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Effect of border sharpness on the size and position of the focal trough of panoramic x-ray machines

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A resolution test pattern was used to determine the size, position, and centers of the focal troughs of four panoramic x-ray machines. The focal troughs were located at slightly different positions for each machine. The center of each focal trough produced varying degrees of sharpness. The average widths of the focal troughs were not greatly different between machines.

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In panoramic radiography, the dentofacial region of the human head is recorded on a single large flat film. The objective is to obtain a continuous image of the teeth and associated structures on one film. The sharp image recorded on the film is of a vertical plane in the patient's head that is scanned by the x-ray beam at the same speed as the film passes through the beam. Objects located medially and laterally away from the sharpest plane appear less sharp because of the tomographic effect of the moving x-ray beam. Objects a short distance from the sharpest plane can be identified by the diagnostician, and the area in which objects can be identified is called the focal trough or zone of sharpness. The borders of the focal trough are situated around the sharpest plane.

In order to outline the focal troughs of panoramic x-ray machines, a degree of sharpness must be established for the border between unsharp and sharp areas. Previous studies used steel pins, steel balls, and brass screws to produce images that were evaluated subjectively or microdensitometrically to establish the degree of sharpness used to outline the border of the focal trough. These studies showed that there were different-sized focal troughs for similar machines because of the different degrees of sharpness used to establish the focal trough border. Pifer[1] and Hassen[2] used resolution to establish a standardized area of sharpness. Resolution is the ability to identify the borders of images of objects separated by a small distance.

The position of the focal trough can be identified as the center of the zone of sharpness or the location of the sharpest plane. The position of the sharpest plane within the focal trough is determined by the film velocity through the x-ray beam and may not be at the center of the focal trough. Points lingual and buccal to the sharpest plane lose sharpness as they get farther from the plane because of the tomographic effect, with the lingually positioned points losing more sharpness than buccal points that are an equal distance from the sharpest plane. The difference is due to lingual points being farther from the film and

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closer to the x-ray source than poings buccal to the sharpest plane; thus, lingual points lose more sharpness as a result of geometric unsharpness produced by the focal spot of the x-ray tube.

Clinically, it is useful to use the center of the zone of sharpness to locate the position of the focal trough since the operator usually tries to position objects to be radiographed in the center of the trough. Because the lingual and buccal borders of the zone may not move from the sharpest plane evenly when the zones are determined with different levels of resolution or sharpness, there may not be a single center for zones delineated with different resolution levels.

The purpose of this study was to describe and compare the size, position, and centers of the focal troughs of the Panelipse,* Panoral,† Orthopantomograph-5,‡ and Panorex-1§ x-ray machines at different degrees of resolution.

MATERIALS AND METHODS

The focal troughs of panoramic x-ray machines were determined by a standard resolution test pattern.‖ This pattern consisted of lead strips 50 μ thick in the form of parallel lines encased in Plexiglas. The lead strips alternate with spaces of equal dimension to form line pairs (Lp). There are twenty two line pair groups, with each group consisting of four line pairs of equal dimension. The resolution range, in line pairs per millimeter (Lp/mm), is 0.25 to 10. The groups have an approximate gradation of 1.9 Lp/mm. A standard film density of 1.5 above base and fog was a requirement for use of the test device. Since the intensity of the beam is very excessive for the thin test pattern and the machines cannot adjust the radiation exposure time, filters of copper and aluminum were used for exposure control.

The four panoramic x-ray machines selected for the study were (1) the Panelipse, (2) the Panoral, (3) the Orthopantomograph-5, and (4) the Panorex-1. The line pair groups used in this study were (1) 1.2 Lp/mm, (2) 1.7 Lp/mm, (3) 2.0 Lp/mm, (4) 2.4 Lp/mm, and (5) 2.9 Lp/mm. A parabolic Plexiglas plate and individual machine mounts were used to retain the resolution test pattern in a position comparable to the location of the occlusal plane of the patient in each machine. The plate and the mounted test pattern are shown in Fig. 1. Nine lines formed by small holes were located at the condyle, midramus, third molar, first molar, midpremolar, cuspid, lateral incisor, central incisor, and anterior midline of the patient. One contralateral line at the first molar was used for a comparison test to determine focal trough symmetry. The locations of the nine lines were based on a previous tooth-position study by Lund and Manson-Hing.[3] The holes in the Plexiglas were drilled at a distance of 1.5 mm from each other and were used to position the test pattern and locate the size and position of focal troughs of each machine. The direction of the lines on the Plexiglas was in the average direction of the x-ray beams of the four machines. A pretest showed that the direction of the beams of these panoramic machines at similar points on the dental arch varied and that the maximum deviation between x-ray beams was not more than 17°. Pifer[1] had shown that radiographic resolution is not affected when the angular approach of the x-ray beam to the test pattern is varied up to 45°.

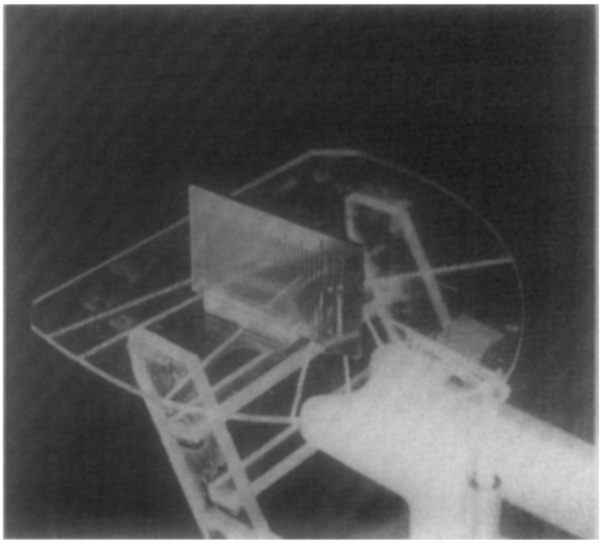

Fig. 1. The Plexiglas plate with the mounted test pattern placed in the patient occlusal plane position.

The test pattern was exposed at each hole on each line, beginning with the outermost buccal position and moving toward the lingual side until changes in resolution from obvious unresolved to obvious resolved and vice versa were obtained. Three to four radiographs were needed to locate each point where the borders of focal troughs crossed the lines on the Plexiglas plate. A total of 1,300 radiographs were obtained. The radiographs were coded, grouped by machine and Lp/mm parameter used, randomized for each group, and viewed by four interpreters.

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†Ritter Co., Rochester, N.Y.
‡Siemens Corporation, Iselin, N.J.
§Pennwalt Corporation, Philadelphia, Pa.
‖Resolution plate: model 07-553, Nuclear Associates, Inc., Westburg, N.Y.

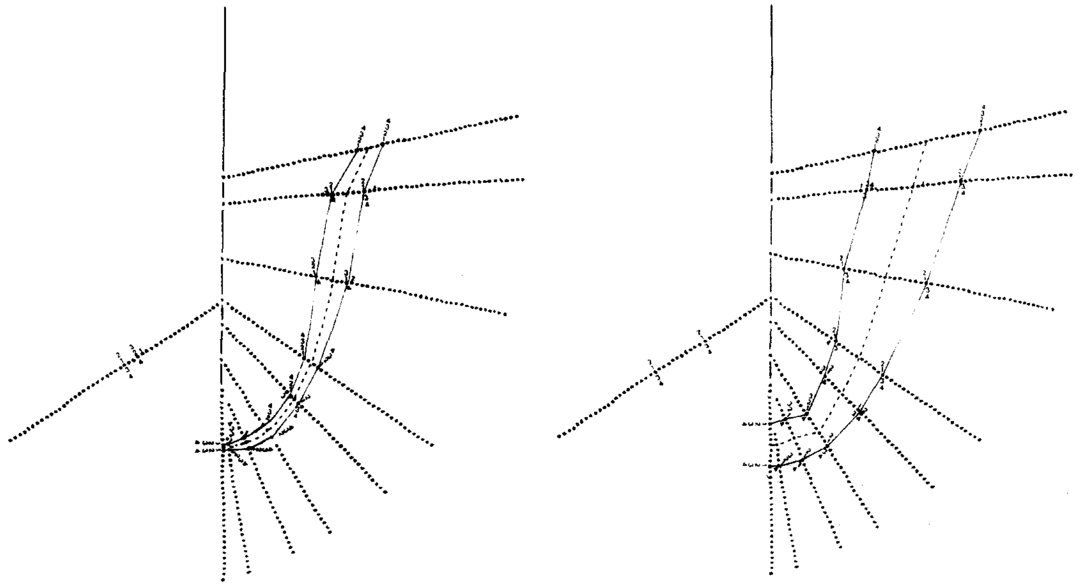

Fig. 2. Orthopantomograph-5 observer graph showing the size, configuration, and center of the focal trough for 2.9 Lp/mm *(left)* and 1.2 Lp/mm *(right)* resolution. The specific border sharpness hole in the Plexiglas plate identified of each of the four observers is shown by the numbers *1, 2, 3,* and *4.*

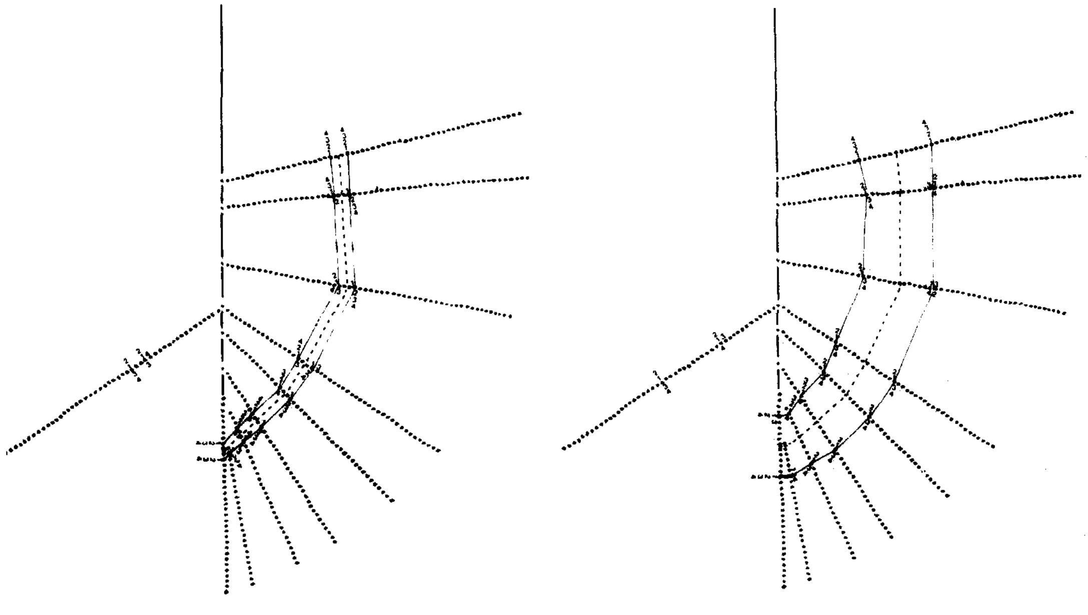

Fig. 3. Panorex observer graph showing the size, configuration, and center of the focal trough for 2.9 Lp/mm *(left)* and 1.2 Lp/mm *(right)* resolution. The specific border sharpness hole in the Plexiglas plate identified by each of the four observers is shown by the numbers *1, 2, 3,* and *4.*

Interpretation was completed in a room with reduced illumination.

The results obtained from the four interpreters were translated into graphs. The focal trough of each machine at each Lp/mm was plotted to scale.

The graphs for two machines made at two different Lp/mm resolutions are shown in Figs. 2 and 3. The centers of the focal troughs were identified at the midpoint between the lingual and buccal borders at each line.

RESULTS AND DISCUSSION

The data from four interpreters were collated for the four machines and five different line pairs per millimeter. The graphs showed that variation in sharpness zone size and configuration among observ-

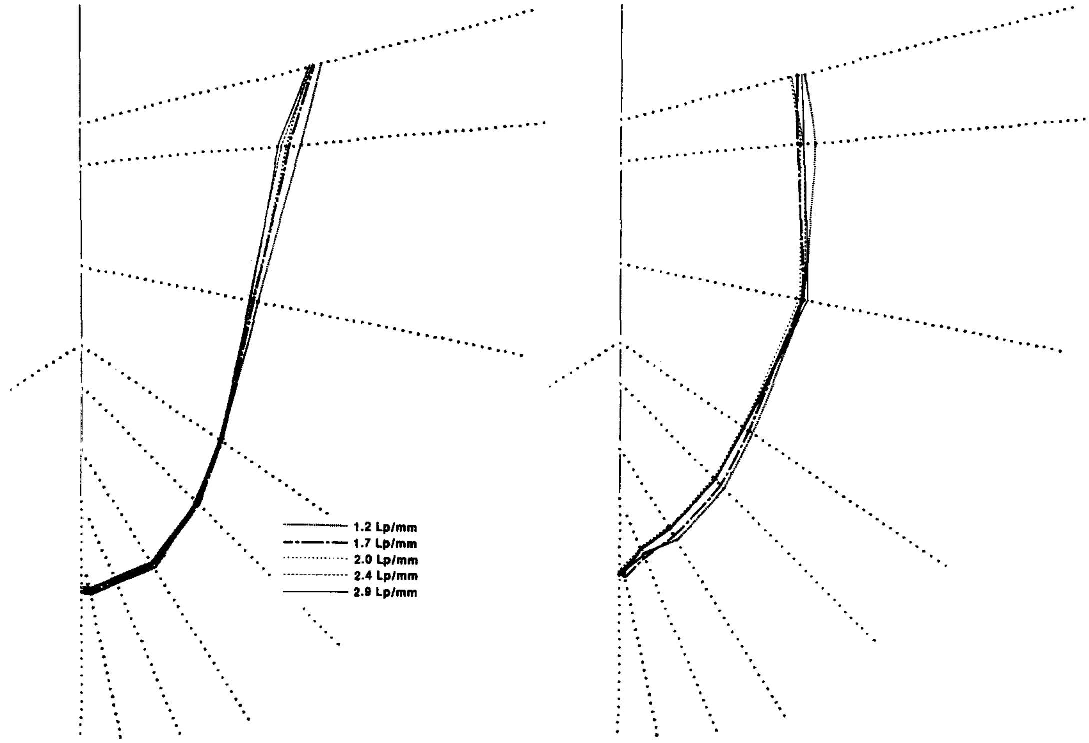

Fig. 4. The position of the centers of the focal troughs made with five different line pair per millimeter resolutions in the Orthopantomograph-5 *(left)* and Panorex-1 *(right)*.

Table I. Width of the Panelipse focal troughs at each line position and line pair per millimeter

Line position	*1.2 Lp/mm (mm)*	*1.7 Lp/mm (mm)*	*2.0 Lp/mm (mm)*	*2.4 Lp/mm (mm)*	*2.9 Lp/mm (mm)*
Midline	10.5	7.5	4.5	4.5	1.5
Central incisor	9.0	6.0	3.2	3.1	1.5
Lateral incisor	9.0	6.0	4.5	3.0	1.5
Cuspid	10.6	6.1	6.0	3.0	1.5
Premolar	12.1	10.5	7.6	6.1	3.0
First molar	15.0	12.0	12.0	9.0	4.5
Third molar	19.5	16.6	15.2	12.1	5.25
Midramus	21.85	19.6	17.25	13.5	7.6
Condyle	27.0	22.5	19.5	15.0	9.0
Totals	134.55	106.8	89.75	69.3	35.35
Average of all lines	14.95	11.87	9.97	7.7	3.93

ers was small. There were 400 places where the borders of the focal troughs intersected with the lines of holes. In 298 intersections all four interpreters had the same reading. The maximum difference between the four observers at any intersection was not more than two holes; thus, there was little observer variation in identification of the intersections of the line holes with the borders of the focal troughs. The maximum was 3 mm, or one hole more or less than two matching interpreters; this variation is the same as measured by Hassen.[2] The position of the contralateral responses for all line pairs per millimeter and four machines did not vary from the opposite side by more than 3 mm. Other investigators[1, 2, 4] also found a slight asymmetry between the left and right sides in panoramic machines.

The width of the focal troughs varied with different line pairs per millimeter in different machines and in different areas of the same machine. The widths of the focal troughs of the four machines at each line position of the Plexiglas plate and line pair per mm sharpness are shown in Tables I to IV.

Table II. Width of the Panoral focal troughs at each line position and line pair per millimeter

Line position	*1.2 Lp/mm (mm)*	*1.7 Lp/mm (mm)*	*2.0 Lp/mm (mm)*	*2.4 Lp/mm (mm)*	*2.9 Lp/mm (mm)*
Midline	6.0	4.5	3.0	0.5	0.5
Central incisor	6.0	4.5	3.0	0.5	0.5
Lateral incisor	9.0	6.0	4.5	1.5	0.5
Cuspid	7.6	6.0	4.5	1.5	1.5
Premolar	16.6	10.6	8.25	6.75	3.0
First molar	19.5	13.5	9.0	6.0	4.5
Third molar	26.25	15.1	9.1	6.1	4.5
Mid ramus	38.9	24.75	18.0	13.6	9.1
Condyle	33.0	22.5	12.0	7.5	3.0
Totals	162.85	107.45	71.35	43.95	27.1
Average of all lines	18.09	11.94	7.93	4.88	3.01

Table III. Width of the Orthopantomograph-5 focal troughs at each line position and line pair per millimeter

Line position	*1.2 Lp/mm (mm)*	*1.7 Lp/mm (mm)*	*2.0 Lp/mm (mm)*	*2.4 Lp/mm (mm)*	*2.9 Lp/mm (mm)*
Midline	12.0	9.0	6.0	4.5	1.5
Central incisor	12.0	9.0	4.5	4.5	1.5
Lateral incisor	12.0	9.0	6.0	3.0	3.0
Cuspid	10.5	9.1	6.1	6.0	3.0
Premolar	14.35	12.1	9.1	6.0	3.0
First molar	16.6	13.5	10.5	7.5	4.5
Third molar	24.0	19.6	12.75	12.1	9.1
Mid ramus	27.0	21.75	18.1	13.5	9.1
Condyle	30.0	21.0	16.5	14.25	7.5
Totals	158.45	124.05	89.55	71.35	42.2
Average of all lines	17.61	13.78	9.95	7.93	4.69

Table IV. Width of the Panorex-1 focal troughs at each line position and line pair per millimeter

Line position	*1.2 Lp/mm (mm)*	*1.7 Lp/mm (mm)*	*2.0 Lp/mm (mm)*	*2.4 Lp/mm (mm)*	*2.9 Lp/mm (mm)*
Midline	16.4	15.0	9.0	7.5	4.5
Central incisor	16.5	12.75	10.4	7.5	4.5
Lateral incisor	15.0	12.75	9.75	6.75	4.5
Cuspid	18.0	13.5	10.5	7.5	4.5
Premolar	18.0	13.5	10.4	7.6	4.5
First molar	19.5	15.0	10.5	7.5	4.6
Third molar	20.25	16.4	13.5	9.1	4.6
Mid ramus	19.4	14.25	11.25	7.6	4.5
Condyle	21.0	15.0	10.5	7.5	4.5
Totals	164.05	128.15	95.8	68.55	40.7
Average of all lines	18.23	14.24	10.64	7.62	4.52

The tables also show the average width of each trough.

The anterior and posterior widths of the focal troughs of the continuous-image machines are different from split-image machines, with the anterior region being much narrower. This finding agrees with previous investigators.[1-8] The Panorex-1 demonstrated the widest and the Panoral the narrowest focal trough in the anterior region. The Orthopantomograph-5 yielded the widest and Panorex-1 the narrowest focal trough in the posterior region. The widths of the focal troughs increased more than 400% when border sharpness was decreased from 2.9 Lp/mm to 1.2 Lp/mm. However, the machines showed relatively similar average trough widths when compared for all troughs.

The positions of the focal troughs can be located by their borders or by their centers. The centers of each machine produced with the five different degrees of sharpness were plotted on graphs. Examples of two of the graphs are shown in Fig. 4. The centers made with greater degrees of sharpness were positioned more lingually. However, the center did not always shift consistently to the buccal as the sharpness used in delineating the focal trough was decreased. This may be due to machine variation between x-ray exposure cycles or to observer variability in interpretation of the radiographs. However, the data show that observer variability was very small. The most consistent shift observed at all line holes was produced by the Orthopantomograph-5 and the least consistent by the Panorex. The inconsistency in the Panorex is probably due to the chair shift, which moves the head positioner with the plastic platform between x-ray exposure cycles. In the other machines the head-positioner movement does not occur. The great consistency of shift in the focal trough center with border sharpness seen in the Orthopantomograph-5 may be due to the fact that this machine is manufactured to expose the film in only one direction while the other three machines expose the film from both directions.

The least distance that the center moved was 0 mm and the greatest distance was 4.5 mm. The distances that the center moved in the anterior cuspid-to-central-incisor region averaged 1.23 mm for the Panelipse, 1.23 mm for the Panoral, 0.56 mm for the Orthopantomograph-5, and 1.69 mm for the Panorex-1. The distance that the center moved in the posterior premolar-to-condyle region averaged 2.95 mm for the Panelipse, 2.55 mm for the Panoral, 1.8 mm for the Orthopantomograph-5, and 2.1 mm for the Panorex-1. In the anterior region of the continuous-image machines the position of the center is basically the same. This was due to the inconsistency in the shift of the trough center and the narrowness of the sharpness zone in the anterior region of these machines. In the posterior region of the machines the center shifted 2 to 3 mm. Clinically, this amount of shift would not appreciably affect an operator's placement of the patient's posterior teeth in the machine for diagnostic radiographs. If critical measurements are attempted, however, the lateral shift can affect the size of the object imaged on the film. In the Panorex-1 the shift in the center of the trough was only slightly less in the anterior than in the posterior region of the trough. This is because the focal trough is relatively wide in both the anterior and the posterior areas.

The buccal shift of the focal trough center with decreasing border sharpness indicates that when a machine's focal trough center is located and the operator attempts to place the object being radiographed in the center, any buccolingual error in object placement will show greater sharpness loss with lingual errors than with buccal errors.

CONCLUSIONS

1. The identification of focal trough border points by interpreters did not vary more than 3 mm and was identical in 298 out of 400 points.
2. The focal troughs of the Panorex-1, Panelipse, Panoral, and Orthopantomograph-5 machines are located at slightly different positions.
3. The Panorex-1 demonstrated the widest and the Panoral the narrowest focal trough in the anterior region.
4. The Orthopantomograph-5 yielded the widest and Panorex-1 the narrowest focal trough in the posterior region.
5. The widths of the focal troughs increased more than 400% when border sharpness was decreased from 2.9 Lp/mm to 1.2 Lp/mm.
6. The average widths of the focal troughs are not greatly different between machines, with the Panoral machine having the smallest and the Panorex the largest troughs.
7. The centers of the focal troughs move bucally with decreasing border sharpness.
8. The consistency of buccal movement of the trough center with decreasing border sharpness was greatest in the Orthopantomograph-5 and least in the Panorex-1.
9. The centers of the focal troughs produced with varying degrees of sharpness are essentially located in the same position in the anterior region of the Panelipse, Panoral, and Orthopantomograph-5. The center of focal troughs produced with 1.2 Lp/mm to 2.9 Lp/mm resolution are located 2 to 3 mm from each other in the posterior region.
10. The placement of teeth in trough centers determined with different degrees of border sharpness is not of great significance in radiographs made for general diagnostic purposes.
11. Operator errors in object placement will show greater sharpness loss with lingual placement errors than with buccal placement errors.

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