

Distortions in panoramic radiographs

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This study was designed to investigate the factors affecting linear distortion in orthopantomography. A test model was constructed with metallic rods positioned to simulate maxillary teeth from the first permanent molar to the lateral incisor. In addition to examining the effects of varying the tilts of the test rods in a mesio-distal or bucco-palatal direction, spatial position changes (sagittal displacement, transverse displacement and horizontal rotation) of the test model were evaluated by determining the magnification changes in the width and length of the test rods. Results showed that significant errors occurred with all variations in magnification when test rods were inclined bucco-palately ($p < 0.001$) at or exceeding 5 degrees relative to the true perpendicular, and for spatial positioning errors ($p < 0.05$) at or exceeding ± 5 degrees and ± 5 mm. Bucco-palately inclined objects in the lateral incisor-canine region were particularly susceptible to large changes in horizontal magnification. Linear measurements and clinical assessments from panoramic radiographs should therefore be undertaken cautiously. To minimise errors in orthopantomography, it is important to position the patient in the focal trough precisely according to the manufacturer's specification. Aust Orthod J 2002; 18 : 92–8

Introduction

Orthopantomography is often used to evaluate the status and relationships of various dental and skeletal structures. Occasionally, dimensional measurements may be required from an orthopantomogram (OPG) for diagnostic and treatment planning purposes. Unfortunately, orthopantomographic images suffer from a variable degree of distortion, even though the OPG overcomes the limitations of bitewing and periapical radiographs in the overall coverage of the orofacial structures.

Distortion of images in orthopantomography arises primarily from the combined effects of different magnification factors in the horizontal and vertical planes at different positions and depths within the image layer.^{1–7} The degree of distortion is dependent on the distance of the object from the central plane of the image layer. It is reported that the most common contributing factor for image distortion in an OPG is poor patient positioning.^{8–12} This is exacerbated by a focal trough that is limited in dimension, particularly in the anterior region.¹³ Errors in positioning distort OPGs through unequal vertical and horizontal magnification.

The aim of this study was to determine the effects of varying the tooth angulations (mesio-distal and bucco-palatal) and the spatial positions of the object (sagittal displacement, transverse displacement and horizontal rotation) on linear distortion in orthopantomography. Understanding how linear projection errors occur is essential to the critical appraisal of OPGs.

Materials and methods

In this study, a Frasaco model AG-3 (Franz Sachs & Co., Tettrang, Germany) provided the maxillary arch form. Most previous research on this topic

has not included the central incisors and to reduce the complexity of the present research method, the central incisor region was excluded as well as the second and third molars. The maxillary model was photocopied onto a clear transparent film. The location and orientation of each tooth on the model was transferred to the copy using a fine black marker pen. Each tooth location was recorded as the mid-point of the line drawn between the mesial and distal contact points.

Fabrication of the maxillary test model used an acrylic platform of dimensions 85 mm x 55 mm x 12 mm. Ten vertical holes, each 8 mm deep, were drilled into the acrylic block using a 1.85 mm high speed steel twist drill on a workshop drill press. These vertical holes allowed the test rods to be inserted in the same positions as those occupied by the teeth of the Frasco model. A black acetyl resin bar was mounted on the front end of the acrylic platform such that the test object could be positioned into the bite-block holder of the panoramic machine in a repeatable fashion. The length and position of the acetyl bar was determined using the manufacturer's bite block, which serves as a guide to optimum positioning of the patient's teeth in relation to the focal trough.

Using 0.08 mm thick double-sided adhesive tape, the template was fixed to the top surface of the acrylic platform that corresponded to the level of the occlusal plane. When the test object was mounted on the bite-block holder of the panoramic machine, the occlusal plane was parallel to the true horizontal plane. To simulate the roots of teeth on the test model, stainless steel rods, each 1.85 mm in diameter and 35 mm long, were used. Three sets of ten test rods were prepared: the first with no angulation, the second with a 5-degree tilt and the third with a 10-degree tilt. The angulations were verified at 10 x magnification on a shadowgraph (Nikon Model 6C, Nippon).

An OrthOralix panoramic X-ray machine (OrthOralix DC Ceph, NV Philips Gloeilampenfabrieken, Eindhoven, Holland) was used to obtain the OPGs. The machine was calibrated by a representative of the manufacturer prior to the commencement of this study. The optimal position of the test object in the focal trough was established using the horizontal and vertical light beam-positioning system, which indicated the positions of the Frankfort plane and the maxillary canine respectively. The lowest voltage setting of 62 kV at 13 mA was selected, with a 13-second exposure time. In addition, four lead sheets, each 0.20 mm thick, were used as filters to reduce the intensity of the X-ray beam.

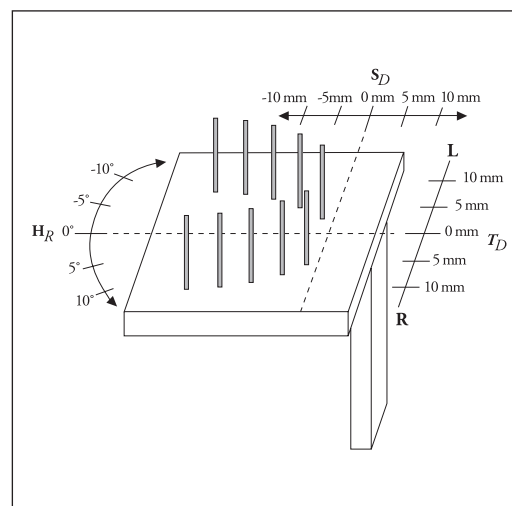


Figure 1. Three-dimensional schematic representation illustrating the three positioning parameters using a maxillary test object with untitled test rods: S_D = Sagittal (antero-posterior) displacement; T_D = Transverse (left-right) displacement from mid-sagittal plane; H_R = Horizontal (left-right) rotation from mid-sagittal plane. (Note that the arrows point in the direction of displacement.)

Six OPGs were obtained for each treatment variable. All films (Fuji Super HR-G30, Fuji Photo Film Co., Tokyo, Japan) were processed in an automatic film processor. The same investigator (DY) performed measurements on all OPGs. Measurements were made directly from the radiographs in a darkened room on a radiographic lightbox under an illuminating magnifying glass. An electronic digital caliper (Max-Cal, Japan Micrometer MFG, Osaka, Japan) was used to measure linear distances to the nearest 0.01 mm.

Magnification of the width and length of the test rods was first determined at 0 degree tilt with the platform at the optimum position. Portions of the rods embedded in the acrylic were not measured because they were below the surface of the platform (equivalent to the occlusal plane). These values were used as the basis for comparison of the changes occurring with variations in mesial tilt (5 degrees, 10 degrees), distal tilt (5 degrees, 10 degrees), buccal tilt (5 degrees, 10 degrees), palatal tilt (5 degrees, 10 degrees), sagittal displacement (no tilt), transverse displacement (no tilt), and horizontal rotation (no tilt) of the platform. The known length of the embedded section of each tilted rod was 8 mm, determined by the depth of the hole provided. The radiographic length of the embedded section is simply determined from the magnification factor for the length of each rod at each tooth position.

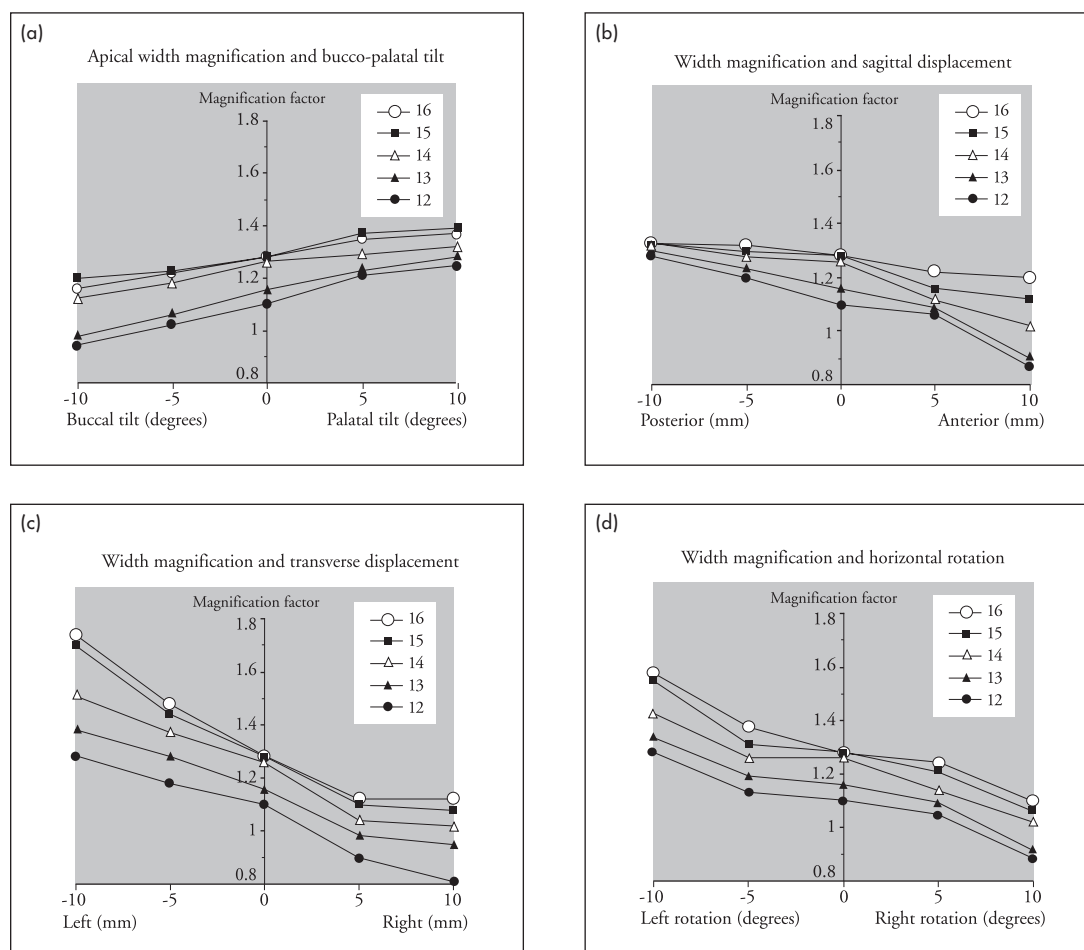


Figure 2. Line graphs showing the width magnification of test rods as a function of the following independent variables: (a) Bucco-palatal tilt (b) Sagittal displacement (c) Transverse displacement (d) Horizontal rotation.

The spatial positioning variables are illustrated in Figure 1. Sagittal displacements were executed by turning the designated knob on the panoramic machine for adjusting the antero-posterior position of the bite block from -10 mm to +10 mm. Transverse displacements were achieved by repositioning the acrylic platform on the acetyl bar at the required position from 10 mm left to 10 mm right. A protractor with 1 degree precision was fixed to the front of the test object to define horizontal rotation angles and exposures made from -10 degrees to +10 degrees.

Reproducibility of positioning method

Using wires at 0 degree tilt, the test object was removed from the positioner and repositioned by the same operator (DY) six weeks later, taking one exposure at each of the 13 positions under the same conditions. The reproducibility of the

positioning method was determined by comparing the complete measurements of the first set of radiographs with the second set of radiographs, and analysing with a two-tailed paired *t*-test. Results showed that the mean difference was not significant ($p > 0.05$) at all object positions.

Error of measurements

The same investigator (DY) repeated complete measurements on 60 randomly selected OPGs one month after initial measurements. Using the method of Dahlberg for duplicate determinations, the measurement error for determining the radiographic width was 0.12 mm. Average difference between the first and second measurements was tested with a paired *t*-test, and a correlation analysis between the two readings was done. Paired *t*-test results showed no significant difference ($p > 0.05$) between the first and second measure-

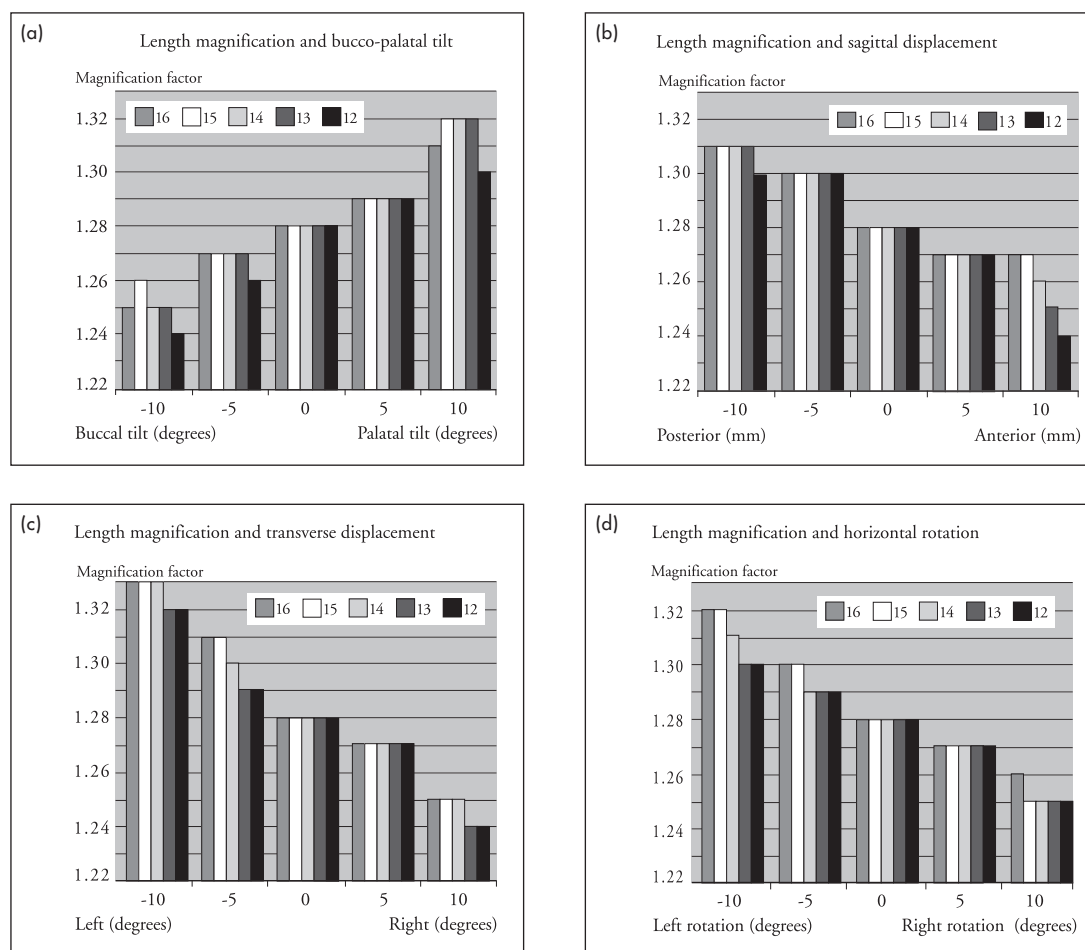


Figure 3. Graphs showing the length magnification of test rods as a function of the following independent variables: (a) Bucco-palatal tilt (b) Sagittal displacement (c) Transverse displacement (d) Horizontal rotation.

ments. With values in excess of 0.9, correlation analysis indicated that there was good reproducibility of measurements.

Statistical analysis

Descriptive statistics (mean, standard deviation) were obtained for the horizontal and vertical magnification factors of each test rod. Paired *t*-tests were conducted between magnification factors of each test rod at the optimal position to each increment of displacement, using the statistical software package PHStat Second Edition (Prentice Hall International Inc., New Jersey, USA) in Microsoft Excel 2000.

Results

In all exposure test positions except for transverse displacements and horizontal rotations, the recorded linear measurements on the right side were essentially symmetrical to those of the left side. For

transverse displacements and horizontal rotations, the changes in magnification across tooth positions 16 to 12 when the test object was displaced to one side (e.g. left) were similar to the changes in magnification across tooth positions 26 to 22 when the object was positioned to the contralateral side (e.g. right). Data are presented for the right side of the test object. Separate graphs illustrate the horizontal magnification (Figure 2) and vertical magnification (Figure 3) of the test rods as a function of bucco-palatal tilt, sagittal displacement, transverse displacement and horizontal rotation.

At the optimal position, the horizontal magnification ranged from 1.10 to 1.28, whereas the vertical magnification remained constant at 1.28. Mesio-distal tilts did not induce significant changes in the magnification for test rods at all tooth positions. However, all test rods showed statistically significant differences ($p < 0.001$) in the magnification of both width and length for all bucco-palatal

tilt increments. As the test rods were tilted up to 10 degrees palatally, the occluso-apical image of the test rods increased and the apical image became stretched horizontally. The horizontal magnification of the apical image at 10 degrees palatal tilt was the largest at 1.37 for the test rod at the position of the second premolar, decreasing anteriorly towards the position of the lateral incisor with a magnification of 1.25.

The opposite effect occurred as the test rods were tilted up to 10 degrees buccally, appearing shorter occluso-vertically and giving rise to a tapered appearance. At 10 degrees buccal tilt, the horizontal magnification of the apical image was also the largest (1.20) for the test rod at the position of the second premolar, and it gradually decreased anteriorly towards the position of the lateral incisor with a magnification of 0.94. A wide range of magnification changes occurred at the width of the tilted apical portion of each test rod when the test rods were tilted up to 10 degrees bucco-palatally. This range was largest for tooth positions of the lateral incisor and canine, at 0.94 to 1.3 and 0.98 to 1.32, respectively.

Displacing the test object away from the optimal position at each increment of the three positioning parameters showed statistically significant variations ($p < 0.05$) in both the horizontal and vertical magnification. The width of all test rods decreased as the test object was displaced from positions 10 mm posterior to 10 mm anterior of the optimum position. Each test rod along the dental arch underwent a wide range of changes in the horizontal magnification during the sagittal displacement of the test object. The first molar recorded the least change at 1.33 to 1.28, while the largest changes were recorded for tooth positions of the lateral incisor and canine, at 0.87 to 1.28 and 0.90 to 1.30, respectively. For a transverse displacement and horizontal rotation to the left of the optimal position, there was an incremental increase in the horizontal magnification for all tooth positions. The opposite effect was true for a displacement or rotation to the right of the optimal position.

Although the direction of changes in the vertical magnification followed that of the horizontal magnification observed for all three positioning parameters, the difference in vertical magnification noted between each tooth position at each successive position change remained generally within a small magnification difference of 0 to 0.02.

Discussion

Although the vertical magnification remained constant at 1.28 for all test rods at the optimal position, there was a decrease in the horizontal magnification from 1.28 at the first molar to 1.10 at the lateral incisor position. This indicated that the test rods were positioned about 5 mm forward of the centre of the image layer in order to accommodate the crowns and roots of teeth within the image layer.¹⁴ The vertical dimension of the test rods is minimally affected by the rotation of the X-ray source as the focal spot in the X-ray tube anode serves as the functional focal spot for the vertical dimension of the projection.¹⁵ To exemplify the differences in horizontal magnification, an 8 mm-wide maxillary canine may measure 9.3 mm, whereas an 8 mm-wide second premolar may measure 10.2 mm on the same OPG.

This study showed that the magnitude of magnification varies with the location of the test rods and test object in relation to the focal trough. Any deviation from the optimal position could result in a change of results. Although this study omitted test rods in the regions of the central incisor, second molar and third molar, the results may be extrapolated generally to these areas since the changes observed for all test rods are incremental and follow predictable patterns. However, a further study would be required to confirm this hypothesis. Nevertheless, it should be noted that the data collected in this study applies only to the OrthOralix machine because of the variation in the size, shape and depth of the image layer of the different rotational panoramic machines on the market.^{13,16}

No obvious dimensional changes were observed with mesio-distal tilting of the test rods because no notable displacement occurred with respect to the film and the rotation centre of the beam. The variability of the magnification occurring mesio-distally for each tooth position was also too small to induce a significant change at the tilted end. However, significant differences were reflected in the magnification between the superior and inferior images of bucco-palatally inclined objects depending on the location and inclination of the object in the focal trough.

In addition to being projected as a mesial change on the radiograph, a palatally inclined object tends to appear curved, particularly in the anterior region of the jaw. Bucco-palatally inclined test rods did not appear curved in this study because the selected magnitude of tilt was not severe enough. Gavel and Dermaut¹⁷ observed a mesial curvature when

they subjected their experimental canine tooth to an increasing palatal inclination ranging from 20 degrees to 60 degrees to the vertical plane. In view of the two-dimensional limitation of an OPG, a second radiograph, such as the periapical radiograph or occlusograph, is recommended for diagnostic purposes.¹⁸

Image curvature on the OPG is associated with large changes in horizontal magnification along the length of the object. This form of distortion may be more apparent for bucco-palately inclined objects in the anterior region of the focal trough since the range of horizontal magnification occurring at bucco-palatal tilt limits of ± 10 degrees was the greatest at the positions of the maxillary lateral incisor and canine. The marked effects of horizontal magnification in the anterior region is caused by the difference in the length of the effective projection radius, which is shorter in the anterior region than in the lateral regions of the OPGs. Despite a relatively wider variation observed in the horizontal magnification, the vertical magnification differed only slightly with displacement from the centre of the image layer.

Various authors⁹⁻¹¹ have reported that errors in patient positioning contributes to diagnostic inadequacy of films in a large sample of OPGs. Frequency of antero-posterior positioning errors ranged from 8 to 54 per cent, while transverse positioning errors ranged from 4 to 24 per cent. A predictable trend of linear distortion was noted for changes observed in response to all three spatial position changes used in this study. This could be explained by considering the position of the test object in relation to the rotation centres and path of the X-ray beam of the OrthOralix X-ray unit. When the test object was displaced too far posteriorly towards the rotation centre of the beam and close to the X-ray source, the magnification factors increased and the test rods appeared magnified. The opposite effect was true when the test object was displaced towards the film cassette. Because of the limitations imposed by the test object, the effect of occlusal plane canting was not evaluated in this study. The relationship between occlusal plane tilting and distortion on OPGs has been addressed by other authors.^{8,19,20}

Patient-positioning systems for different panoramic X-ray units are unique and distinct. Any given manufacturer's unit will effectively image a given patient's jaw, provided it is symmetrical and of an average size and shape that allows optimal positioning in the focal trough. However, it is difficult to position all teeth optimally within the focal trough all the time in clinical practice. Although

positioning errors in clinical practice typically occur within a range of ± 5 degrees and ± 5 mm,²¹ this study has shown that statistically significant changes in magnification can occur at or exceeding these limits. A strict adherence to the manufacturer's protocol for optimal patient positioning during orthopantomography can help minimise these errors. By recognising the characteristic distortion produced by each positioning error during orthopantomography, the problem can usually be rectified by a simple change in the position of the patient when retaking an OPG.

This study was not conducted on the lower arch. Although a different result might occur because of variations in focal trough, arch form and tooth positions, similar patterns of changes in magnification can be anticipated.

Conclusions

Within the limitations of the study, the following conclusions may be made:

1. Horizontal measurements are considered more unreliable than vertical measurements since the amount of horizontal magnification is not uniform throughout the same OPG when the object is positioned at the optimum position.
2. Dimensional measurements from the OPG should be undertaken cautiously in view of the statistically significant errors ($p < 0.05$) in magnification that can result with poor patient positioning at or exceeding ± 5 degrees and ± 5 mm.
3. Objects with prominent bucco-palatal inclination, particularly at the anterior region of the focal trough, are susceptible to large changes in horizontal magnification. Linear measurements of obliquely positioned objects cannot be relied upon on the OPG since they have the tendency to appear curved in the film and show statistically significant differences ($p < 0.001$) in the magnification for bucco-palatal angulations at or exceeding 5 degrees relative to the true perpendicular.
4. The results demonstrated the importance of proper patient positioning in the panoramic machine, according to the manufacturer's protocol for acquisition of an optimal OPG for diagnostic and treatment planning purposes.

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