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QUANTITATIVE MEASUREMENTS FROM PANORAMIC RADIOGRAPHS

by

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QUANTITATIVE MEASUREMENTS FROM
PANORAMIC RADIOGRAPHS

Abstract

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JOHN H. DIGIULIO, B.S., D.D.S.

A study was performed to determine if accurate quantitative measurements could be obtained from panoramic radiographs utilizing an intraoral scale specially designed by the author. Thirty human skulls were selected from over five-hundred specimens of the Todd-Hamann collection of the Natural Science Museum in Cleveland, Ohio. The only criterion for selection was completeness of dentition; no preference was given to size, shape, age, race, or sex. Markers consisting of .010 stainless-steel ligature wire were placed between the mandibular right-and-left second bicuspids and first molars of each skull. The skulls were orientated on the Panorex by the use of a special cephalostat. The intraoral scale was adapted to the mandibular arch of each of the skulls; effort was made to position the skulls as accurately as possible using visual alignment. Each of the thirty skulls, with the intraoral scale in place, was then placed successively in the cephalostat and x-rayed. Three sets of data were collected for each skull:

(1) Mandibular arch-length measurements of each skull taken from the radiographs utilizing the intraoral scale (Pxg).

(2) Mandibular arch-length measurements taken directly from each skull (d).

(3) Mandibular arch-length measurements of each skull taken directly from the radiographs without the use of the intraoral scale (Pxd).

To conduct an error study, the skulls were numbered from one to thirty. The first ten numbers listed in a table of random numbers were selected from the thirty to choose the skulls that would be used in the error study. The experiment was then repeated with these ten skulls.

The following is a list of conclusions that have evolved from this study:

(1) Measurements taken from radiographs utilizing the intraoral scale are highly and positively related to the same measurements taken directly from the corresponding human skull.

(2) Measurements utilizing the intraoral scale are more highly related to direct skull measurements than measurements obtained from radiographs without the scale.

(3) The difference in values for measurements obtained by the use of the intraoral scale and the actual values is statistically insignificant.

(4) Actual values can be obtained from intraoral scale values by applying the regression formula $d = 4.35 + .943\ (Pxg)$, this procedure, however, seems unnecessary due to close agreement between (d) and (Pxg) values.

(5) Measurements obtained from radiographs utilizing the intraoral scale are as accurately reproducible as direct measurements.

DEDICATION

To my father, Hugo, and my late mother,

Florence DiGiulio, for their sacrifices

in behalf of my education.

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TABLE OF CONTENTS

	page
ABSTRACT	ii
DEDICATION	iv
ACKNOWLEDGEMENTS	v
LIST OF TABLES	vii
LIST OF ILLUSTRATIONS	viii
INTRODUCTION	1
HISTORY AND REVIEW OF LITERATURE	8
METHODS AND MATERIALS	27
RESULTS	36
DISCUSSION	42
SUMMARY AND CONCLUSIONS	45
LIST OF REFERENCES	47
APPENDIX	52

LIST OF TABLES

Table		page
1	Product-Moment Coefficients and Efficiency	36
2	Z-Transformations	37
3	Reliability Coefficients	38
4	Efficiency and Z- Transformations	38
5	Measurements	39
6	Error Study Measurements	41

LIST OF ILLUSTRATIONS

Figure		page
1	The Panagraph	11
2	The Rotagraph	13
3	The Panorex	20
4	The Orthopantomograph	25
5	Scale holder, intraoral scale, and comparison ruler .	33
6	Intraoral scale adapted to a mandibular arch.	33
7	Skull mounted in cephalostat on Panorex	34
8	Panoramic radiograph of skull and intraoral scale . .	35

INTRODUCTION

Radiography is an indispensible aid in dental diagnosis and treatment planning. One recent contribution in this field has been the development of a number of panoramic dental X-ray machines which apply the principle of laminography or tomography to the facial region. One of the problems inherent to panoramic radiography is image distortion, and although considerable work on image distortion has been done in the past, no suitable method has yet been developed to effect accurate quantitative measurements from these records. If such a method could be devised, it would add a valuable tool to our armamentarium. In order to better understand the problems associated with panoramic radiography, a brief discussion of the various panoramic techniques will be presented at this time.

Tomography is a general term applied to techniques that provide a distinct image of a selected layer of tissue in the body while the images of structures that lie on either side of the selected layer are obscured. A number of distinguishing names have been given to different variations of these techniques. A few of the more common terms are body-section radiography, laminagraphy, planigraphy, tomography, stratigraphy, and vertigraphy. The differences among them involve primarily the path of movement of the tube and film in relation to the subject, and the inclination of the film relative to the central ray (38).

In dental tomography, the film and the tube are rotated about a pivot point which is situated at the selected plane of tissue that one wishes to record. Throughout the movement, the image of a structure in the same plane as the pivot point is recorded. Images of structures which are not in that plane are recorded in a series of positions on the film and therefore appear blurred (38). Thus, the movement causes blurring of structures that interfere with the visualization of the areas that one wishes to examine, while permitting a distinct recording of the structures that are desired.

The concentric and eccentric techniques are two of the basic techniques employed in panoramic radiography. They are distinguished from each other by the rotational axes followed by the film, patient, and X-ray source during the exposure.

The concentric technique was the first employed and used only one center of rotation. The unit was named the Rotagraph and was manufactured by Watson and Wembley of England. This machine took satisfactory pictures of young children and adults with brachycephalic faces, but produced considerable distortion in the films of individuals with mesocephalic and dolicocephalic faces (12). This machine is no longer produced because of excessive distortion.

The eccentric technique employs more than one center of rotation. The Panorex and the Orthopantomograph are currently the two most popular machines utilizing this principle.

The S. S. White Panorex uses two axes of rotation. One center of rotation is for the right side and the other center is for the left side. Each center is located just distal to the third molar opposite the side that is being recorded. The patient is positioned in the Panorex with his head mounted on a chin rest while the tube and film move around him. As the tube moves, the film itself moves past a narrow exposure slit within the film holder. This exposes a different part of the film as each structure is penetrated by X-rays from the rotating X-ray tube. As the X-ray tube approaches the midline, both the chair and patient shift three to four inches to avoid the overlapping image of the vertebral column and a new center of rotation is established and followed on the opposite side. The movement of the tube and film holder is accomplished by means of irregularly shaped cams and cables to maintain a coordination between the X-ray source and the film cassette. Since the central part of the film is blurred by the movement of the chair and the shift of rotational axis, and since there is a slight overlapping as a result of the movement, this area is usually cut out and the two films are spliced and mounted with cellulose tape (13).

The Siemens Orthopantomograph provides a continuous image on a single film. During the exposure of the film the patient remains stationary while the X-ray tube circulates from the right side of the patient's face, to behind his neck, then to the left side of his

face. As this is occuring the film rotates about the axes of the cassette holder. The X-ray tube and the axis of the cassette holder are attached to a horizontal bar which turns successively about three rotational axes. The center of rotation during the first portion of the exposure coincides approximately with the right side of the patient's face near the angle of the mandible. The left posterior portions of the jaws are recorded utilizing this center of rotation, while the film moves along a curve which approximates the shape of that portion of the dental arch. When the beam has reached a point which corresponds approximately to the premolar region, the center of rotation shifts to a position which coincides approximately with the midsagital plane opposite the premolar region. The anterior portions of the arches are recorded during this portion of the cycle. The center of rotation then shifts to a position near the left angle of the mandible, and the right posterior portions of the jaws are recorded (38).

In a comparison of the concentric and eccentric techniques it becomes apparent that a single rotational axis would be incapable of accurately reproducing all segments of the dental arch. Since it is obvious that more than one axis is required, then one might suspect that the Orthopantomograph with its three separate axes would produce the most accurate results. However, due to its shift of axes in the bicuspid region, blurring and distortion are more

evident in these areas (41). The Panorex, therefore, with its two axes of rotation and midline shift gives the least amount of distortion in the buccal segments. It produces films that are more suitable for measurements and consequently is the machine of choice for this study, although either machine could have been used.

Phillips (7) suggests that the advantages of using panoramic radiographic examinations are numerous. He cites: The wide scope of the examination, the simplicity of operation of the units, the low radiation exposure of the patient, the ease of examining "difficult" patients, and the short time required for such examinations. The limitations are few : Mild distortion and a lack of fine definition are the most frequently mentioned (39).

In recent years, researchers have tried to establish techniques for making quantitative measurements from panoramic radiographs. Although a complete review of the literature will be presented in the next section, I will cite a few of the many studies that have been done to date in order to orientate the reader.

In 1962 Gilbert (11) studied the rate of linear distortion using the Panorex. He found that direct measurements of the total image size indicated 5 percent distortion. In the remaining 26 percent the distortion ranged between 7 and 15 percent. Distortion was found to be both positive and negative, with the greatest amount of linear distortion in the molar area and the least amount in

the incisor area.

In 1962, Haataja and Somer (16) used the Orthopantomograph in a quantitative study using a sample of twenty normal dentitions and thirty orthodontically treated subjects. They measured certain areas in a horizontal plane and then compared casts and radiographs. They found the total relation of both sets to be the same; however, enlargements in different sections deviated from each other. They stated that the differences between the enlargements must be known when panoramic X-rays are used in orthodontic diagnosis.

In 1962 Kite and associates (23) evaluated the Panorex for linear distortion. Their results showed that the distortion varied from segment to segment, and that no single correction factor for small segments could be applied to the data.

Brueggeman (9) in 1967, using the Panorex unit, did a study on variations in image distortion. He found that variations in image distortion did occur within the anterior and posterior dental arches in both the clinical patient and the human skull. The vertical distortion remained fairly constant throughout the dental arches, but the linear distortion exhibited great variation. The central incisor region showed a change from a negative to a positive distortion that continued through the molar regions.

In 1969, Kahler (20) tried to assess the accuracy with which fully errupted lower canines and premolars could be measured on a

Panorex film. A ratio and proportion were used to compute an estimated width for each tooth. Comparison of the estimates with the actual widths showed a considerable difference due to X-ray-angulated related distortion. The X-ray image width was more accurate, but still not accurate enough for use in a tooth-size analysis.

As indicated above there is a very positive need for development of a method to obtain reliable measurements directly from panoramic radiographs. This study will attempt to ascertain if accurate quantitative measurements can indeed be obtained from panoramic radiographs utilizing a specially devised intraoral scale.

HISTORY AND A REVIEW OF THE PERTINENT LITERATURE

Panoramic radiography is a general term that is applied to the radiographic techniques which permit the recording of the entire dental arches and contiguous structures on one or two extraoral films. Panoramic radiography had its conception in 1897 when Rollins in the United States and Bouchacourt in France simultaneously announced their independent findings (7). Both of these investigators utilized an intraoral anode in conjunction with extraoral film placement.

Body-section radiography or tomography, on the other hand, are terms applied to techniques that produce a distinct image of a selected segment of tissue in the body, while the images of structures that lie on either side of the selected segment are obscured. Kene (21) states that in the 1920's Bocage in France and Kieffer in America, while working independently, brought forth essentially the same conclusion. If one glides an x-ray tube over an object, and simultaneously has the film moving in the opposite direction, an image of a certain plane or layer in the object can be obtained.

In 1930 Vellebona (50) utilizing the principles of body-section radiography, rotated the patient about an axis in the plane to be recorded while maintaining the tube and film in a fixed position.

Heckman working in Germany just prior to 1940, was the first to apply body-section radiography to curved surfaces such as the head.

A modified application of body-section radiography or tomography is utilized in our present day Orthopantomograph and Panorex units. Both of these units are designed to record curved sections of tissue rather than flat sections; this is necessary because the dental arches are curved. A second feature is that the pivot point is not located in the section of tissue that is being recorded. In both units the distinct recording of the desired dental structures is achieved by moving the structures and the film through the x-ray beam with an equal linear velocity. These units, in effect, select out the dentoalveolar structures, flatten them, and lay them on a film.

There are two basic methods of obtaining panoramic radiographs. The first method is by use of an intraoral anode with the film placed externally around the face. This method is exemplified by the Panagraph. The second method is by use of the principles of tomography as described earlier. The tomographic principle is utilized in the Rotagraph, the Panorex, and the Orthopantomograph respectively (41). A review of the most common units employed in panoramic radiography will now be presented.

THE PANAGRAPH

The panagraph was developed by Blackman of England in 1961 (6). It is a modification of an intraoral panoramic technique first developed by Walter Ott of Switzerland, and employs an intraoral anode as the source of x-rays. The total angle of divergence of the x-ray beam is 270 degrees in two perpendicular planes and has a focal area of 1/250 of an inch. The film is enclosed in a flexible cassette, and is closely adapted to the patient's face.

This unit is very compact and mobile and produces a one-plane panoramic picture of the teeth and supporting structure of each arch. It is capable of producing radiographs that show good detail with fine contrast, although the structures are magnified approximately two times (7).

The Panagraph requires separate exposures for the maxilla and mandible, but each area of exposure is less than that obtained from the machines using the curved layer Roentgenographic techniques.

Blackman (7) states that the unit is free from penumbra and shows minimal distortion. He also implies that the intraoral x-ray source is its major disadvantage. This could increase patient apprehension and could cause possible gagging. Its use would also be impractical in conditions involving fractures of the face or trismus, where the mouth can not be opened to

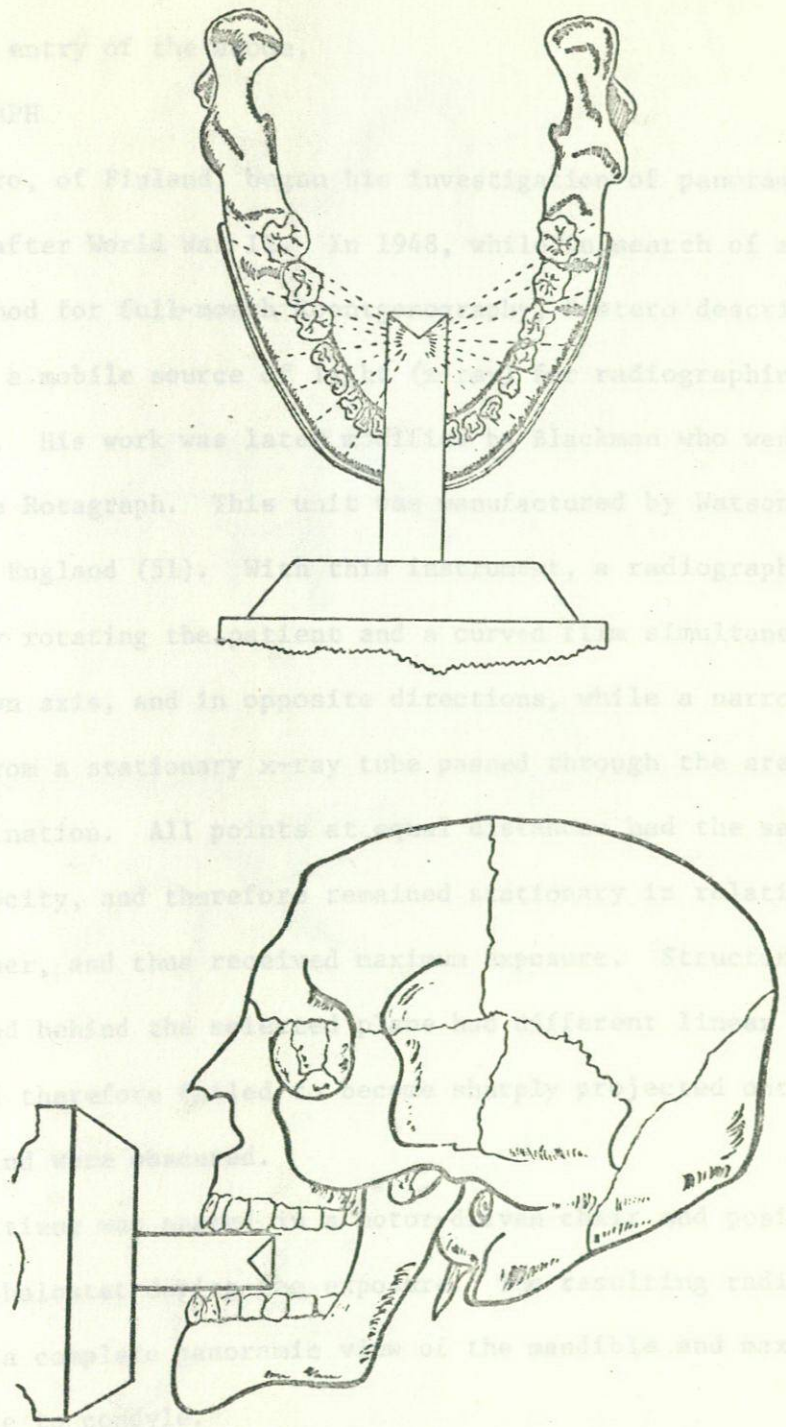


Figure 1. The Panagraph. Schematic drawings showing placement of the intraoral anode (After Updegrave).

facilitate entry of the anode.

THE ROTAGRAPH

Paatero, of Finland, began his investigation of panoramic radiology after World War II. In 1948, while in search of a simple method for full-mouth Roentgenography, Paatero described the use of a mobile source of light (x-ray) for radiographing teeth (29). His work was later modified by Blackman who went on to develop the Rotagraph. This unit was manufactured by Watson and Wembley of England (51). With this instrument, a radiograph was produced by rotating the patient and a curved film simultaneously on their own axis, and in opposite directions, while a narrow beam of x-ray from a stationary x-ray tube passed through the area under examination. All points at equal distances had the same linear velocity, and therefore remained stationary in relation to each other, and thus received maximum exposure. Structures in front of and behind the selected plane had different linear velocities and therefore failed to become sharply projected onto the film, and were obscured.

The patient was seated in a motor-driven chair and positioned in a cephalostat during the exposure. The resulting radiograph gave a complete panoramic view of the mandible and maxilla from condyle to condyle.

The Rotagraph employed the concentric technique utilizing one axis of rotation for the entire exposure. Graber (12)

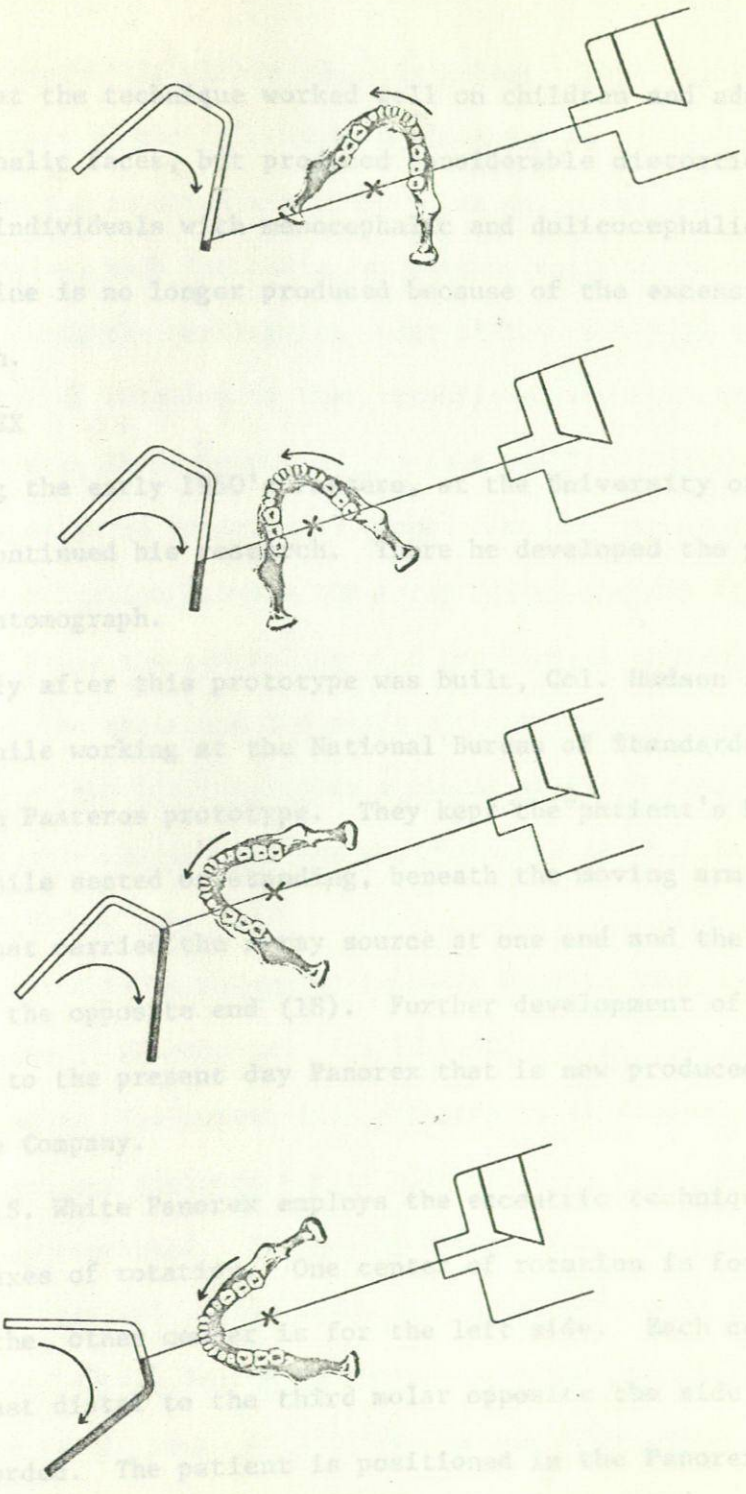


Figure 2. The Rotagraph. Schematic drawings of half-cycle exposure (After Updegrave).

stated that the technique worked well on children and adults with brachycephalic faces, but produced considerable distortion in the films of individuals with mesocephalic and dolicocephalic faces. This machine is no longer produced because of the excessive distortion.

THE PANOREX

During the early 1950's Paatero, at the University of Washington, continued his research. There he developed the prototype of the Pantomograph.

Shortly after this prototype was built, Col. Hudson and J.W. Kumpula while working at the National Bureau of Standards, improved upon Paateros prototype. They kept the patient's head immobile, while seated or standing, beneath the moving arm of a machine that carried the x-ray source at one end and the flat film holder at the opposite end (18). Further development of this machine led to the present day Panorex that is now produced by the S.S. White Company.

The S.S. White Panorex employs the eccentric technique, and uses two axes of rotation. One center of rotation is for the right side and the other center is for the left side. Each center is located just distal to the third molar opposite the side that is being recorded. The patient is positioned in the Panorex with his head mounted on a chin rest while the tube and film move around him. As the tube moves, the film itself moves past a

narrow exposure slit within the film holder. This exposes a different part of the film as each structure is penetrated by x-rays from the rotating x-ray tube. As the x-ray tube approaches the midline, both the chair and patient shift three to four inches to avoid the overlapping image of the vertebral column. A new center of rotation is then established and followed on the opposite side. The movement of the tube and film holder is accomplished by means of irregularly shaped cams and cables to maintain a co-ordination between the x-ray source and the film cassette. Since the central part of the film is blurred by the movement of the chair and the shift of rotational axis, and since there is a slight overlapping as a result of the movement, this area is usually removed and the two films are spliced and mounted with cellulose tape (13).

The Panorex is an automatic exposure machine that has an actual exposure time of 22 seconds. Its 90 K.V.P. x-ray tube has an 0.8-mm. focal spot. The target-film distance is 17 inches, although the target-object distance varies with the head size and the region being radiographed. It usually ranges from 7-13 1/2 inches.

Routine panoramic films taken with this instrument do not always have the same degree of sharpness in various areas of the mouth. The focal trough or the area in which the image is reasonably sharp in detail is relatively narrow; it ranges from 1/2 to 3/4 of an inch.

Variations in jaw morphology can and do result in some areas lacking definition because they lie outside this focal trough or arc around the rotational axis. In addition, it is essential to use intensifying screens. Since these convert x-radiation into light, they cause a slight blurring effect and reduce the sharpness of the image.

As indicated before, there are in reality two exposures with the Panorex, one for each rotational axis or one for each side of the head. Due to these eccentric rotational axis, the lower incisors are not seen in true profile and often appear to slant toward the midline with a certain degree of distortion. While the Panorex does not produce as symmetrical a projection of the anterior teeth and supporting structures as is made by the concentric technique, it does make a better projection of the buccal segments.

Ionization chambers indicate that the Panorex has an output of 0.230 r. per second at a 12-inch target-chamber distance.

In 1965, Hudson and Kumpula (17), using the Panorex prototype found the maximum amount of skin exposed to radiation during any phase of the cycle was less than one square inch. This was compared to an exposure area of twelve square inches for the exposure of each intraoral film. The highest level of radiation during the Panorex cycle was found to be 0.42 r. in the vertebral area.

In 1963, Mitchell (26) reported that the highest level of radiation at the skin surface did not exceed 0.21 r. This was

less exposure than found with one intraoral film.

Jung and Grisewood separately stated in 1965 that the radiation received by the patient is considerably less from the Panorex than from a conventional periopical examination (19), (15). A routine panoramic exposure with the Panorex set at 86 K.V.P. and 8 M.A. exposes the patient to a total of 5.06 r.

In recent years, investigators have tried to establish methods for obtaining accurate quantititive measurements from panoramic films.

One of the first studies initiated to determine the rate of linear distortion using the Panorex was that of Gilbert's (11) in 1962. His results revealed that direct measurements of total image size produced 5 per cent or less distortion in 67 per cent of the radiographs taken with the instrument. In 7 per cent of the 50 radiographs there was more than 15 per cent distortion. He suggested that the greatest amount of linear distortion was present in the molar area and the least amount in the incisor area. He concluded that distortion could be minimized by proper positioning of the patient, thus yielding results that were accurate enough to enable the Panorex to be used as a reliable tool in clinical research.

Again in 1962, Kite and associates (23) evaluated the Panorex for linear distortion. First they formed a wire mesh screen into the shape of a dental arch and positioned it on the chin rest. Measurements were compared from the resultant radiographs

with those obtained directly from the wire mesh screen. This procedure was then duplicated by adapting a segment of this wire mesh screen to the dental arch of a human skull. Both sets of data revealed the same findings. The results showed that the distortion varied from segment to segment, and that no single correction factor for small segments could be utilized to obtain accurate measurements. They further evaluated linear distortion by adapting a single wire with measured soldered intervals to the vestibule of a human subject. The data obtained reflected their previous findings. They concluded that with the Panorex, a 1:1 object-to-image ratio only will be found when the plane of the object is sufficiently eccentric to the beam to compensate for the object-film enlargement caused by diverging x-rays. They stated that distortion could be exaggerated in three ways: Improper positioning of the patient, movement of the patient, and differences in width and symmetry of the jaws.

Graber (14) in 1967, suggested that distortion is present in all curved layer Roentgenograms due to varying arch form and dimensions. He concluded that this distortion, inherent in the films produced by the Panorex, limits their value for the purpose of mixed dentition analysis.

Brueggeman (9) in 1967, evaluated the Panorex unit for variations in image distortion. His sample consisted of one skull and one clinical patient, He placed lengths of round wire in a

vertical position along wax bites. With the wax bites in position the skull and patient were radiographed. He observed that variations in image distortion did occur within the anterior and posterior dental arches in the radiographs of the patient and the skull. He noted that linear distortion exhibited variation. The central incisor region changed from a negative to a positive distortion posteriorly while there was an increase in positive distortion in the molar regions. He also found a proportional increase in distortion as the ala-tragus line was varied.

Sheridan (41) in 1968 conducted a quantitative analysis of the Panorex unit. His sample consisted of 10 human skulls with stainless-steel markers placed in various horizontal and vertical planes. The skulls were positioned in a special cephalostat deigned for the Panorex, then x-rayed. The skulls were removed and repositioned to the original settings, then x-rayed again. The radiographs were finally compared to each other and to the direct measurements. He found that magnification differed from segment to segment with no apparent relationship and that magnification in similar areas of different skulls, varied in an unpredictable manner. In conclusion, he stated that apparently the Panorex unit cannot be used to measure small changes in tooth position and growth.

In 1969 Kohler (20) tried to assess the accuracy with which fully erupted lower canines and premolars could be measured on

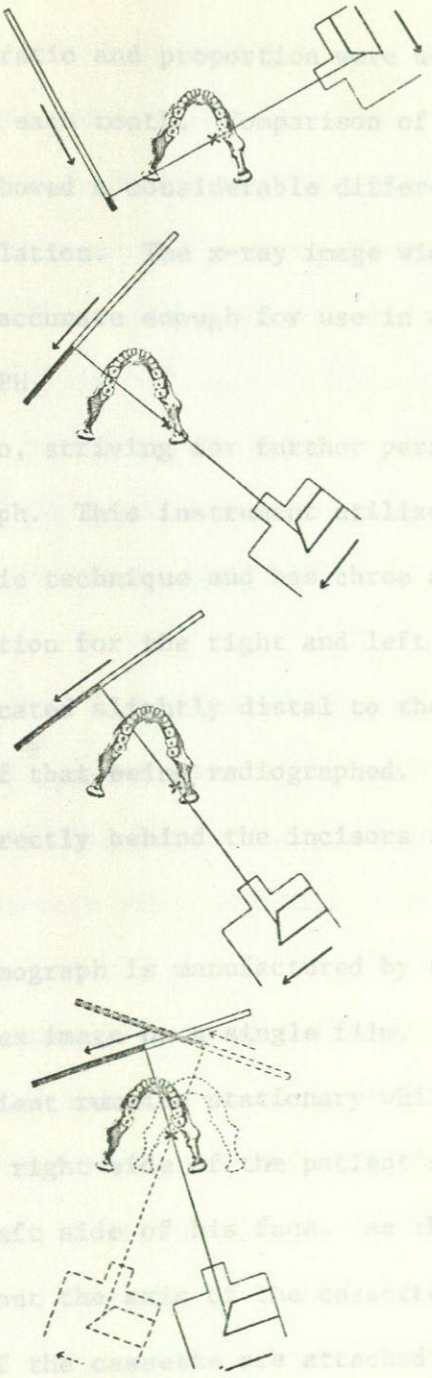


Figure 3. The Panorex. Schematic drawings of half-cycle exposure (After Updegrave).

a Panorex film. A ratio and proportion were used to compute an estimated width for each tooth. Comparison of the estimates with the actual widths showed a considerable difference due to distortion from x-ray angulation. The x-ray image width was more accurate, but still not accurate enough for use in a tooth-size analysis.

THE ORTHOPANTOMOGRAPH

In 1959 Paatero, striving for further perfection, developed the Orthopantomograph. This instrument utilizes both the concentric and the eccentric technique and has three axes of rotation. Two centers of rotation for the right and left buccal segments respectively are located slightly distal to the third molars on the opposite side of that being radiographed. The third center of rotation lies directly behind the incisors in the bicuspid region.

The Orthopantomograph is manufactured by the Siemens Co. and provides a continuous image on a single film. During the exposure of the film the patient remains stationary while the x-ray tube circulates from the right side of the patient's face, behind his neck, then to the left side of his face. As this is occurring the film rotates about the axis of the cassette holder. The x-ray tube and the axis of the cassette are attached to a horizontal bar rotating successively about three rotational axes. The center of rotation during the first portion of the exposure coincides approximately with the right side of the patient's face near the angle of the mandible. The left posterior portions of the jaws are

recorded utilizing this center of rotation, while the film moves along a curve which approximates the shape of that portion of the dental arch. When the beam has reached a point which corresponds approximately to the premolar region, the center of rotation shifts to a position which coincides approximately with the midsagittal plane opposite the premolar region. The anterior portions of the arches are recorded during this portion of the cycle. The center of rotation then shifts to a position near the left angle of the mandible, and the right posterior portions of the jaws are recorded (38).

Jung (19) suggested that radiation received by the patient from the Orthopantomograph is comparable to that received by the patient from the Panorex. He also found that the gonadal radiation doses of the Orthopantomograph were one-tenth that of the intraoral survey.

Tammisalo and Karhuvaara (47) found that radiation exposure from the Orthopantomograph was approximately one-third that of the total exposure from a fourteen-film intraoral survey.

The Orthopantomograph, like the Panorex, has been evaluated quantitatively for image distortion. In 1962 Haataja and Somer (16) did a quantitative study using the Orthopantomograph. Their sample consisted of 20 untreated and 30 orthodontically treated subjects. They measured 13 areas in the horizontal plane. Measurements taken from dental casts and radiographs were compared

showing that enlargement could be found on the films, and that if differed from segment to segment along the dental arch. They stated that differences between enlargements must be known when these radiographs are used for orthodontic diagnosis.

In 1964 Tammisalo (44) evaluated the Orthopantomograph for dimensional reproduction. He suggested that dimensional reproduction on film is forst influenced by the projection, which effect is defined by the distance between the focal point, object point, and film. A second factor that he considered was the mutual movement of the object and the film which is defined be the position of the object point in relation to the sharp image layer (one-half to three-quarters of an inch in thickness). Tammisalo states that we must know the exact form of the image layer, course of the film, and position of the object and the film in relation to each other in order to calculate the effect of each factor. He adds that in the horizontal plane, projection is accompanied by motion to cause distortion. This projection of any point not in the exact center of the image layer moves at a different speed on the film from that of the film itself. The difference in speed of image to film causes horizontal distortion. He also stated that projection is the cause of distortion in the vertical plane.

In 1966 Altiere (1) evaluated the Orthopantomograph for magnification and distortion. His sample consisted of 16 Caucasion patients undergoing orthodontic therapy. He concluded that the

radiographs produced from this instrument showed asymmetrical magnification from left to right side with the left side showing a wider range than the right side. High values of magnification were consistently found in the second bicuspid region, while lower values were found in the cuspid region. The main magnification value was 1.55 with the range of magnification between .78 and 2.32. He concluded that magnification for any given x-ray is quite likely a function of the patient being x-rayed.

In 1967 Gattozzi (10) did a quantitative analysis on the Orthopantomograph. His sample consisted of ten human skulls marked in both the horizontal and vertical planes. The skulls were placed in a special cephalostat to assess the accuracy of this instrument when repositioning is desired. His results showed that the Orthopantomograph could not be used to obtain quantitative measurements in either the horizontal or vertical direction within reasonable limits. Gattozzi suggested that differences in size and proportion of each skull, machine error, and inherent error present in the principles of laminagraphy accounted for this inadequacy.

The Panorex and the Orthopantomograph are currently the most widely used instruments of the four described above, though all offer special advantages unique to each type. Despite the fact that each instrument has certain limitations, panoramic radiography is a great contribution to clinical diagnosis.

Graber (14) feels that panoramic radiography offers the

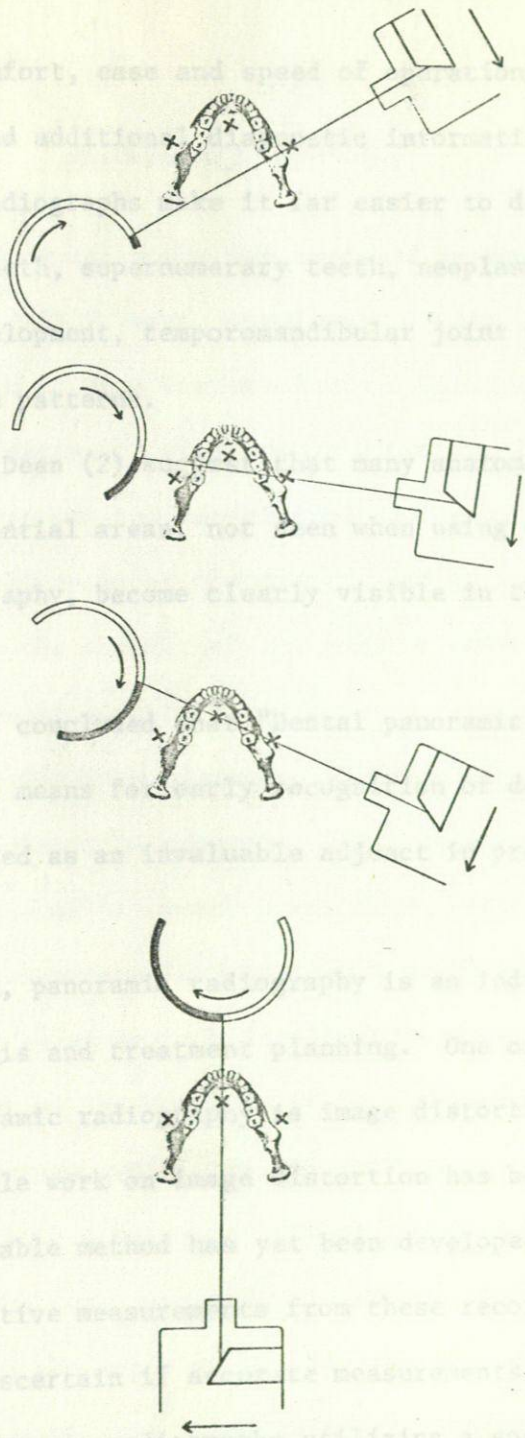


Figure 4. The Orthopantomograph. Schematic drawings of half-cycle exposures (After Updegrave).

advantages of comfort, ease and speed of operation, reduced radiation hazard, and additional diagnostic information. He suggests that panoramic radiographs make it far easier to detect impacted teeth, missing teeth, supernumerary teeth, neoplasms, cysts, the rate of root development, temporomandibular joint pathology, and abnormal eruptive patterns.

Banasik and Dean (2) suggest that many anatomical landmarks and dentally essential areas, not seen when using conventional intraoral radiography, become clearly visible in the panoramic x-ray.

Blackman (8) concluded that "Dental panoramic radiography is probably the best means for early recognition of dental disease and may be regarded as an invaluable adjunct in prevention of disease."

In summation, panoramic radiography is an indispensible aid in dental diagnosis and treatment planning. One of the problems inherent to panoramic radiography is image distortion, and although considerable work on image distortion has been done in the past, no suitable method has yet been developed to effect accurate quantitative measurements from these records. This study will attempt to ascertain if accurate measurements can indeed be obtained from panoramic radiographs utilizing a specifically devised intraoral scale.

METHODS AND MATERIALS

A special intraoral scale was designed by the author and fabricated by Mr. Adolf Vozka, machinist, in the Department of Dental Research of Case Western Reserve University. The intraoral scale was constructed of 1/8-inch diameter, low-density, polyethelene rod. This was the material of choice because: (1) it displayed excellent dimensional stability; (2) it could be readily adapted to follow the contour of any size or shape dental arch; (3) it could be machined with accuracy.

A section of 1/8-inch diameter, low-dentisty, polyethelene rod 132-mm. long was placed in a special jig. Holes, .065 inch in diameter, were then milled every 4 mm. from center to center along the rod. The holes were milled to such a depth that when stainless-steel bearings, 3/64 of an inch in diameter, were pressed to their bottom, the center of the bearings would lie in the long axis of the rod. The bearings, which were slightly larger than the holes, were then coated with a suitable bonding medium and pressed to the exact center of the rod. A midline marker of .018-inch diameter wire was placed in the scale at the midline to facilitate ease of interpretation when viewing it on an X-ray. Reference was made to a machinists handbook. It revealed that there would be a distortion of .00016 of an inch between each marker when the grid was adapted

to the circumference of a circle whose radius was 2.54 cm.

Thirty human skulls were selected from over five hundred specimens of the Todd-Hamann Collection of the Natural Science Museum in Cleveland, Ohio. The only criterion for selection was completeness of dentition; no preference was given to size, shape, age, race, or sex. The skulls were then transported to the laboratory where any loose teeth were stabilized. Markers consisting of.010 stainless-steel ligature wire were then placed between the mandibular right-and-left second bicuspids and molars of each skull. The wire was inserted inferiorly to the contact points and left a "tail" or "barb" of twisted wire projecting occlusally. This tail was then bent so that it was parallel to the long axis of the teeth, then trimmed to 1/8 inch in length.

The Panorex to be used for this study was next calibrated by Mr. Paul Paszke, technical representitive from the S. S. White division of the Pennwalt Corporation. This machine was completely aligned and adjusted so that it would be in excellent working condition decreasing the possibility of mechanical error.

The skulls were orientated on the Panorex by the use of a special cephalostat that was designed by Sheridan (41). The Cephalostat consists of a main horizontal bar which fastens to the horizontal bar of the chin rest of the Panorex. Two vertical beams

extend from the main horizontal bar of the cephalostat approximating the right and left ear holes of the skull. The cephalostat is adjustable in three planes of space. The right-and-left vertical beams adjusted from the midline laterally, and also adjust up and down to approximate the height of the ear holes. The final adjustment can be made anteroposteriorly.

The cephalostat was mounted on the Panorex. The intraoral scale was adapted to the mandibular arch of one of the skulls and held in place with a small amount of soft carding wax. Effort was made to position the skull as accurately as possible using visual alignment. The skull was positioned symmetrically on the chin-rest with its midsagittal plane located directly behind the black line on the chin-rest guard. The occlusal plane was adjusted so that it had a 5° downward-and-forward angulation which corresponded to the ala-tragus line on the cassette holder. Next, the horizontal support arm assembly was adjusted so that the reading from the scale on the front surface of the vertical bar of the chin-rest corresponded to the reading on the tall shroud. The Panorex was activated for a trial cycle to check for clearence between the skull and the cassette holder.

A series of five exposures was then made of this skull varying the milliamperage and kilovoltage in order to determine the best exposure settings for the skull. The combination of five milliamps

and fifty kilovolts was found to produce radiographs exhibiting fine definition and excellent contrast. These settings were used for all succeeding exposures. Dupont-Cronex Panoramic dental X-ray film was used for these and all succeeding exposures. The films were developed for four minutes, fixed for ten minutes, and washed for one hour. Each film was identified by marking the appropriate skull number on a strip of X-rite Radiopaque tape and placing it one inch off the center line on the left upper quadrant of the Bakelite side of the cassette.

Each of the thirty skulls, with the intraoral scale in place was then placed successively in the cephalostat and X-rayed using the same procedure as described above.

After the X-rays were developed and dried, three sets of data were collected for each skull:

(1) Mandibular arch length measurements of each skull taken from the radiographs utilizing the intraoral scale. (Pxg)

(2) Mandibular arch-length measurements taken directly from each skull. (d)

(3) Mandibular arch-length measurements of each skull taken directly from the radiographs without the use of the intraoral scale. (Pxd)

Mandibular arch length, obtained through the use of the intraoral scale, was determined in the following manner. The number of whole 4 mm. spaces that appeared along the scale between the ligature wire markers were counted. If a fraction of a space existed at

one or both first molar markers, a small millimeter ruler was used to determine what fractional part of a space extended between the last whole space and the ligature wire marker. The number of whole spaces plus the fraction or fractions were then multiplied by four to obtain the arch length measurement in millimeters. This figure along with the skull number was then recorded on a slip of paper and placed into a large envelope marked (Pxg). This process was then repeated for the X-ray of each skull. When all the measurements had been recorded, the envelope was sealed and placed aside.

Direct mandibular arch-length measurements for each skull were obtained as follows: The intraoral scale was carefully adapted to the mandibular arch so that a measurement could be read directly from the scale. It was decided to use the scale for these measurements in order to eliminate possible error between different systems. This measurement along with the skull number was recorded on a slip of paper and placed into a second envelope marked (d).

Mandibular arch-length measurements directly from the radiographs without the use of the intraoral scale were taken with heavy wax-coated thread. A knot was tied in one end of the thread, the thread was then placed along the line of occlusion on the X-ray. The thread was measured, and these figures recorded and placed in an envelope marked (Pxd).

In order to conduct an error study, the skulls were numbered from one to thirty. The first ten numbers listed in a table of random numbers were selected from the thirty to choose the skulls that would be used in this error study. The experiment was then repeated with these ten skulls as above. When the error study was completed, all of the measurements were then transferred to data sheets in order to facilitate statistical analysis.

Statistical computations were made with the Hewlett-Packard calculator model number 09100A, manufactured by the Hewlett-Packard Company of Loveland, Colorado. A summary of defining equations and assumptions employed in the present investigation will be found in appendix A.

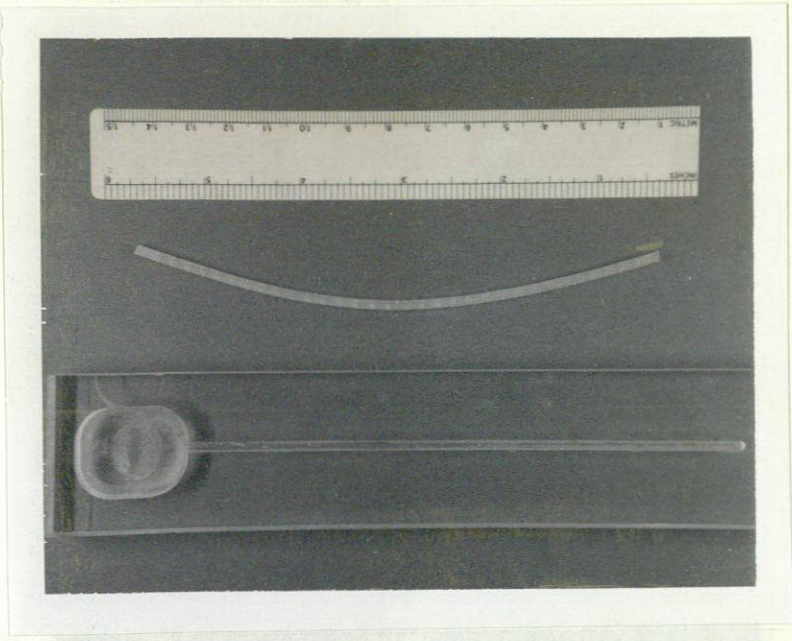


Figure 5. Scale holder, intraoral scale, and comparison ruler.



Figure 6. Intraoral scale adapted to a mandibular arch.

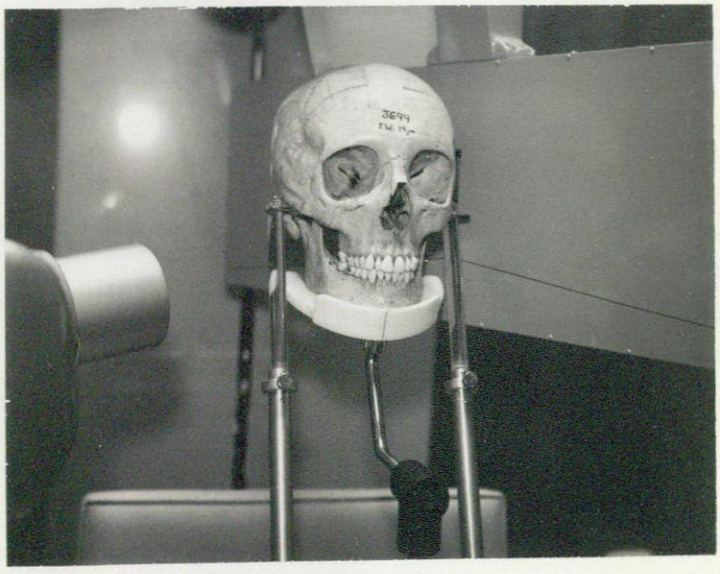


Figure 7. Skull mounted in cephalostat on Panorex.

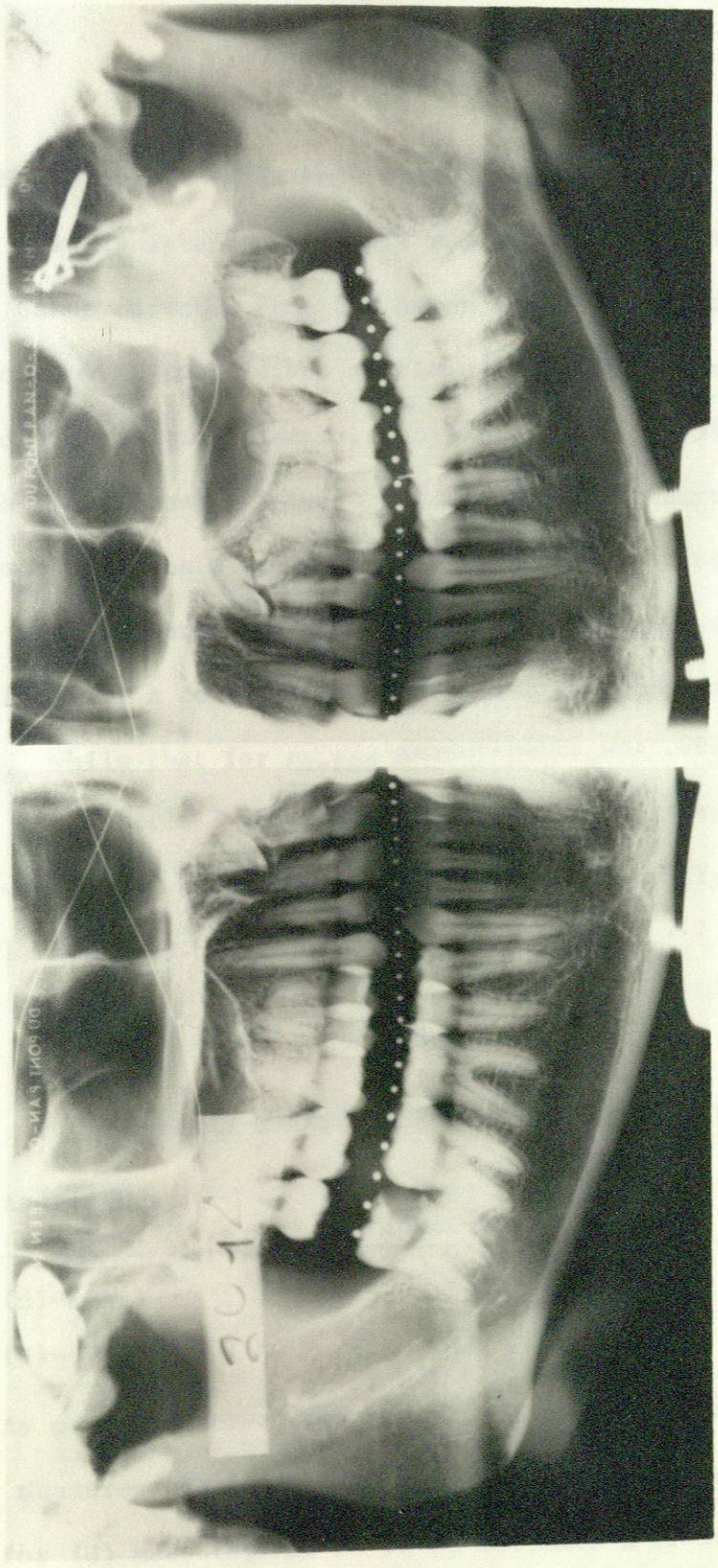


Figure 8. Panoramic radiograph of skull and intraoral scale.

RESULTS

Measurements taken from radiographs utilizing the intraoral scale are highly and positively related statistically to measurements taken directly from the human skulls. When the Pearson product-moment coefficient of linear correlation is applied to the data of the original sample, a coefficient of +.959 is obtained for the relationship between (d) and Pxg). Measurements utilizing the intraoral scale are more highly related to direct skull measurements than measurements obtained from radiographs without the scale. Specifically, a correlation coefficient of .959 was obtained for r_{d-Pxg}, while that for r_{d-Pxd} measurements was .497 (Table 1). As shown by Fisher's Z-transformation, this higher degree of correlation between (d) and (Pxg) measurements is statistically significant ($P < .01$, Table 2).

TABLE 1

PRODUCT-MOMENT COEFFICIENTS AND EFFICIENCY

Measurements Correlated:	r: (product moment)	Efficiency: $E=(1-\sqrt{1-r^2} \cdot 100)$
(d)-(Pxg)	.959	71.6%
(d)-(Pxd)	.497	13.2%

As may be observed from examining the raw data (Table 5 and 6), (Pxg) measurements tend to be smaller than (d) measurements. The mean for (d) measurements is 62.55 mm. with a standard deviation of

of ±3.96. Correspondingly, the mean for (Pxg) is 61.78 ±3.99mm.

TABLE 2

Z-TRANSFORMATIONS

Z-transformation to test: r(d).(Pxg) = r(d).(Pxd)				
r(d).(Pxg)	30	.959	1.9330	.037
r(d).(Pxd)	30	.497	0.5493	.037
		Diff.=	1.3847	Σ =.074

t=5.09

d.f.= ∞

P ⋘ .01

This difference, however, is insignificant (.760, .4<P<.5). Values of (d) may be obtained from the corresponding (Pxg) measurements by using the following regression formula: d = 4.35 +.943 (Pxg). In view of the close agreement between the values of (d) and (Pxg), however, recourse to regression equation procedure hardly seems necessary.

As might be expected, measurements obtained from radiographs utilizing the intraoral scale are as reproducible as direct measurements (Table 1,2,3) but, in spite of a slightly larger coefficient of reliability, not more so. Specifically, the coefficient of reliability, $r_{(Pxg).(Pxg)'}$, does not differ significantly from that for the direct measurements (Table 4). Thus, (d) and (Pxg) are highly and indistinguishably reproducible.

TABLE 3

RELIABILITY COEFFICIENTS

Measurements Correlated:	r. (1st. means v.s. 2nd. means)
(d).(d)'	.961
(Pxg).(Pxg)'	.987
(Pxd).(Pxd)'	.556

TABLE 4

EFFICIENCY AND Z-TRANSFORMATIONS

Measurements	rxx	n	Z	1/7
(d).(d)	.9607	10	1.9588	.1428
(Pxg).(Pxg)	.9869	10	2.5147	.1428
		diff.	0.5559	.2856

t=1.04

P>>.10

TABLE 5

MEASUREMENTS

	Skull Number	(d)	(Pxg)	(Pxd)
1.	2582	58.0	57.8	54.5
2.	2091	62.0	62.0	62.8
3.	2094	63.0	62.0	61.5
4.	656	64.8	64.5	67.5
5.	2970	66.4	65.8	60.0
6.	2208	67.6	66.7	62.8
7.	3126	66.4	63.5	55.5
8.	717	66.8	66.7	65.0
9.	1896	57.2	53.6	53.8
10.	412	64.4	63.4	60.0
11.	1729	68.0	66.6	62.0
12.	3159	68.8	67.4	64.7
13.	455	66.9	66.1	69.3
14.	1208	61.0	60.1	56.5
15.	1205	67.6	66.3	57.0
16.	459	58.4	57.3	58.5
17.	3092	63.2	62.3	65.0
18.	2586	59.2	57.9	56.2
19.	2538	59.2	59.1	57.0

TABLE 5 Cont.

MEASUREMENTS

	Skull Number	(d)	(Pxg)	(Pxd)
20.	1246	64.4	62.7	59.5
21.	456	61.2	64.0	70.5
22.	543	61.2	60.0	60.5
23.	3061	60.4	59.5	60.0
24.	383	54.0	53.2	58.0
25.	394	60.4	60.5	60.0
26.	1430	56.8	56.1	54.5
27.	492	64.8	62.9	65.0
28.	3699	60.0	61.2	60.5
29.	1204	66.8	66.4	60.2
30.	1582	59.6	57.5	58.0

TABLE 6

ERROR STUDY MEASUREMENTS

	Skull Number	(d)	(d)'	(Pxg)	(Pxg)'	(Pxd)	(Pxd)'
15.	1205	66.8	67.6	66.4	66.3	59.5	57.0
5.	2970	65.8	66.4	64.6	65.8	59.5	60.0
28.	3699	61.8	60.0	60.0	61.2	56.5	60.5
17.	3092	63.0	63.2	62.8	62.3	60.0	65.0
6.	2208	65.8	67.6	67.2	66.7	67.5	62.8
24.	383	52.2	54.0	52.1	53.2	59.5	58.0
16.	459	56.4	58.4	55.7	57.3	60.5	58.5
19.	2538	60.0	59.2	58.5	59.1	58.7	57.0
7.	3126	65.5	66.4	64.0	63.5	53.9	55.5
10.	412	65.7	64.4	64.5	63.4	62.5	60.0

DISCUSSION

The development of a number of panoramic dental x-ray machines which apply the principle of laminography or tomography to the facial region have expanded the field of dental radiography. Image distortion, inherent to all panoramic radiographic techniques, has caused an inability to obtain accurate quantitative measurements from these records, (1), (9), (10), (11), (14), (16), (20), (23), (41), (44).

The purpose of this study was to ascertain if accurate quantitative measurements could be obtained from panoramic radiographs utilizing a specially devised intraoral scale. It was shown that measurements taken from radiographs utilizing the intraoral scale are highly and positively related to the same measurements taken directly from the corresponding human skulls. These favorable findings were in contrast to those of Kahler (20) and others who utilized ratio and proportion to estimate actual measurements from those of the radiographs. Comparison of the estimates obtained by ratio and proportion with the actual measurements showed a considerable difference, the X-ray image being more accurate. Accordingly, measurements of the present study obtained by the use of the intraoral scale are highly related to actual measurements, much more so than measurements from radiographs without the use of the scale. Although the difference in values for measurements obtained by the use of the intraoral scale and actual values is insignificant, it was found that actual values

could be obtained from intraoral scale values by applying the regression formula d = 4.35 + .943(Pxg). In view of the close agreement between the values of (d) and (Pxg), recourse to regression equation procedure hardly seems necessary.

The present study has also shown that measurements obtained from radiographs utilizing the intraoral scale are as reproducible as direct measurements. The coefficient of reliability was slightly, but insignificantly, higher for (Pxg) measurements than (d) measurements due to a slight repositioning error. Thus, actual measurements and measurements obtained from the radiographs were shown to be highly and indistinguishibly reproducible.

The results of this study have shown that accurate measurements from panoramic radiographs can be obtained through the use of the intraoral scale when applied to a sample of human skulls. One would anticipate the same degree of accuracy when this technique is applied to human subjects. A follow-up study would be useful to ascertain if the same accurate results can be obtained when living subjects are used. If the results of this technique when applied clinically proved to be not quite as accurate as those of this study, they, in all probability, would be much more accurate than measurements taken directly from the radiographs, therefore still indicating the use of the intraoral scale as a valuable clinical tool.

Further uses of this technique would include adapting a segment of the intraoral scale to the temporomandibular joint region when

panoramic radiographs are used to assess joint pathology. Accurate quantitative measurements in this area would enable one to determine the degree of subluxation present. The intraoral scale could also be adapted to the vestibule adjacent to the apices of the teeth, thereby enabling one to obtain accurate measurements in this region. Finally, the use of the intraoral scale could enable one to make a mixed-dentition analysis directly from a single panoramic radiograph.

SUMMARY AND CONCLUSIONS

A study was performed to determine if accurate quantitative measurements could be obtained from panoramic radiographs utilizing an intraoral scale specially designed by the author. Thirty human skulls were selected from over five-hundred specimens of the Todd-Hamann collection of the Natural Science Museum in Cleveland, Ohio. The only criterion for selection was completeness of dentition; no preference was given to size, shape, age, race, or sex. Markers consisting of .010 stainless-steel ligature wire were placed between the mandibular right-and-left second bicuspids and first molars of each skull. The skulls were orientated on the Panorex by the use of a special cephalostat. The intraoral scale was adapted to the mandibular arch of each of the skulls; effort was made to position the skulls as accurately as possible using visual alignment. Each of the thirty skulls, with the intraoral scale in place, was then placed successively in the cephalostat and x-rayed. Three sets of data were collected for each skull:

(1) Mandibular arch-length measurements of each skull taken from the radiographs utilizing the intraoral scale (Pxg).

(2) Mandibular arch-length measurements taken directly from each skull (d).

(3) Mandibular arch-length measurements of each skull taken directly from the radiographs without the use of the intraoral scale (Pxd).

To conduct an error study, the skulls were numbered from one to thirty. The first ten numbers listed in a table of random numbers were selected from the thirty to choose the skulls that would be used in the error study. The experiment was then repeated with these ten skulls.

The following is a list of conclusions that have evolved from this study:

(1) Measurements taken from radiographs utilizing the intraoral scale are highly and positively related to the same measurements taken directly from the corresponding human skull.

(2) Measurements utilizing the intraoral scale are more highly related to direct skull measurements than measurements obtained from radiographs with the scale.

(3) The difference in values for measurements obtained by the use of the intraoral scale and the actual values is statistically insignificant.

(4) Actual values can be obtained from intraoral scale values by applying the regression formula $d = 4.35 + .943\ (Pxg)$, this procedure, however, seems unnecessary due to close agreement between (d) and (Pxg) values.

(5) Measurements obtained from radiographs utilizing the intraoral scale are as accurately reproducible as direct measurements.

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APPENDIX A

LINEAR REGRESSION AND CORRELATION COEFFICIENT

Program number 70803 of the Hewlett-Packard Company for linear regression and correlation coefficients. This program calculates the equation of the straight line of best fit of a set of data points, and also calculates a correlation coefficient r, an indication of goodness of fit. The best fit is determined by minimizing the sum of the squares of the deviations of the data points from the line.

The program calculated m and b for the equation:

$$Y = bX + a$$

The defining equations are:

$$b = \frac{\sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y})}{\sum_{i=1}^{n} (X_i - \bar{X})^2}$$

$$a = \bar{Y} - m\bar{X}$$

where $\bar{Y} = \frac{\sum_{i=1}^{n} Y_i}{n}$ and $\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n}$

$$r = \frac{\sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2 \sum (Y_i - \bar{Y})^2}}$$

T STATISTICS FOR MEANS OF TWO SAMPLES

Program number 70809 of the Hewlett·Packard Company for T statistics for means of two samples. This program calculates the value of the T statistic from the equation:

$$t = \frac{\bar{X} - \bar{Y}}{\sqrt{\frac{1}{n_x} + \frac{1}{n_y}} \quad \sqrt{\frac{\sum (X_i - \bar{X})^2 + \sum (Y_i - \bar{Y})^2}{n_x + n_y - 2}}}$$

where $X_1, X_2, \ldots . X_{n_x}$ and $Y_1, Y_2, \ldots . Y_{n_y}$ are samples from normal populations with means $_x$, and $_y$, both with same variance ^{2}. the number of degrees of freedom $n = (n_x + n_y - 2)$. The sample means are calculated by the equations:

$$\bar{X} = \frac{\sum X_i}{n_x} \qquad \bar{Y} = \frac{\sum Y_i}{n_y}$$

The sample estimates of the standard deviations are also displayed. these are calculated by the equations:

$$Sd_x = \sqrt{\frac{\Sigma (X_i - \bar{X})^2}{n_x - 1}} \qquad Sd_y = \sqrt{\frac{\Sigma (Y_i - \bar{Y})^2}{n_y - 1}}$$

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