Charge-Coupled Device Panoramic Radiography: Area Image Distortion Factors as Selected Image Layer Contours

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Summary

Objectives: *The aim of this study was to determine the distortion factor characteristics for selected image layer resolution contours of the Orthopantomograph OP 100® (Instrumentarium Imaging, Tuusula, Finland), combined with the DigiPan® (Trophy Radiologie, Vincennes, France) charge-coupled device receptor.*

Material and Methods: *Using a resolution grid positioned at intervals along empirically determined beam projection paths, the image layer contours produced with the DigiPan® modification of the Orthopantomograph OP 100® had previously been determined for resolution limits of 4.0, 3.0 and 1.5 lp mm^{-1}. An hexagonal test device was used to determine the magnification factors at the selected resolution limits and horizontal beam angulations using the resident measurement algorithm of the DigiPan® proprietary software. The horizontal and vertical magnifications were then used to determine the distortion factors at each resolution contour along selected beam angulations.*

Results: *At the image layer resolution contours of 4 lp mm^{-1} all area distortion factors approached unity. Furthermore, in the region bounded by these resolution contours the measurement algorithm compensated for the inherent magnification distortion artefact caused by the X-ray beam geometry. At 1.5 lp mm^{-1}, the area distortion factors ranged from 1.16 to 1.19 facially and 1.14 to 1.22 lingually to image layer contour of maximum resolution. The image layer contour of maximum spatial resolution was positioned lingually to the geometric center of the focal trough.*

Conclusion: *Using the DigiPan®, and the op 100® the distortion values conform of those previously found using conventional film/screen receptors. In the region of maximum resolution, the software measurement algotirhm effectively compensated for beam-projection magnification distortion.*

Key words: *digital image processing, distortion factor, measurement algorithm, panoramic radiology*

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Several digital panoramic radiography systems have been desinged during the last 12 years (Table 1. (1-16). These systems are based either on storage phosphor or on charge-coupled device (CCD) technology.

Table 1. *Digital panoramic radiography systems*

System	Ref.	Year	Manufacturer	Place
FCR®*	1-5	1985	Fuji Photo Co	Tokyo, Japan
McDAvid/Dove Prototype	6-10	1992	UTHSCSA Dental School	San Antonio Texas, USA
Arai Prototype	11	1992	Nihon University Dental School	Tokyo, Japan
Orthophos Digital®	12, 13	1995	Simens AG	Bensheim, Germany
DigiPan®	13	1996	Trophy Radiologie with Instrumentarium	Vincennes, France, and Tuusula, Finland
DXIS®	Proprietary literature	1996	Signet	St Maur des Fossés, France
Digital Panoramic®	13	1996	Planmeca	Helsinki, Finland
Digital AZ3000®	14	1996	Asahi Roentgen	Kyoto, Japan

Storage phosphors were first applied to panoramic dental radiography by Kashima et al. at Kanagawa Dental College, Japan (1-5). Utilizing storage phosphors the method is very similar to conventional panoramic radiography using X-ray file; i.e. a moving two-demensional detector is employed (10). The film is merely replaced by the storage phosphor plate.

Digital panoramic radiography can also be achieved by use of a narrow two-dimensional detector, such as the CCD array of the DigiPan® (Trophy Radiologie, Vincennes, France) receptor modification for the Instrumentarium Orthopantomograph OP 100® (Instrumentarium Imaging, Tuusula, Finland). In such system, the CCD detector is made to emulate conventional film-based image acquisition by controlling the movement of the charge carriers (10).

A preliminary overview of the DigiPan® system, including a description of the image layer resolution contours, has been reported elsewhere (17). The objective of the present study was to evaluate the DigiPan® modification in terms of the area distrotion factors at selected image layer contours of 4.0, 3.0 and 1.5 lp mm^{-1}. booth lingual and facial to the image layer contour of maximum spatial resolution.

Material and Methods

1. *The X-ray generator and detectors:* The Orthopantomograph OP 100® (Instrumentarium Imaging, Tuusula, Finland) is a software controlled high frequency dental panoramic X-ray machine operating at variable current (2-10 mA ± 1mA) and variable potential difference (57-85 ± 5 kVcp) with an exposure time of 17.6 ± 0.05 s for the standard panoramic imaging sequence. Total filtration is 2.5 mm Al equivalent. The X-ray tube has a nominal focal spot size of 0.5 mm (2). For film-based images photo timing is used. Photo timing is not applicable to the DigiPan® modification. However, three levels of spine shadow compensation area possible and "equalization" algorithm compensates for the tissue attenuation variability.

The DigiPan® conversion interchanges with the standard film cassette for the Orthopantomograph OP 100® (Figure 1). The CCD matrix is 1244 x 63

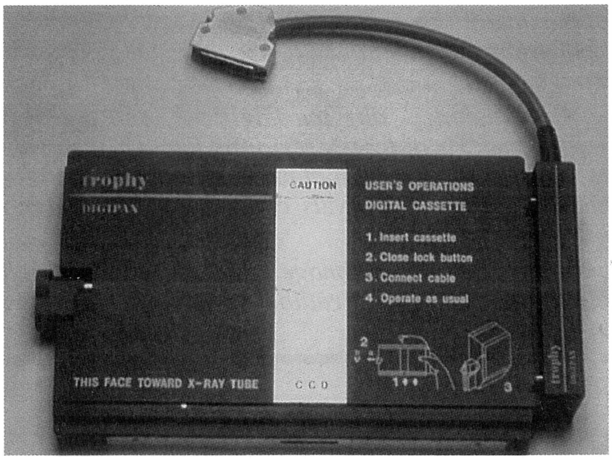

Figure 1. *The DigiPan® cassette. This is interchangeable with standard film cassette for the OP 100®. The active area is in the central region of the panel*

with pixel size of 104 μm x 104 μm and a sensitive area of 129.4 x 6.6 mm. The uncompressed image matrix is 2550 x 1244 over an area of 265 mm x 129 mm. The scintillator is separated from the CCD via a non-tapered fiber optic. Information concerning the scintillator type and its decay time is presently unavailable as the manufacturer holds this to be a trade secret. The acquisition is 10 bit, but storage is of an autocompensated 8 bit TIFF image. The image file size is 3 Mbyte (3,021,616 byte) without compression of 220 kbyte with Joint Photographers Expert Group (JPEG) compression. The image is displayed immediately upon acquisition forming continuously on the screen during exposure. The resident software permits zoom magnification up to times four. Distances on the image can be measured in additive segments permitting measurement along either straight or curved lines.

2. *Resolution and image layer contours:* The methods and results for determining the image layer contours for the DigiPan® appear in detail elsewhere (17). For image layer determination, digital images were made of a lead resolution grid, Kyokko No. 1 X-ray Grid (Kasei Optonix Co., Tokyo, Japan) positioned at fractional millimeters along the selected empirically-determined beam projection angulations. The method employed was similar to that described by Paibon and Manson-Hing (1985) and Martinez-Cruz and Manson-Hing (1987) (18,19)

3. *Magnification:* A hexagonal nut (7.82 mm vertically x 8.88 mm horizontally) was used as the test object to determine vertical and horizontal magnifications along each contour line of the mapped image layer. Measurements were made by the first author to two decimal places using the measurement algorithm of the resident software. All readings were made 20 times then averaged and the standard deviation determined in each case. Magnification factors for the horizontal and vertical dimensions were then determined at each pre-determined resolution contour.

4. *Distortion:* A comparison between the magnification in the vertical and horizontal axes was made after the method of Sämfors and Welander, using the ratio of horizontal to vertical magnifications (20). This ratio was used as the index of area image distortion.

Results

1. *Image magnification*

(a) Horizontal: Figure 2 graphically details the horizontal magnifications effective for the 1.5 lp mm^{-1}, 3.0 lp mm^{-1} and 4 lp mm^{-1} resolution image

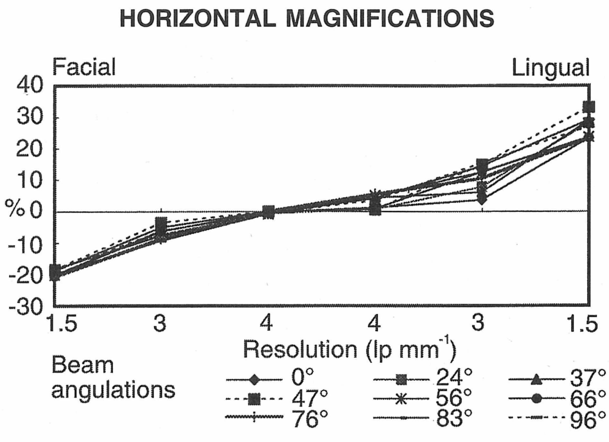

Figure 2. *Horizontal magnification (%) for selected image layer contours at selected horizontal beam projection angulations using DigiPan®*

layer contours of the focal trough. At the 1.5 lp mm^{-1} resolution limits, the calculated horizontal magnifications were -19% facial and +23% lingual to the image layer of maximum resolution in the anterior midline (0° horizontal angulation), -19% facial and +28% lingual to the image layer of maximum resolution in the lateral incisor region (24° horizontal angulation), -19% facial and +29% lingual to the image layer of maximum resolution in the canine region (37° horizontal angulation), -19% facial and +33.1% lingual to the image layer of maximum resolution in the first premolar region (47° horizontal angulation), -20% facial and +24% lingual to the image layer of maximum resolution in the second premolar region (56° horizontal angulation), -21% facial and +24% lingual to the image layer of maximum resolution in the first molar region (66° horizontal angulation), -21% facial and +23% lingual to the image layer of maximum resolution in the second molar region (76° horizontal angulation), -20%facial and +29% lingual to the image layer of maximum resolution in the third molar region (83° horizontal angulation), and -19% facial and +27% lingual o the image layer of maximum resolution in the temporomandibular region (96° horizontal angulation).

At 4 lp mm^{-1}, midline horizontal magnification was -3% facial and +1.1% lingual to the image layer of maximum resolution, -0.7% facial and +0.56% lingual to the image layer of maximum resolution in the lateral incisor region (24° horizontal angulation), 0% facial and +4% lingual to the image layer of maximum resolution in the canine region (37° horizontal angulation), 0% facial and +0.6% lingual to the image layer of maximum resolution in the first premolar region (47° horizontal angulation), -0.9% facial and +5% lingual to the image layer of maximum resolution in the second premolar region (56° horizontal angulation), 0% facial and +0.8% lingual to the image layer of maximum resolution in the first molar region (66° horizontal angulation), 0% facial and +5% lingual to image layer of maximum resolution in the second molar region (76° horizontal angulation), -0.9% facial and +4% lingual to the image layer of maximum resolution in the third molar region (83° horizontal angulation), and -0.7% facial and +3.4% lingual to the layer of maximum resolution in the temporomandibular region (96° horizontal angulation).

(b) Vertical: For each of the resolution contours and beam angulations studied, the determined vertical magnifications were consistently low when compared with their horizontal magnification counterparts. The greatest vertical magnifications were found at 1.5 lp mm^{-1} lingual to the image layer of maximum resolution in the temporomandibular joint region (9%) and in the premolar region (8%). Mean vertical magnification measurements are displayed in Figure 3 for the studied image layer contours at the selected horizontal beam projection angulations.

2. *Distortion:* Table 2 lists the distortion factors at selected horizontal beam projection angulations. These are graphically desplayed in Figure 4. The distortion factors at 4 lp mm^{-1}, for the midline were 0.99-1.00 facial and 0.98-1.02 lingual to the image layer of maximum resolution. At 3 lp mm^{-1}, the distortion factors were 1.02-1.08 facial and 1.00--1.12 lingual to the image layer of maximum resolution. At 1.5 lp mm^{-1}, the distortion factors were 1.16-1.19 facial and 1.14-1.22 lingual to the image layer of maximum resolution. The distortion factors at 4 lp mm^{-1} approximated unity (i.e. little distortion was evident).

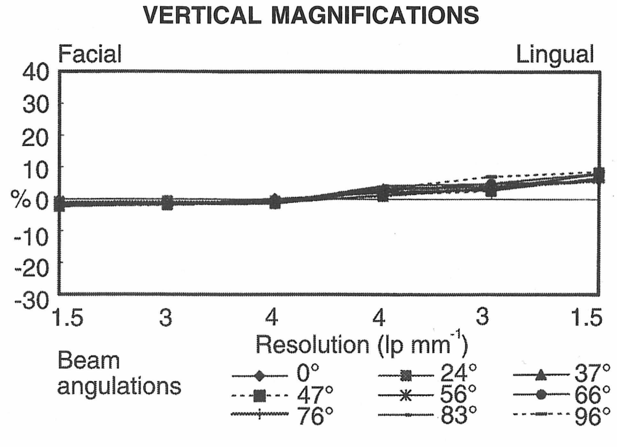

Figure 3 . *Vertical magnification (%) for selected image layer contours at selected horizontal beam projection angulations using DigiPan®*

Table 2. *Distortion factors*

Beam angulation	Resolution (facial) lp mm^{-1}			Resolution (lingual) lp mm^{-1}		
	1.5	3.0	4.0	1.5	3.0	4.0
0° (central incisior)	1.16	1.06	1.00	0.99	1.00	1.16
24° (lateral incisior)	1.17	1.06	1.00	0.98	1.04	1.20
37° (canine)	1.17	1.04	0.99	1.03	1.03	1.20
47° (first premolar)	1.16	1.02	0.99	0.99	1.12	1.22
56° (second premolar)	1.18	1.05	1.00	1.03	1.07	1.16
66° (first molar)	1.17	1.04	0.98	0.98	1.07	1.16
76° (second molar)	1.19	1.07	0.99	1.02	1.06	1.17
83° (third molar)	1.18	1.08	0.99	1.00	1.06	1.22
96° (TMJ)	1.17	1.04	1.00	1.00	1.07	1.17

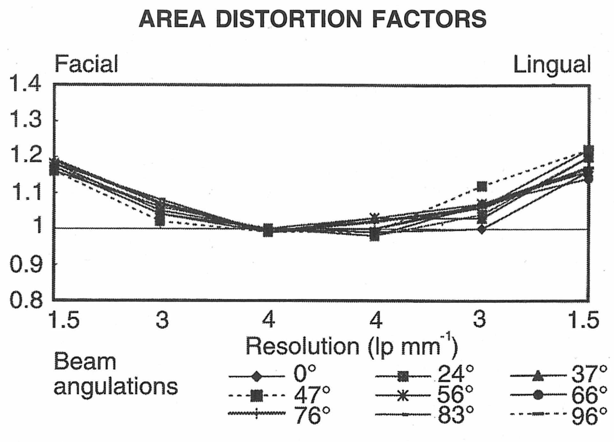

Figure 4. *Area distortion factors for selected image layer contours at selected horizontal beam projection angulations using DigiPan®*

Discussion

CCD-based intraoral radiography systems have been criticized for having a poorer spatial resolution than film (21,22). For film-based panoramic radiography, the spatial resolution does not exceed 5 lp mm^{-1} and the contour of the acceptable range of unsharpness is usually selected as approximately 1.5 lp mm^{-1} (19). Hence, spatial resolution requirements are not so demanding for panoramic radiology as they are for intraoral radiography where spatial resolution with direct-exposure emulsion film can reach as high as 16 lp mm^{-1} (23).

The image layer of maximum resolution can be estimated for the DigiPan® by interpolation from the locations of the 4 lp mm^{-1} image contours with respect to the 1.5 lp mm^{-1} image contours. Is should be noted that along this interpolated line (Figure 5) the distortion factor theoretically should equal unity. With the DigiPan® software, objects situated within the 4 lp mm^{-1} image contours were indeed represented very closely to their exact dimensions.

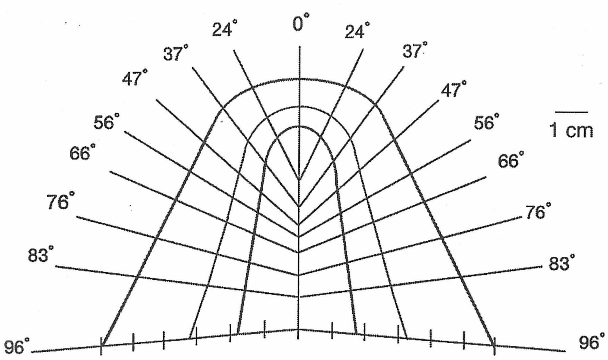

Figure 5. *Interpolated position of the image layer of minimum distortion within the DigiPan® focal trough. Note that this is not in the center of the focal trough; it is lingually situated within the focal trough*

Razmus et al. (1989) discovered that the focal trough dimensions and locations were inconsistent among the same type of panoramic machine when they inspected units from four different manufacturers (24). They suggested the need for better quality assurance in the production process. McDavid et al. (1989) described a method to overcome these dificiencies by maintaining a constant magnification factor throughout the exposure of rotational panoramic radiographs (25). For the DigiPan® system this is acheivelable either with the computer controlled movement of the OP 100® or by customizing the image acquisition and display software.

For panoramic radiography, magnification factor variation in the vertical dimension is usually minor (26,27). With film-based imaging, an error in the vicinity of 10% can be expected; however with the DigiPan®, the software measurement algorithm factored the innate distortion and produced an accurate reflection of the vertical height of the test object. While vertical measurements are reliable within certain limits, horizontal measurements may be highly distorted using conventional panoramic radiographic receptors (28,29).

Measurement accuracy for a number of different panoramic machine has been carried out using conventional film/screen receptors (26,30-35). Area distortion was determined for the selected image layer contours during the present study. However, the effects of spatial resolution combined with distortion factors were not examined. Future studies are needed to address angular and form distortions (36,37). While these can be extrapolated from the area distortions for the various image contours provided in this paper, three certainly is room for more empirical studies similar to those made earlier with conventional film-screen receptors (30-35). Providing an accurate measurement algorithm for digital panoramic systems could prove a difficult task in view of the distortions that are implicit from panoramic radiographic theory.

Differences in the measured magnification for image layer contours determined, using the DigiPan® and those previously reported for the OP 100® with conventional receptors, can largely be attributed to the method employed. Scarfe et al. (38) used direct measurement on film images whereas the present study relied on the proprietary measurement algorithm provided by Trophy Radiologie. It is apparent from the near absence of magnification in the image layer contours of greatest resolution that the software algorithm provided with the DigiPan® accurately compensates for beam projection magnification effects inherent in all radiographic techniques.

Conclusions

The OP 100 DigiPan® distortion factors and image layer contours conform to those produced using standard film-screen combinations. The image layer contour of maximum resolution is lingual to the geometric center of the focal trough. In this site the provided measurement algorithm compensates well for all innate image distortion.

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