± 3.59	.000†
		5	2.21 ± 4.18	10	2.53 ± 3.65	.560
		5	2.21 ± 4.18	15	3.74 ± 3.59	.155
		10	2.53 ± 3.65	15	3.74 ± 3.59	.050

*Based on Wilcoxon signed rank test; †$P < .008$ after Bonferroni adjustment.

Table VIII. Effect of varying mA on image quality for 9-in FOV (mean rank [μ] and standard deviations were compared for images taken at different mA values)

kV(p)	*Filter*	mA_1	$\mu_1 \pm SD$	mA_2	$\mu_2 \pm SD$	P *value**
100	No	2	−3.87 ± 4.61	5	−1.20 ± 5.55	.082
		2	−3.87 ± 4.61	10	0.50 ± 5.59	.005†
		2	−3.87 ± 4.61	15	0.90 ± 5.66	.005†
		5	−1.20 ± 5.55	10	0.50 ± 5.59	.376
		5	−1.20 ± 5.55	15	0.90 ± 5.66	.144
		10	0.50 ± 5.59	15	0.90 ± 5.66	.781
	Yes	2	0.53 ± 4.45	5	0.67 ± 4.72	NA
		2	0.53 ± 4.45	10	−1.33 ± 5.08	NA
		2	0.53 ± 4.45	15	0.77 ± 4.82	NA
		5	0.67 ± 4.72	10	−1.33 ± 5.08	NA
		5	0.67 ± 4.72	15	0.77 ± 4.82	NA
		10	−1.33 ± 5.08	15	0.77 ± 4.82	NA
120	No	2	−1.77 ± 3.78	5	−1.50 ± 4.87	NA
		2	−1.77 ± 3.78	10	0.73 ± 4.53	NA
		2	−1.77 ± 3.78	15	0.80 ± 4.95	NA
		5	−1.50 ± 4.87	10	0.73 ± 4.53	NA
		5	−1.50 ± 4.87	15	0.80 ± 4.95	NA
		10	0.73 ± 4.53	15	0.80 ± 4.95	NA
	Yes	2	−0.63 ± 5.31	5	2.77 ± 4.95	.016
		2	−0.63 ± 5.31	10	0.43 ± 4.21	.422
		2	−0.63 ± 5.31	15	2.20 ± 4.53	.032
		5	2.77 ± 4.95	10	0.43 ± 4.21	.059
		5	2.77 ± 4.95	15	2.20 ± 4.53	.483
		10	0.43 ± 4.21	15	2.20 ± 4.53	.095

*Based on Wilcoxon signed rank test; †$P < .008$ after Bonferroni adjustment; *NA,* not applicable.

Table IX. Effect of varying mA on image quality for 12-in FOV (mean rank [μ] and standard deviations were compared for images taken at different mA values)

kV(p)	*Filter*	mA_1	$\mu_1 \pm$ *S.D.*	mA_2	$\mu_2 \pm SD$	P *value**
100	No	2	−3.00 ± 5.38	5	0.87 ± 3.76	.007†
		2	−3.00 ± 5.38	10	2.63 ± 5.20	.002†
		2	−3.00 ± 5.38	15	1.83 ± 5.87	.003†
		5	0.87 ± 3.76	10	2.63 ± 5.20	.073
		5	0.87 ± 3.76	15	1.83 ± 5.87	.257
		10	2.63 ± 5.20	15	1.83 ± 5.87	.277
	Yes	2	−3.53 ± 3.46	5	−0.83 ± 4.95	.049
		2	−3.53 ± 3.46	10	2.47 ± 4.01	.000†
		2	−3.53 ± 3.46	15	1.63 ± 4.13	.000†
		5	−0.83 ± 4.95	10	2.47 ± 4.01	.004†
		5	−0.83 ± 4.95	15	1.63 ± 4.13	.074
		10	2.47 ± 4.01	15	1.63 ± 4.13	.347
120	No	2	−1.57 ± 4.76	5	−0.47 ± 4.23	.288
		2	−1.57 ± 4.76	10	1.97 ± 4.92	.009
		2	−1.57 ± 4.76	15	1.80 ± 5.55	.035
		5	−0.47 ± 4.23	10	1.97 ± 4.92	.038
		5	−0.47 ± 4.23	15	1.80 ± 5.55	.084
		10	1.97 ± 4.92	15	1.80 ± 5.55	.829
	Yes	2	−3.13 ± 4.87	5	−2.77 ± 4.04	.598
		2	−3.13 ± 4.87	10	2.00 ± 3.60	.000†
		2	−3.13 ± 4.87	15	0.10 ± 4.84	.011
		5	−2.77 ± 4.04	10	2.00 ± 3.60	.000†
		5	−2.77 ± 4.04	15	0.10 ± 4.84	.017
		10	2.00 ± 3.60	15	0.10 ± 4.84	.085

*Based on Wilcoxon signed rank test; †$P < .008$ after Bonferroni adjustment.

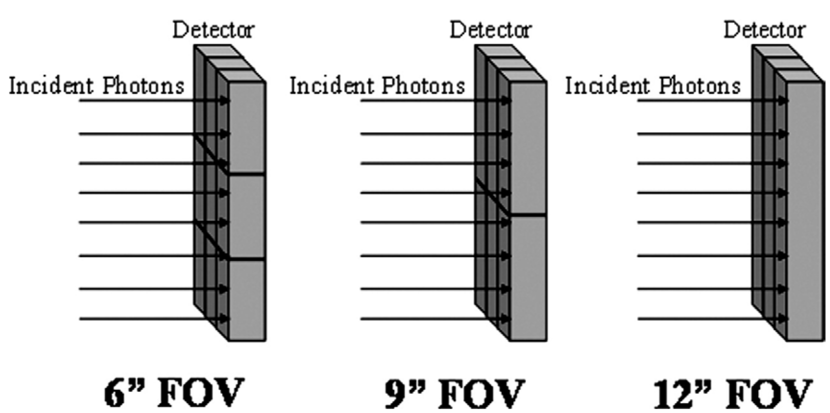

Fig 4. The relationship between voxel size, milliamperage, and image quality. Depending on the FOV, the size of the element at the level of the detector varies. Small FOVs correspond with small detector elements (voxels). If the number of photons is kept constant, the voxel size limits the number of incident photons that can strike each voxel: eg, it is shown above that the 6-, 9-, and 12-in FOVs are struck by 3, 4, and 8 incident photons per voxel, respectively. The number of photons that strike each voxel affects the quality of a digital image. The photon count is controlled by the milliamperage setting and the capture time (which remains constant in the Hitachi CB MercuRay). Better image quality is associated with a larger number of photons/voxel.

structures of low density and was not a factor for the skull.

The 12-in group showed significant image quality differences when the milliamperage was varied. The overall ranks showed that all 10-mA images were ranked higher than the 15-mA images. After reviewing matched 10- and 15-mA images, their histograms showed a minor shift toward the right from 10 to 15 mA. This suggests not only that the judges preferred images of less darkness, but also that a small change in density was visually detectable. Although there was considerable variation in the ranking as shown by the maximum and minimum rankings, the judges considered the diagnostic quality of all images very high, implying that a clinically significant difference between the images might not exist.

Few significant differences were found as a result of varying kilovolt (peak). In all radiographic imaging, increasing the kilovolt (peak) increases the average photon energy and decreases the grayscale resolution. Siegel et al[13] found that, in pediatric CT imaging, a decrease in tube voltage from 140 to 80 kV(p) resulted in decreased image quality. A direct comparison to our study cannot be drawn for several reasons: Siegel et al[13] measured image quality based on evaluation of grayscale resolution, and a reduction in tube current of 60 kV(p) is not equivalent to a reduction of 20 kV(p). CBCT image quality with the CB MercuRay device can be maintained when tube current is reduced from 120 to 100 kV(p).

The copper filter affected image quality only in the 6-in images. It altered the beam quality by removing low-energy photons from the x-ray beam.[14] Low-energy photons do not penetrate the subject and tend to be absorbed by the subject. Gonçalves et al[15] studied the effect of copper-aluminum alloy and aluminum filters and found no difference in plain film image quality. Although our study cannot be directly compared with theirs, our results agree that the addition of a copper filter did not affect the overall image quality of the Hitachi CB MercuRay.

Although the examiners were not calibrated, there was good agreement between 2 time points when evaluating the 6-in images. This suggests that the examiners agreed when image quality differed. The 9- and 12-in images showed low levels of agreement. Although differences in image quality existed, it was difficult for clinicians to agree where the differences were.

For the diagnosis data, at the first time point, 56%, 99%, and 99% of the judges thought that the 6-, 9-, and 12-in images were diagnostic, respectively. At the second time point, 86%, 96%, and 100% of the clinicians graded these images as diagnostic. The variation between the 2 time points for the 6-in images suggests that the judges might have become more comfortable with the images, or that they were more lenient in their grading. The variation in diagnostic quality also suggests that that image quality could be improved for the 6-in images.

Our study highlighted the difficulties of defining and quantifying clinical image quality. The judges commented that image scoring was difficult in the 9- and 12-in groups, despite efforts to be as consistent as possible. A limitation in our study was that the ranking system did not allow 2 images to be ranked the same. It is possible that image quality differences did not exist between images. Another limitation is that our study evaluated only 2-dimensional images reconstructed from a 3-dimensional volume. We chose to use the 2-dimensional images as a tool for image quality evaluation because clinicians are familiar with these. We believe that the use of this new technology to produce familiar images might limit the usefulness of 3-dimensional data for diagnosis. The key issue in terms of image quality is whether an image enables an appropriate diagnosis to be made. To answer diagnostic questions appropriately, the proper images need to be segmented.

CONCLUSIONS

Our results indicate that it is possible to lower the CBCT settings in the CB MercuRay device and maintain diagnostic quality. To minimize the dose to the patient, images should be captured at 100 kV(p) with a copper filter. The choice of the milliamperage setting depends on the FOV chosen. Many significant differences were found for the 6-in FOV. Overall, the 5- and 10-mA views were considered diagnostic for periodontal structures 68% and 78% of the time, respectively. Before choosing between the 5- and 10-mA views, the clinician should consider that images acquired with lower milliamperage settings were generally less preferred. Our study suggests that, although statistically significant differences in image quality were found in the 9- and 12-in images, clinically significant differences do not exist in the diagnostic quality. To minimize the radiation dose to the patient, the 2-mA images should be sufficient for the 9- and 12-in images. For a good balance between the "as low as reasonably achievable" principle and the image quality needed, the ability to select various milliamperage settings could be helpful. The clinician should also consider that "image quality requirements vary for different types of examination or even different tasks within single examinations."[16]

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