Analysis of Panoramic Cephalometrics Using a Skeletal Cephalostat

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The lateral cephalometric X-ray is currently used in orthodontic diagnosis of skeletal dysplasia. These radiographs superimpose right and left sides of the skull making diagnosis of asymmetries difficult. Panoramic radiography eliminates skeletal superimposition. However, due to the inherent, infinitively variable magnification present in these radiographs, quantitative measurements are not accurate. The purpose of this study is to attempt to show that the General Electric Panelipse X-ray System, equipped with a skeletal head positioner (the Skeletal Cephalostat), can produce a radiograph from which the diagnostician can make accurate quantitative measurements of the lengths of the maxillary and mandibular bony bases and the related dental arches. This study also attempts to demonstrate that accurate repositioning is possible with the Skeletal Cephalostat (S.C.) for growth and development studies.

The S.C. serves as a head positioner to center and stabilize the maxilla and the mandible within the adjustable elliptical path of the focal trough of the GE Panelipse. If the jaws are within this trough and their image is reflected onto a parallel film by X-rays striking the bony arches perpendicularly, then the resultant radiograph should show uniform vertical and horizontal magnification (approximately 19 percent). This type of radiograph would be accurate for making quantitative measurements. For the first time the orthodontist or oral surgeon would be able to measure exactly the anterior, posterior, and symmetrical skeletal and tooth dysplasias (and determine which is which). The orthodontist, by including this diagnostic instrument in his armamentarium, could know whether he is dealing with a dental or skeletal disharmony. The oral surgeon would know the exact amount of bone to be removed or repositioned prior to surgical exposure.

Review of Literature

The most important problem in orthodontics today is diagnosis. But with all his available tools, the practitioner sometimes finds diagnosis difficult, especially when skeletal asymmetry and growth and development problems are present. Lateral, oblique, posterior-anterior, and even reverse Townes cephalometric X-rays do not permit exacting diagnosis (due to skeletal superimposition and angular distortion) of skeletal dysplasia, especially if it is asymmetrical in nature.

There exists today a great deal of controversy concerning cephalometric analysis. Most orthodontists and oral surgeons agree that the lateral cephalometric X-ray is a useful tool, but that it should not be the only diagnostic factor in determining the treatment of a patient.

This method presents only a lateral profile view which superimposes the right and left sides of the maxilla and mandible. This superimposition makes diagnosis of skeletal asymmetry difficult if not impossible.

The introduction of panoramic radiography permitted the diagnostician to circumvent superimposition through the use of curved surface laminagraphy. Thus a dentist could select the exact skeletal layer he wished to view, and blur out all the intervening structures.

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Paatero,[1] who developed the orthopantomograph in 1949, states, "The method, rotational tomography, is based on the principle that a sharp image of a rotating object (in practice, a thin layer which is immobile in relation to the film) is projected upon a lineally moving or rotating film when the tissue surfaces (or layer) and film are exposed by a narrow X-ray beam. The surface and the film must move through the beam with an equal linear velocity."

In the current model of the orthopantomograph the patient stands stationary, and the X-ray tube and the film mounted in a curved cassette rotate around the patient. The rotation occurs in three axes in an attempt to have the central ray pass through the dental arch at ninety degrees. The film cassette has a curve corresponding to a normal curve of a mandibular arch.

In 1957 Hudson and Kumpula[2] described and patented a machine which used two axes of rotation. This machine changed the axis of rotation halfway through the exposure by shifting the patient's chair. The film was mounted in a flat cassette carrier.

In 1970 General Electric Company introduced the GE-3000 panoramic X-ray machine.

Describing the GE-3000, Manson-Hing[3] emphasizes that it, "has a continuously moving axis that follows the arc of the mandible and maxilla." He also states, "In addition, the arc is not of fixed size but can be adjusted for different-sized jaws. The shape of the arc is essentially one half of a two-to-one ellipse." Manson-Hing believes this machine represents a major advance in panoramic radiography because ". . . the rotational axis of the tube head film holder assembly traces the dental arc, the object-to-film and object-to-radiation source distances are kept constant, and vertical magnification is uniform over the entire radiograph. The magnification is approximately 19 percent."

The main problem encountered with the GE-3000 was in head positioning. This unit attempted to achieve proper alignment of the patient's head with a set of lights. A more advanced model eliminates these lights and utilizes an anterior bite block in addition to the chin rest and two lateral side bars which attempt to center the patient's head. This unit is called the General Electric Panelipse Panoramic X-ray System.

The obvious advantage of all panoramic radiographs (that the entire maxilla and mandible are unfolded before the dentist's eyes) is often overshadowed by distortion. This can occur in the form of vertical or horizontal magnification or diminution, blurring, and even superimposition (mostly by the vertebral column).

Distortion in the Panorex has been examined by many authors, among them Kite, Swanson, Lewis and Bradburn,[4] Shaheen,[5] Christed and Segreto,[6] Updegrave,[7] Furman,[8] and Prado.[9]

Kahler[10] concluded that width distortion prevented the use of Panorex measurements when compared with alginate impression measurements, and that width distortion prevented the use of Panorex X-rays for tooth size analysis.

Ryan, Rosenberg, and Law[11] concluded recently, after much investigation and statistical analysis, that the distortion in the Panorex is statistically significant and, furthermore, unpredictable. They add that distortion does improve with better head positioning.

One method of radiographic head positioning that has become fairly standard is the Broadbent cephalometer which is used in most cephalometric X-ray units. Several authors, Kane,[12] Zach, Langland, and Sippy,[13] Richardson, Langland, and Sippy,[14], Altiere,[15] Gattozzi,[16] Prado,[9] and Ryan, Rosenberg, and Law[11] have attempted to adapt some of the principles of the cephalostat to panoramic X-ray machines.

All the previous research with cephalostats on panoramic X-ray machines was handicapped by one main problem. As Graber[17] states, "Since the dental arches are not true circles, but varying degrees of parabaloid curvatures, considerable distortion could be created during the radiographic process."

The General Electric Panelipse X-ray machine has apparently eliminated the inherent distortion of fixed axis machines. The problem of proper head positioning, however, still exists. Only if the patient is positioned in the center of the X-ray focal trough and stabilized can a radiograph be obtained that could be used for quantitative measurements. In addition, the patient should be able to be exactly repositioned in the machine at any later date so that growth and development studies could be accomplished.

Methods and Materials

While the new Panelipse machine eliminates most of the vertical and horizontal distortion present in previous panoramic X-ray machines, it can permit improper placement and stabilization of the patient's head producing radiographic distortion. With precise head positioning with a skeletal head positioner, the remaining vertical and horizontal magnification can be eliminated yielding quantitatively measurable and reproducible panoramic radiographs.

The Panelipse head positioning device utilizes a control box to which are attached two lateral adjustable arms, a fixed chin rest, a vertically and horizontally movable bite block, and a dental arch size measuring scale.

The existing Panelipse head positioner cannot accomplish the purposes of this study because the lateral side arms contact the head in the temporal region arbitrarily, without calibrations, permitting soft tissue deflection. Since our purpose requires the teeth to be in centric occlusion, the anterior bite block cannot be used.

Therefore, a skeletal head positioner was designed: (1) to center the patient in the machine, (2) to be sturdy enough to prevent deflection, and (3) to be calibrated for all dimensional deviations for each individual patient. Not only would the head be centered, but the patient would also be prevented from tilting the head. In addition, several positive anterior stops were designed to orient the anterior extents of the bony bases of the jaws without separating the teeth. A nasion stop was also designed to add increased stability and, since this stop along with others was to be calibrated, repositioning would be possible.

The S.C. consists of an anterior segment and two lateral segments all of which are connected to the control box of the Panelipse. The anterior segment consists of base member 20 (Fig. 1) which is attached to the control box 5. This base member is calibrated, slotted, and contains four supporting members consisting of a chin rest 7, intraoral stop B which is 42, intraoral stop A 34, and a nasion stop 30. A refers to anatomical point A and B refers to anatomical point B illustrated on the drawing.

The chin rest is attached on vertical slot 27 permitting vertical movement for adjustments and removal if necessary. The two intraoral stops which rest on the patient's anatomical points A and B are also attached to the slot 27 and permit calibrated vertical and horizontal movements at fixed angles. Stop A member 34 is notched to accommo-

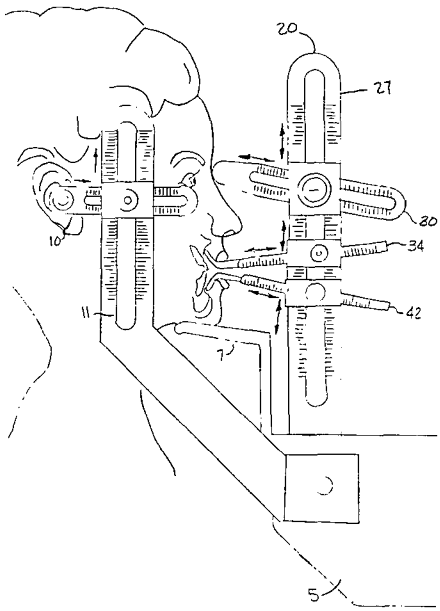


Fig. 1

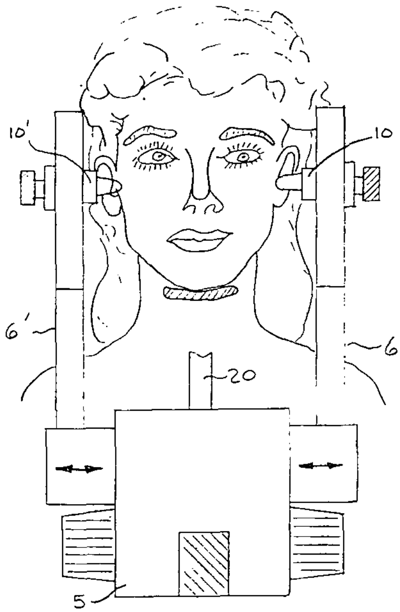


Fig. 2

date the maxillary labial frenum and still maintain close approximation with the maxilla. Thus members 34 and 42 permit the operator to orient the most anterior extents of the maxillary and mandibular bony bases within the 4 mm wide anterior extent of the X-ray focal trough. Those members also can make A-B almost parallel to the film plane thus permitting a uniformly magnified radiograph to be exposed with the patient's teeth in centric occlusion. The nasion stop 30 is also attached to slot 27 and permits calibrated vertical and horizontal movements at a fixed angle. This member supplies additional support to the patient's head.

The two lateral segments consist of angled members 6 and 6′ which are attached where the existing Panelipse lateral arms were previously secured (Fig. 2). These members have slots, 11 and 11′ (Fig. 1), to which are attached ear rod members 10 and 10′, permitting calibrated vertical and horizontal movements at a fixed ninety degree angle.

All of the previously described and illustrated members of the S.C. were constructed of radiolucent material to eliminate interference with X-ray penetration. All calibrations are in millimeters.

Rationale for Modifications: Once the ear rods are in place, a patient will be able to rotate only the head; tilting is eliminated. Viewed laterally, the patient with ear rods in place can rotate clockwise or counterclockwise. The anterior segment with the four stops (chin rest, A, B, and nasion) then provides positive positioning and stabilization to this rotational movement around the ear rods. Any desired anatomical area of the lower face can be centered within the elliptical path of the X-ray focal trough. Since members A and B (34 and 42) rest against the bony bases of the maxilla and mandible, the A-B plane can be made nearly parallel to the film plane by guiding the rotation of the patient's head, thus a uniformly magnified radiograph will be obtained.

Finally, since five points of contact (two ear rods, A, B and nasion) are calibrated, by recording these measurements a patient may be repositioned at any later time and differences noted. With the resultant radiographic and head positioning measurements, accurate assessment of growth and development changes can be obtained.

Kodak blue brand panoramic 5″ x 12″ film exposed for twenty seconds was used.

In the process of aligning the S.C. with the Panelipse machine, both points A and B could not be accurately placed within the focal trough when they were an equal distance from the film plane. We decided after consultation to move the point B intraoral stop one mm farther away from the film plane. When this was done, a clear, sharp radiograph was routinely produced. This appeared to indicate that points A and B were within the focal trough of the X-ray beam. The only plausible explanation for this finding is that the trough of a panoramic X-ray machine which rotates around the patient may be convex in morphology.

Experimental Procedures

Quantitative testing was performed to determine whether this technique could be used to accurately measure the skeletal and dental segments of a patient's lower face. Ten human dentulous skulls of mixed ages were selected at random.

To test the amount of vertical and horizontal magnification of the Panelipse, twenty-six steel ball bearings approximately 3 mm in diameter were used as radiopaque reference markers on each skull (Fig. 3). The location of each marker was selected not only to test vertical and horizontal distances, but also for identification of known anatomical areas that are reproducible in all skulls and identifiable and measurable for statistical comparison.

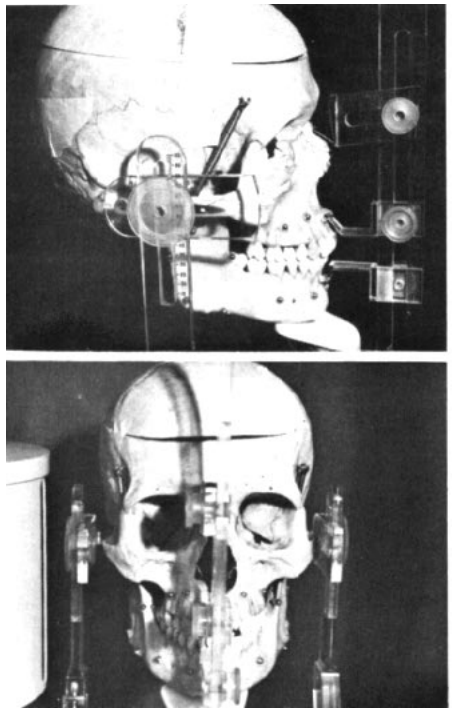


Fig. 3

A panographic tracing (Fig. 4) illustrates the following markers and their locations (right and left sides, upper and lower, dental and anatomic).

1. RC-LC = center of the lateral surface of the mandibular condyle.
2. RMN-LMN = in the deepest portion of the mandibular (sigmoid) notch.
3. RPR-LPR = deepest point on the posterior surface of the mandibular ramus tangent to ramal plane.
4. RAR-LAR = deepest point on the anterior portion of the ascending ramus tangent to a line parallel to the ramal plane.
5. RLP-LLP = junction of the external oblique line and the retromolar pad area of the mandible.
6. RGo-LGo = anatomical gonial angles.
7. RAN-LAN = deepest point of the antegonial notch on the mandible.
8. RLM-LLM = points established by projecting a perpendicular from the mesial contact point of the mandibular first molar onto a plane constructed from RGo to PM to LGo.

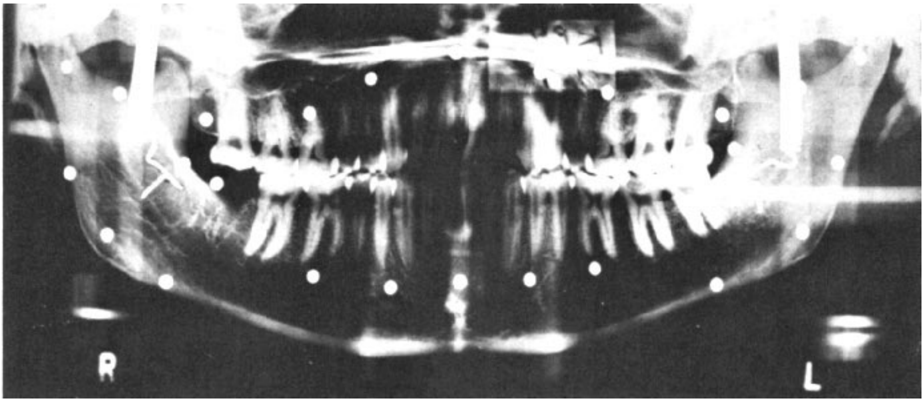


Fig. 4

9. RLC-LLC = points established by projecting a perpendicular from the mandibular cuspid tip onto a plane constructed from RGo to PM to LGo.

10. PM = protuberance menti. Ricketts[18] defines this as a point on the superior aspect of the anterior contour of the mandibular symphysis.

11. RT-LT = intersection of the maxillary tuberosity and the pterygoid process.

12. RUM-LUM = points on the maxilla found by projecting a perpendicular from the mesial contact point of the first molars onto lines constructed from RT and LT to SANS.

13. RUC-LUC = points on the maxilla found by projecting a perpendicular from the cuspid tips onto the RT and LT-SANS planes.

14. SANS = midpoint on the anterior inferior slope of the anterior nasal spine between the tip of the spine and anatomical point A.

Measurementation: Following completion of all the skull radiographs, a sharpened Boley gauge was used to make vertical and horizontal millimetric measurements from the center of each uniform ball bearing to the center of the adjacent ball bearing and compared with the same measurements made directly on the ten skulls.

The mean and standard error were calculated for each of the forty-three measurements. The differences between the skeletal and radiographic measurements were noted, the percentage of magnification found, and a "t" test was performed on each of the magnification findings.* Each magnification mean was calculated with its appropriate range. This could enable a clinician to accurately evaluate the measurements he takes from these types of panoramic radiographs.

Results and Findings

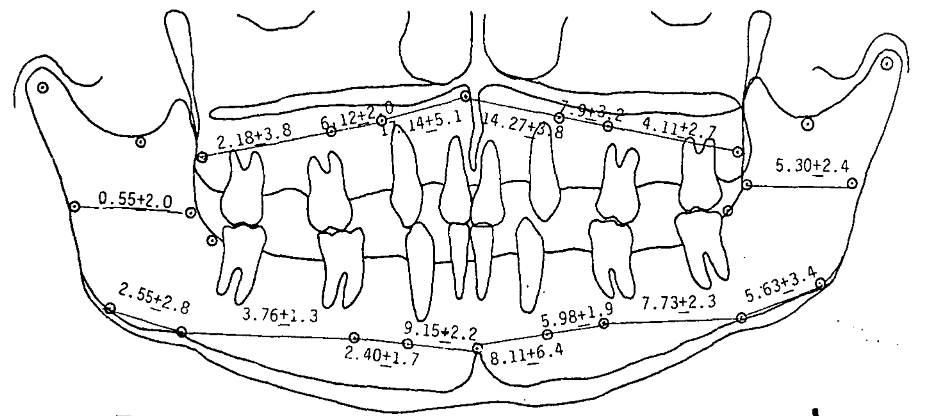
With all skulls the following results were found: For the most part, quantitative measurements of magnification taken from panoramic radiographs were calculable and predictable. In many skeletal locations this magnification was small in amount. The range of the mean magnification was also generally not large.

Summary findings of this study are shown in Figures 5 and 6. These are illustrated in the manner in which they appear on a panoramic radiograph.

Discussion

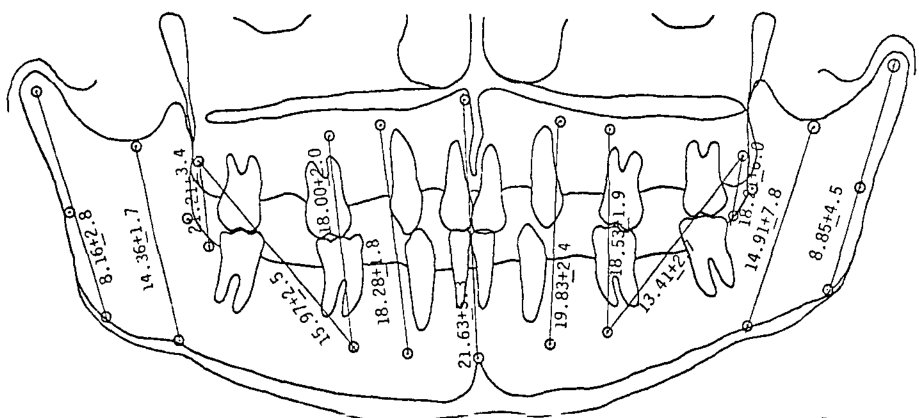
Analysis of the findings for horizontal and vertical magnification indicates that for Class I skulls, panoramic cephalometrics with the S.C. is feasible. While the magnification varied anatomically, it was predictable. The percentage of magnification as well as its

*Complete statistical data can be obtained from the author.



R PERCENTAGE OF HORIZONTAL MAGNIFICATION OF PANORAMIC RADIOGRAPHS L
USING THE SKELETAL CEPHALOSTAT Confidence Level = 95%

Fig. 5



R PERCENTAGE OF VERTICAL MAGNIFICATION OF PANORAMIC RADIOGRAPHS L
USING THE SKELETAL CEPHALOSTAT Confidence Level = 95%

Fig. 6

variance was found for each anatomical area measured. Additionally, the amount of magnification was less than that found in many previous studies thus making linear measurements usable. Finally, replication of findings was feasible indicating the potential importance of the use of this technique in growth and development studies.

The measurements made directly from the skulls were statistically found to be useful as anatomic norms for Class I skulls. Thus, one can not only utilize panoramic cephalometrics, but also compare findings to skeletal norms.

Skeletal Horizontal Magnification with the Skeletal Cephalostat: Sixteen horizontal measurements were compared (skulls against measurements taken from panoramic radiographs). In eleven of sixteen horizontal areas magnification was consistently reproduced (each with a relatively narrow range of variance), and "t" tests of the results were highly significant. Of the remaining five horizontal areas two had a wider deviation, but were still significant. These two were the PM-LLC and the LLC-LLM areas (Figs. 4 and 5).

Three horizontal measurements showed magnification that was statistically not significant. These were LAN-LGo, LPR-LAR, and LT-LUC.

All five of the less significant areas were on the left side of the skulls. When one examines all of the results, a difference in right to left horizontal magnification is noted. This difference was noted in several previous panoramic studies.[15,16] This suggests that the right to left difference in horizontal magnification could be due to improper alignment of the Panelipse to the S.C.

It must also be noted that horizontal magnification in the tuberosity to molar measurement could be influenced by where the metal marker was placed on the tuberosity. The more lingually the marker was placed, the farther away from the film plane and the larger the magnification. The morphology of the maxilla also influenced the amount of magnification. The inherent shape of the basal bone of the maxilla tends to curve medially as the tuberosity fuses with the pterygoid plates. This places the tuberosity farther away from the film plane than the maxillary first molar area which is convex laterally and thus will be located closer to the film plane.

Also noteworthy was the amount of horizontal magnification in the cuspid to molar basal bone measurements, highly significant in three areas and significant in one other area. The RLM-RLC, LUM-LUC, RUC-RUM results were highly significant. The LLC-LLM was shown by the "t" test to be significant, and almost at the highly significant level. These figures suggest that the S.C. and the Panelipse could be useful in accurately determining the mesial-distal width of erupting premolar teeth for arch length analysis and in serial extraction treatment.

Skeletal Vertical Magnification with the Skeletal Cephalostat: The percentage of vertical magnification was greater than the percentage of horizontal magnification. The range was from 8.16 ± 2.8% in the RC-RGo area to 21.63 ± 5.3% in the SANS-Pm area (Figs. 4 and 6). This increase in vertical magnification was due to the fact that the Panelipse X-rays are columnated through a slot in the tube head which is narrow horizontally and long in a vertical dimension. The diverging X-rays cause image magnification vertically.

As all previous studies have found, vertical magnification varied as to location.

The statistical results for all areas were highly significant. This finding indicates that the mean magnification percentage and the range were found to be predictable for these ten skulls at the 95% and 99% confidence levels.

The asymmetrical magnification found in the horizontal areas was not as pronounced in the vertical. One possible explanation for the small amount of this asymmetrical difference may be that vertical magnification is not as critically influenced by being exactly within the X-ray focal trough as is horizontal magnification.

Vertical magnification in the anterior region (specifically the SANS-Pm area) was greater than in most other areas. The mean difference between the films and the skulls was 9.7 mm. Inherent in this finding was the method of measuring the skulls; all skulls were measured with a Boley gauge. The SANS-Pm measurement involved measuring a curved area with a straight-line technique. The reason for noting this difference in technique is that a comparison of anterior facial height versus posterior facial height is needed for complete skeletal orthodontic diagnosis.

The clinician needs to be aware that the posterior facial height measurements do not involve this curvature noted in the anterior region. Future research may shed light on this area.

One could conclude from the vertical magnification, its relatively small range, and the highly significant statistical evaluation of the findings that the clinician could use this panoramic technique for vertical evaluation of skeletons.

Dental Segment Horizontal Magnification with the Skeletal Cephalostat: The percentage of magnification of the dental segments was similar to horizontal skeletal magnification, but there were notable differences. The range of dental segment magnification was variable and, in most instances, was much larger than the magnification mean itself.

One exception was measurements from the mandibular molar and premolars on the left side. Statistical analysis of these means was highly significant. This again suggests that the Panelipse focal trough was not focused on the basal areas on the left side of the skulls. Instead, the results indicate that the focal trough may have been focused on the crowns of the mandibular teeth, since these teeth alone seem to be in focus.

Several other exceptions in the dental segments were in focus and had either significant or highly significant findings. However, one must conclude from a perusal of *all* of the dental segment results that the uneven distribution of the results tends to indicate that the S.C., using the A and B stops, does not place the crowns of the teeth in focus when the basal jaw segments are in focus.

Analysis of variance tests on replication of procedures with the S.C. indicated no significant differences in measurements. This suggests that replication is entirely feasible. Thus, the S.C. aids in obtaining a linearly measurable radiograph. It also permits the orthodontist to measure dimensional changes of facial growth.

The distance from nasion to the chin rest will denote the total anterior facial vertical growth. The positions of A and B stops will denote whether growth changes occurred in the maxilla or the mandible or a combination of both. Horizontal growth changes will also be demonstrated by anterior-posterior location of A and B members.

Once these growth changes have been recorded, the operator can reposition the patient to ascertain where and to what extent growth and development have occurred.

During the construction and alignment procedures prior to the skeletal study, several phenomena were noted. Rotational tomography can cause some objects to be magnified, while other objects are actually diminished in size vertically and horizontally. Dentists are accustomed to seeing magnification or enlargement on radiographs, since routine X-rays are really a form of shadow casting. However, shadow casting principles need to be adjusted when interpreting radiographs produced by rotational laminagraphy.

A second phenomenon noted by the study was that, when points A and B were placed the same distance away from the film plane, both objects could not be accurately focused within the four mm wide anterior focal trough. The only explanation that seems plausible is that in rotational laminagraphy, the focal trough (at least in the anterior region) may be curved in form corresponding to the curvature of the profile form of the human skull.

It was also noted that, since the metal markers used in this study were not imbedded within the skulls, skeletal measurements would represent a greater radius than the actual position within the skull. However, the author assumes that the external or surface placement of the markers merely represents a greater radius of placement, and that similar results would be attained with imbedded metal markers. A future test should authenticate this statement.

Conclusions

The results of this study indicate that uniform magnification is not completely possible with the combination of the General Electric Panelipse and the Skeletal Cephalostat. This is due to individual differences in morphology of the human maxilla and mandible as they fit into the focal trough of the Panelipse. However, the results of this study do tend to indicate that for Class I normal skulls a small amount of anatomically variable magnification is produced which is calculable and predictable to a high degree of accuracy. With more accurate alignment of the two devices, the magnification, while somewhat variable, could be minimized. Furthermore, all horizontal and vertical magnification would be predictable enough to permit the orthodontist to have an adjunctive tool for the diagnosis of skeletal dysplasia.

Repositioning of skulls for replication of radiographs was found to be accurate. Thus the clinician could monitor growth and development and orthodontic and surgical treatment.

The percentage of magnification and the limited range of this percentage in the molar to cuspid basal skeletal areas suggest this technique may be valuable in predicting the size and variation of erupting premolar teeth and the leeway space available in arch length analysis and serial extraction treatment.

As with other panoramic machines, there were asymmetrical right to left

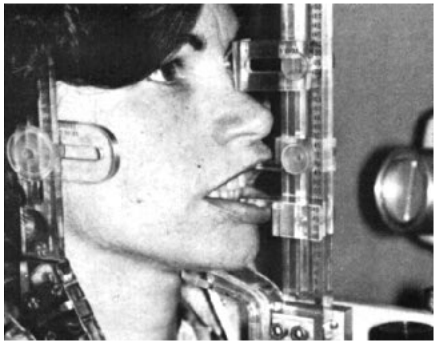


Fig. 7

differences in magnification. This was believed due to improper alignment between the Panelipse and the S.C. The asymmetrical differences were most apparent in horizontal magnification and less pronounced vertically. Vertical magnification appeared to be consistently accurate enough in the mandibular ramus area to permit assessment of posterior facial height.

A critical examination of maxillary and mandibular skeletal measurements yielded a percentage of magnification, and a range of variance at the 95% confidence level.

To initially test repositioning, skulls were used successfully. One must assume that accurate repositioning is also possible with live human beings. Thirty patients had routine panoramic X-rays taken with the Panelipse using the S.C. merely to center and hold the patient (Fig. 7). Calibrations were still possible and an excellent radiograph was achieved without retakes.

It must be remembered that the percentage of magnification for each area is not only dependent on the enlargement factor but must also, from a clinical standpoint, be related to the actual distance being measured. Therefore, since the percentage of magnification is relatively small, and for Class I skulls this percentage of magnification as well as each range is known, one could conclude that panoramic cephalometrics is probable and possible. This statement assumes that alignment of the S.C. and the General Electric Panelipse would eliminate the asymmetrical magnification present with the existing system.

Summary

A panoramic head positioning device, the S.C., was tested for magnification production of radiographs and for repositioning. Ten skeletal Class I dentulous skulls with uniform metal markers were examined. The purpose was to see if a skeletal analysis could be obtained from panoramic radiographs.

Basal skeletal magnification varied anatomically both vertically and horizontally, but the magnification percentages and their ranges, for the most part, were calculable. The few exceptions were believed due to lack of proper alignment of the S.C. and the General Electric Panelipse. Proper alignment could also correct the right to left asymmetrical magnification differences.

Means and standard errors from 290 skeletal measurements were calculated and could serve as standards for skeletal analysis using panoramic cephalometrics.

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