Original Article

Dose Reduction by Direct-Digital Cephalometric Radiography

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Abstract: Patient radiation exposure was determined for conventional and direct-digital cephalometric radiography. An anthropomorphic phantom was positioned to expose lateral cephalographs from the patient's left side. The conventional radiographs were exposed with a Siemens Orthophos C unit (77 kV, 14 mA, 0.5 s) and a film-screen system of a relative speed of 400. The direct-digital radiographs were exposed with a Siemens Orthophos DS Ceph (73 kV, 15 mA, 15.8 s). A set of 108 thermoluminescence detectors (TLDs; Bicron STI/Harshaw, Solon, Ohio) was used for dose measurements. For each measurement, 84 TLDs were placed at the surface of the head and neck, as well as inside the phantom, at anatomically relevant positions. The remaining detectors were employed for calibration purposes and quality control. The highest absorbed doses were recorded for the conventional technique at the skin of the left parotid region (132 μGy), in the left parotid gland (103 μGy), and in the ocular lens of the left eye (81 μGy). Digital cephalometry resulted in an absorbed dose about 2 times lower than the dose received by the conventional technique. The effective doses had the same relation (conventional 2.3 μSv; digital 1.1 μSv). The results demonstrate that direct-digital cephalometric radiography cuts the patient's dose in half compared with the conventional screen-film technique. Direct-digital cephalometry is more advantageous than the conventional technique from the perspective of radiation protection. (*Angle Orthod* 2001;71:159–163.)

Key Words: Digital radiography; Dosimetry; Patient's exposure; Dose reduction

INTRODUCTION

Digital imaging and image processing have a key position in the future of dental radiography. The main advantages of the digital systems are the immediate availability of the image, the elimination of the chemical darkroom process, and a reduced radiation dose. Image contrast, brightness, magnification, and other features of the image can be adjusted right to the user's needs by digital image processing. The measurement of distances and angles is facilitated.

Basic investigations into the diagnostic value of digital cephalometric radiographs have been performed by several authors in the last decade. In all of these papers, the digital cephalograms were obtained either by using storage phosphor plates from general radiology or by digitizing conventional radiographs.

In 1992, Calderazzi et al[1] used storage phosphor plates to demonstrate that conventional and digital cephalometry did not differ relative to bone structure representation. The digital imaging technique provided better visualization of soft tissue structures. In 1998, Geelen et al[2] found no clinically relevant differences in locating landmarks on conventional and digital radiographs. Three research groups showed independently that a dose reduction between 50% and 75% is possible with storage phosphor plates.[3–5] Despite these encouraging results, storage phosphor plates were not available in dentistry for a long time because of high costs and protection by patent. In 1998, the ''DenOptix combo,'' a scanner for storage phosphor plates in the format of cephalograms, was introduced (Gendex/Dentsply International Inc., Haywood, Calif.).

In 1996, Forsyth et al[6,7] mounted conventional radiographs on a light box to capture the digital images by a video camera connected to a computer. The resulting images had a resolution of 512 × 512 pixels, which was quite low compared with today's standards. They found that the random error associated with angular or linear measurements and landmark identification tended to be greater with the digital images than with conventional radiographs. They concluded that, for digital imaging of cephalometric radiographs, a pixel matrix larger than 512 × 512 is required. This requirement is easily met by scanning conventional radiographs with modern image scanners, but the main ad-

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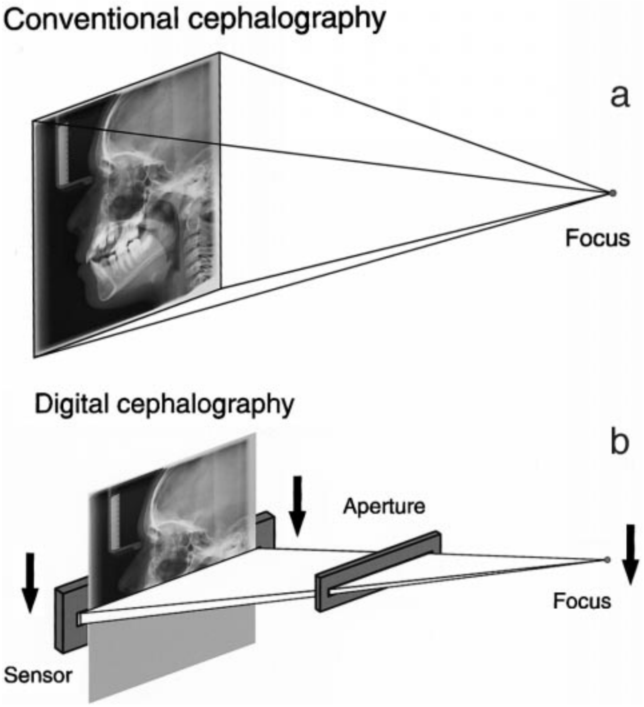

FIGURE 1. (a) Conventional lateral cephalography with film-screen systems: the whole skull is pictured simultaneously with a pyramid-shaped x-ray beam. The typical total exposure time for a sensitive film-screen system is about 0.5 seconds. (b) Digital cephalography with the slot technique: the skull is scanned in linear slices with a fan-shaped x-ray beam. From the total height of the scanned distance (210 mm) and the height of the fan-shaped x-ray beam in the plane of the sensor (3.6 mm), the ratio of the total to the effective exposure time can be calculated: 210/3.6 = 58.3. Therefore, a time of 15.8 seconds for acquisition of the digital image yields an effective exposure time in each part of the skull of (15.8/58.3) = 0.27 seconds.

vantages of direct-digital radiography, ie, time saving and dose reduction, are lost.

In 1996, a device for direct-digital cephalometric radiography was introduced by Sirona (formerly Siemens Dental, Bensheim, Germany). This unit is equipped with a charge-coupled device (CCD) sensor chip for image acquisition and can be used for rotational panoramic radiography and lateral cephalography as well. In the cephalographic mode, the unit works with a narrow beam linear scanning process called a ‘‘slot technique.’’ The patient’s head is scanned in lines with a flat, fan-shaped x-ray beam. During the scanning process, which takes about 15.8 seconds, the patient must stay motionless. Figure 1 sketches the principles of both conventional cephalography and this kind of slot-technique digital cephalography.

Although the total exposure time for slot-technique direct-digital cephalography is much longer than for conventional radiography, a plain dose reduction is expected because of the greater sensitivity and the lower overall system noise of the CCDs. At any given time during the scanning process, only a small linear slice of the skull is exposed to the x-rays. Under the presumption that all other exposure parameters are identical, a dose reduction by a factor of 2 can be expected for this type of digital radiographic device.

The theoretical estimation of dose reduction is comprehensive, but an experimental verification remains necessary. As part of an extensive survey of patient exposure by dental radiography, we have performed dose measurements on conventional and direct-digital cephalography.

MATERIALS AND METHODS

Cephalometric radiography

The conventional cephalometric radiographs were taken with a Siemens Orthophos C (Sirona Dental, Bensheim, Germany). A film-screen system of a relative speed of 400 (18 × 24 cm; Du Pont Cronex Ortho TG films and Cronex Ortho Regular intensifying screens, Du Pont de Nemours, France) was used. The exposure settings were 77 kV, 14 mA, and 0.5 seconds.

A Siemens Orthophos DS Ceph (Sirona Dental, Bensheim, Germany) was employed for direct-digital cephalography. This radiographic system uses a CCD sensor chip as an image receptor. The resulting image has a pixel matrix of 2052 × 2348. It requires about 4 MB on hard disk without image compression. The exposure parameters for the digital cephalographs were 73 kV, 15 mA, and 15.8 seconds.

All radiographic examinations were performed at a focus-film distance of 150 cm, with the left side of the phantom facing the tube. The phantom was positioned by means of ear plugs. All radiologic examinations were performed according to daily practice, ensuring an image quality appropriate for all diagnostic needs.

Dosimetric phantom

We used an anthropomorphic head and neck phantom especially designed for dosimetry studies on dental radiography. The phantom was developed and built at the University of Göttingen (Germany).[8] It is made completely of synthetic, tissue-equivalent materials by using a computerized milling machine. The phantom consists of 48 transverse sections, each 6 mm thick. All parts can be reproduced exactly and are interchangeable. The dosimetric phantom is representative of the essential anatomical structures in the head and neck, including the eyes, salivary glands, thyroid, calcified tissues, nasopharyngeal canal, paranasal sinuses, and esophagus. It was evaluated in detail and passed all tests with good results. Dosimetric data on panoramic and intraoral radiography obtained with the new phantom matched well with the data from a clinical dosimetric study. In comparison with an Alderson Rando phantom, it proved to be superior in measurement accuracy and handling.[8–10]

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Dosimetry

The absorbed doses were measured by using a set of 108 individually calibrated thermoluminescence detectors (TLD 100; LiF, Mg, Ti; Bicron STI, Harshaw, Solon, Ohio). The processing of the TLDs was identical to previous studies.[8–10] The TLDs were packed in thin bags of polyethylene to avoid contamination by dirt or humidity. Each of the 28 packages contained 3 TLDs, and the packages were placed on the anthropomorphic phantom as follows: 9 packages were placed on the skin surface of the head and neck, and 19 packages were placed inside the phantom at anatomically defined positions that represented radiosensitive tissues or organs. Twenty of the measuring sites were symmetric, eg, left and right ocular lens. The remaining TLDs were used for calibration purposes and quality control. Each measurement was repeated at least once.

The data from the respective radiographic procedures were summed up. Minimum, maximum, median, arithmetic mean, standard deviation, and coefficient of variation were determined for all measuring positions. The arithmetic means of the absorbed doses were used to calculate the effective doses according to the International Commission on Radiological Protection 60.[11]

RESULTS

The absorbed doses at the sites under investigation are summarized in Table 1. With both techniques, the highest absorbed doses were recorded at the skin of the left parotid region, at the left parotid gland, and at the skin below the left eye. These measuring sites had the shortest distance to the focal spot of the x-ray tube.

At the critical organs of the head and neck, the absorbed dose from conventional radiography was approximately 2-fold higher than for the digital radiographic unit. On the side of the head directed toward the tube, we measured 81 vs 34 μGy at the lens of the eye, 103 vs 45 μGy at the parotid gland, 53 vs 34 μGy at the submandibular gland, and 3 vs 2 μGy at the thyroid gland. Figure 2 shows a direct comparison of the doses to the critical organs in terms of median boxplots with arithmetic means. The effective doses were 2.3 μSv for conventional and 1.1 μSv for direct-digital cephalometric radiography.

We recorded distinctly higher exposures for the digital device only at the skin of the nasion, philtrum, and labiomental sulcus. These measurement sites are located right in the median line of the face. Small deviations in positioning the phantom can result either in direct irradiation of the TLDs or in shielding effects by the phantom. It is likely that minor positioning differences are the cause of the deviation in the measurement values in the median line of the face. When both sides of the head are compared, the attenuation of the radiation by the tissue or the tissue-equivalent phantom materials are evident. The absorbed doses were

TABLE 1. Absorbed Doses From Lateral Cephalography in μGy

Organ/Measuring Position	Absorbed Dose, μGy Conventional Cephalography	 Digital Cephalography
Nasion (skin)	26	45
Pituitary gland	19	5
Ocular lens (facing the tube)	81	34
Ocular lens (facing the film/sensor)	11	4
Infraorbital skin (facing the tube)	72	53
Infraorbital skin (facing the film/sensor)	11	6
Maxillary sinus (facing the tube)	35	18
Maxillary sinus (facing the film/sensor)	8	8
Philtrum (skin)	11	42
Parotid skin (facing the tube)	132	58
Parotid skin (facing the film/sensor)	4	2
Parotid gland (facing the tube)	103	45
Parotid gland (facing the film/sensor)	8	3
Premolar/maxilla (facing the tube)	65	36
Premolar/maxilla (facing the film/sensor)	16	11
Premolar/mandible (facing the tube)	71	41
Premolar/mandible (facing the film/sensor)	16	12
Mandibular angle (facing the tube)	64	30
Mandibular angle (facing the film/sensor)	8	9
Labiomental sulcus (skin)	9	41
Submandibular gland (facing the tube)	53	34
Submandibular gland (facing the film/sensor)	14	8
Third cervical vertebra	13	9
Neck (skin)	2	2
Spinal cord	3	1
Thyroid (skin)	4	4
Thyroid gland (facing the tube)	3	2
Thyroid gland (facing the film/sensor)	3	1

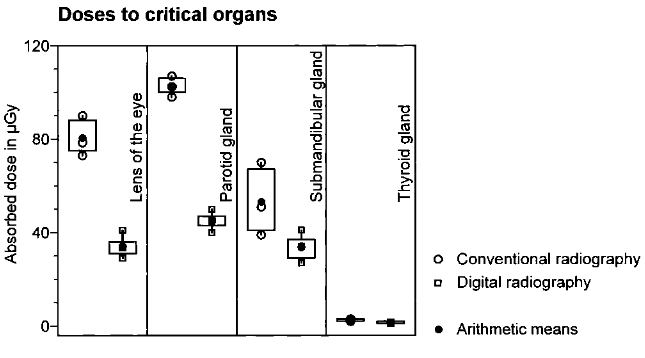

FIGURE 2. Doses to the critical organs by conventional and direct-digital cephalography at the side of the head facing the tube: median boxplots and arithmetic means.

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TABLE 2. Dosimetric Data on Conventional Cephalography From the Literature and Results of This Study in Chronological Order.

	Absorbed Dose, μGy											
	Lens of the Eye			Parotid Gland			Submandibular Gland			Thyroid Gland		
Reference	Facing the Tube	Facing the Film	Average	Facing the Tube	Facing the Film	Average	Facing the Tube	Facing the Film	Average	Facing the Tube	Facing the Film	Average
Block et al[12]	—	—	—	—	—	—	—	—	—	170–850	60–230	—
Copley et al[13]	320	80	—	—	—	—	—	—	—	—	—	40
Bankvall and Hakansson[14]	—	—	160	—	—	—	—	—	—	—	—	60
Eliasson et al[15]	57	25	—	157	46	—	89	41	—	6–123	4–89	—
Ewen and Lukoschek[16]	—	—	—	—	—	—	—	—	—	—	—	6
Patsakas et al[17]	170	170	—	900	630	—	—	—	—	820	730	—
Tyndall[18]	—	—	—	—	—	—	—	—	—	—	—	13–51
Tanimoto et al[19]	102–147	30–42	—	473–484	30–37	—	66–132	61–100	—	46–420	28–190	—
Tsiklakis et al[20]	110	150	—	500	400	—	—	—	—	350	370	—
Gilda and Maillie[21]	—	—	—	113	9	—	126	19	—	4–57	0–26	—
Freeman and Brand[22]	—	—	45	—	—	56	—	—	44	—	—	35
Blanc et al[3]	—	—	700	—	—	—	—	—	—	—	—	70
This study	81	11	46	103	8	56	53	14	34	3	3	3

about 9 times lower in the side of the head toward the film than in the side toward the x-ray tube.

DISCUSSION

Our results with conventional cephalography are in agreement with the dosimetric data from the recent literature, which are shown in Table 2. The fact that our data are in the lowest range described so far can be explained with the use of a sensitive film-screen system of a relative speed of 400. The relations between the different measuring sites are concurrent with the data published so far.

The measurements of the absorbed dose and the calculation of the effective doses demonstrate that direct-digital cephalography yields an average dose reduction by a factor of 2. This corresponds closely with the theoretical estimate of dose reduction: from the total height of the scanned area (210 mm) and the height of the fan-shaped x-ray beam in the plane of the sensor (3.6 mm), the ratio of the total to the effective exposure time can be calculated: $210/3.6 = 58.3$. Therefore, a total time of 15.8 seconds for digital image acquisition is equivalent to an effective exposure time (15.8/58.3 seconds) of 0.27 seconds for each point of the head. Conventional cephalography with a sensitive film-screen system requires a typical exposure time of 0.5 seconds for an adult person. Under the presumption that all other exposure parameters are constant, the absorbed dose is proportional to the effective exposure time. Thus, the theoretical estimation yields a dose reduction by a factor of 2. In clinical practice, the relatively long exposure time of 15.8 seconds for the direct-digital cephalographs causes no problems; blurred exposures are rare.

The inevitable exposure to ionizing radiation from natural and man-made sources is about 4 mSv/y.[8] Compared with this, the effective dose by lateral cephalometric radiographs in the range of 1–2 μSv is small. Nevertheless, the radiological ALARA principle (as low as reasonably achievable) should always be kept in mind. The sensitivity to radiation detriment is age dependent. Children and adolescents have a much higher risk than adults. This is illustrated in a dramatic manner by the follow-up data from 2 incidents in the early years of therapeutic x-ray use. In the years between 1949 and 1960, about 10,000 children in Israel were exposed to intensive x-rays for treatment of tinea capitis, a disease of the scalp. In Rochester, NY, about 2600 children were irradiated for treatment of thymic enlargement. Both groups had a significantly higher rate of malignant as well as benign head and neck tumors compared with control groups.[23,24] Many other studies, such as the follow-up of Hiroshima, the case-control studies on thyroid or parotid cancer, or the Beaver Dam eye study indicate that radiation protection is clearly an important issue.[8,11,25–27] Even with a high level of radiation protection, further technical achievements for dose reduction in cephalography, such as storage phosphor plates or direct-digital radiography, are appropriate.

SUMMARY

The use of direct-digital cephalometry can reduce patient exposure by a factor of 2 when compared with conventional technique with a film-screen combination of a relative speed of 400. From a radiation protection point of view, direct-digital cephalography is superior to conventional radiography.

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REFERENCES

1. Calderazzi A, Palla L, Battolla L, Caramella D, Barbieri L. La radiologia digitale con fosfori a memoria nello studio cefalometrico nell'ortodonzia. *Radiol Med (Torino).* 1992;84:216–220.

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2. Geelen W, Wenzel A, Gotfredsen E, Kruger M, Hansson LG. Reproducibility of cephalometric landmarks on conventional film, hardcopy, and monitor displayed images obtained by the storage phosphor technique. *Eur J Orthod.* 1998;20:331–340.
3. Blanc M, Nessi R, Paruccini N, Castellana L. Valutazioni dosimetriche nella radiologia odontoiatrica: sistema digitale con fosfori fotostimolabili e tradizionale a confronto. *Radiol Med (Torino).* 1995;89:319–323.
4. Näslund EB, Kruger M, Petersson A, Hansen K. Analysis of low-dose digital lateral cephalometric radiographs. *Dentomaxillofac Radiol.* 1998;27:136–139.
5. Seki K, Okano T. Exposure reduction in cephalography with a digital photostimulable phosphor imaging system. *Dentomaxillofac Radiol.* 1993;22:127–130.
6. Forsyth DB, Shaw WC, Richmond S. Digital imaging of cephalometric radiography, part 1: advantages and limitations of digital imaging. *Angle Orthod.* 1996;66:37–42.
7. Forsyth DB, Shaw WC, Richmond S, Roberts CT. Digital imaging of cephalometric radiographs, part 2: image quality. *Angle Orthod.* 1996;66:43–50.
8. Visser H. *Investigations Into the Optimization of Periodontal Radiography (Untersuchungen Zur Optimierung der Parodontologischen Röntgendiagnostik).* Berlin, Germany: Quintessenz Publishing; 2000.
9. Visser H, Matheis B, Richter B, Hermann KP, Krüger W. A clinical dosimetric study on periodontal radiography. *J Dent Res.* 1996;75(special issue):156. Abstract 1110.
10. Visser H, Hermann KP, Schorn C, Krüger W. Doses to critical organs from computed tomography. In: Farman AG, Ruprecht A, Gibbs SJ, Scarfe WC, eds. *Advances in Maxillofacial Imaging.* Amsterdam, Netherlands: Elsevier Science; 1997:401–406.
11. International Commission on Radiological Protection 60. 1990 *Recommendations of the International Commission on Radiological Protection. ICRP 60.* Oxford, England: Pergamon Press; 1991.
12. Block AJ, Goepp RA, Mason EW. Thyroid radiation dose during panoramic and cephalometric dental x-ray examinations. *Angle Orthod.* 1977;47:17–24.
13. Copley RL, Glaze SA, Bushong SC, West DC. Patient radiation dose in conventional and xerographic cephalography. *Am J Orthod.* 1979;76:505–510.
14. Bankvall G, Hakansson HAR. Radiation-absorbed doses and energy imparted from panoramic tomography, cephalometric radiography and occlusal film radiography in children. *Oral Surg Oral Med Oral Pathol.* 1982;53:532–540.
15. Eliasson S, Julin P, Richter S, Stenström B. Radiation absorbed doses in cephalography. *Swed Dent J.* 1984;8:21–27.
16. Ewen K, Lukoschek J. Somatisches Strahlenrisiko bei dentalen Röntgenuntersuchungen. *Dtsch Zahnärztl Z.* 1984;39:48–53.
17. Patsakas AJ, Donta CN, Tsiklakis KD. Determination of absorbed doses of radiation during lateral cephalometric radiography. *Greek J Oral Maxillofac Surg.* 1989;4:91–95.
18. Tyndall DA. Order of magnitude absorbed dose reductions in cephalometric radiography. *Health Phys.* 1989;56:533–538.
19. Tanimoto K, Ogawa M, Kodera Y, Tomita S, Wada T. A filter for use in lateral cephalography. *Oral Surg Oral Med Oral Pathol.* 1989;68:666–669.
20. Tsiklakis KD, Donta CN, Patsakas AJ. Determination of absorbed doses of radiation during posteroanterior cephalometric radiography. *Paidodontia.* 1990;4:27–31.
21. Gilda JE, Maillie HD. Dosimetry of absorbed radiation in radiographic cephalometry. *Oral Surg Oral Med Oral Pathol.* 1992; 73:638–643.
22. Freeman JP, Brand JW. Radiation doses of commonly used dental radiographic surveys. *Oral Surg Oral Med Oral Pathol.* 1994;77: 285–289.
23. Cox R, Muirhead CR, Stather JW, Edwards AA, Little MP, and the National Radiological Protection Board. Risk of radiation-induced cancer at low doses and low dose rates for radiation protection purposes. In: *Documents of the NRPB.* Vol 6. No. 1. National Radiological Protection Board, Chilton, Didcot, Oxon OX11 ORQ 1995.
24. White SC. 1992 assessment of radiation risk from dental radiography. *Dentomaxillofac Radiol.* 1992;21:118–126.
25. Hallquist A, Hardell L, Degerman A, Wingren G, Boquist L. Medical diagnostic and therapeutic ionizing radiation and the risk for thyroid cancer: a case-controlled study. *Eur J Cancer Prev.* 1994;3:259–267.
26. Preston-Martin S, White SC. Brain and salivary gland tumors related to prior dental radiography: implications for current practice. *J Am Dent Assoc.* 1990;120:151–158.
27. Klein BE, Klein R, Linton KL, Franke T. Diagnostic x-ray exposure and lens opacities: the Beaver Dam eye study. *Am J Public Health.* 1993;83:588–590.

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