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PANORAMIC RADIOGRAPHY IN ORTHODONTICS

USING A SPECIAL CEPHALOSTAT

by

JAMES NICK ALTIERE, JR.

Submitted in partial fulfillment of the requirements

for the Degree of Master of Science

Department of Orthodontics

WESTERN RESERVE UNIVERSITY

June 1966

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ACKNOWLEDGMENTS

The author is greatly indebted to many persons for their generous co-operation in making this study possible. The writer wishes to thank Doctor Ike Slodov for much of his valued time as well as for the use of his Orthopantomograph and office facilities.

The investigator expresses his gratitude to Doctor B. Holly Broadbent, Sr., Professor Emeritus of Dentofacial Morphology, Western Reserve University and Director of the Bolton Study of Dentofacial Developmental Growth for making this Study's facilities available.

He, also, is sincerely appreciative of the guidance and timely suggestions which he received from Doctor Richard C. Beatty, Professor of Orthodontics, Doctor Sanford Neuger, Assistant Professor of Orthodontics, and Doctor Philip Burwasser, Director of Graduate Courses, all of Western Reserve University, School of Dentistry.

The writer especially wishes to thank his wife and family whose sacrifices helped to make this period of his education possible.

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INTRODUCTION

Panoramic radiography offers a rapid and practical method to produce a panoramic view of the entire dentofacial complex on one flat surface. This is accomplished by a tomographic technique which produces a roentgenographic panorama of a predetermined curved layer of tissue within a three-dimensional object. Several methods are now available for obtaining a panoramic image of the stomatognathic system. Pantomography, now in its infant stage, has its growing pains, but shows great potential as a useful diagnostic tool in dentistry.

Graber, in his paper entitled "Panoramic Radiography in Dentistry," feels that panoramic x-rays can be diagnostically helpful in studying growth and development, resorption and eruption patterns, the temporomandibular joints, and serial extractions procedures (1). Certainly, the above mentioned areas are of great interest and importance to the progressive orthodontist. Graber concludes that panoramic radiography is a useful diagnostic tool.

Among the criticisms leveled at present day panoramic x-rays are those of magnification, distortion of the image, and lack of standardization of measurements. To be sure, refinements must take place in the near future if panoramic roentgenography is to achieve a high degree of acceptance by the profession. One panoramic x-ray unit, the Orthopantomograph, apparently gives promise of standardization to the point of deriving meaningful measurements.

This thesis is a discussion of the Orthopantomographic technique as described by Paatero and its usefulness as a diagnostic tool. In conjunction with panoramic radiography a major point of interest in this study is concerned with the Frankfort-mandibular plane angle. Two areas of present controversy in orthodontics concern the following:

1. Is there any difference in tooth migration in those patients with high, low, or middle Frankfort-mandibular plane angle?

2. Does the bite open more readily in high Frankfort-mandibular plane angle cases than low Frankfort-mandibular plane angle ones?

The Orthopantomograph is a most useful tool in seeking the answers of these current questions. Therefore, this study represents an attempt to evaluate:

1. The use of orthopantomography in orthodontics.

2. The importance of the Frankfort-mandibular plane angle in relation to bite opening and tooth migration.

PURPOSES

The purposes of this study are:

1. To test the reliability of repositioning living human subjects for serial study, using a cephalostat especially designed for the Orthopantomograph;
2. To establish standardized reference landmarks on film from the Orthopantomograph;
3. To determine mesiodistal movement of the mandibular first molar, second bicuspid, and cuspid after seven weeks of leveling;
4. To determine the amount of tooth movement into the extraction site during the seven-week leveling period of orthodontic patients who have had mandibular first-bicuspid extractions;
5. To determine if there are any differences in the amount of migration in those patients with high, low, or middle Frankfort-mandibular plane angle;
6. To determine if the bite has a greater tendency to open more readily in high Frankfort-mandibular plane angle cases than in low Frankfort-mandibular plane angle cases; and
7. To evaluate the usefulness of panoramic radiography as a diagnostic adjunct in orthodontics.

REVIEW OF THE LITERATURE

A thorough search of the literature shows many references concerning panoramic roentgenography. Most of the references are concerned with two differently designed panoramic instruments, the Panorex and the Orthopantomograph. The Panorex employs the eccentric tomographic principle of roentgenography while the Orthopantomograph combines the concentric and eccentric tomographic principle. The Panorex is a dental x-ray unit manufactured by X-Ray Manufacturing Corporation of America and S. S. White Company of the United States. The Orthopantomograph is a dental x-ray unit manufactured by Siemens' of Germany and Sarjavilmiste of Finland. This study utilized the Siemens' Orthopantomograph modified by the addition of a special cephalostat.

The review of the literature will be divided into three categories:

1. History and development of panoramic radiology in general.
2. Discussion of orthopantomography as developed by Paatero.
3. Discussion of the Frankfort-mandibular plane angle and its importance in orthodontics concerning bite opening and migration of the teeth.

History and Development

Panoramic roentgenography offers a rapid and practical technique to produce a continuous image of the entire stomatognathic system on a single film (figure 1). This is accomplished by a tomographic technique

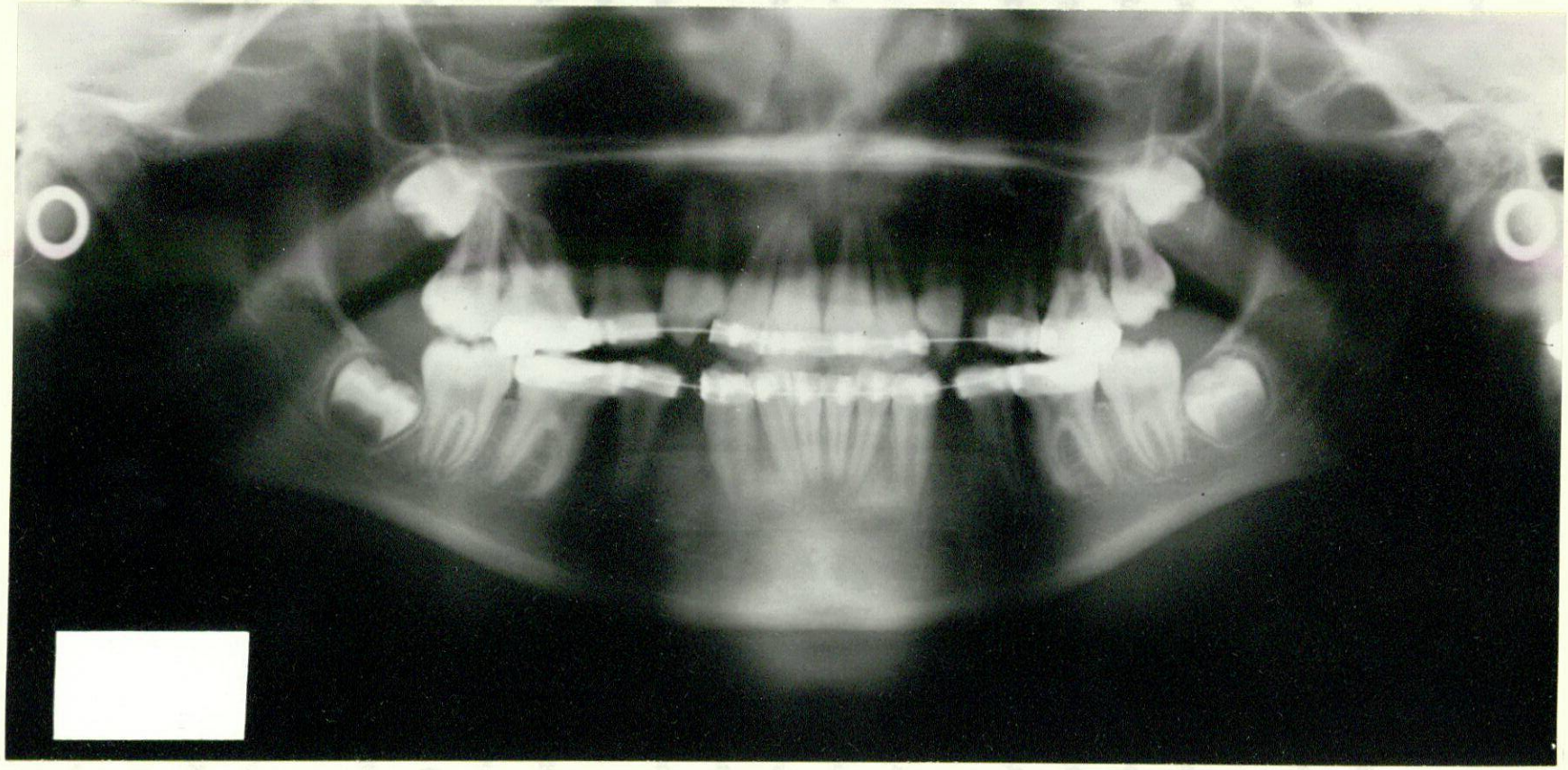


Figure 1. Panoramic roentgenogram of a twelve-year-old patient taken with the Orthopantomograph.

which produces a roentgenographic panorama of a predetermined curved layer of tissue within a three-dimensional object.

Tomography is a method of obtaining such a radiographic image as mentioned above and is based on "the even motion existing between the roentgen tube and the object to be pictured"(2). By rotating the x-ray tube around the object and simultaneously moving the film cassette, only the particular layer of interest will be in focus while all other layers are blurred out. It is very similar to focusing an object with a camera. All intervening structures are blurred out except the object in focus.

Panoramic roentgenography is of recent development. Some of the pioneers in this field are: Heckman, Paatero, Nelsen, Kumpula, and Blackman. Prior to World War II, the German investigator, Heckman, was the first person to apply the tomographic process to curved surfaces (3). However, his work was interrupted by the war, and he could not perfect his technique. After the war, Paatero of Finland, began his investigation in panoramic radiology. In 1948, while in search of a simple method for full-mouth roentgenography, Paatero described the use of a mobile source of light (x-rays) for radiographing teeth (4). In 1949, he outlined a new tomographic technique and its application to curved surfaces (2).

In 1952, Nelsen and Kumpula (5) began their investigation of "panographic radiography" at the National Bureau of Standards in the United States. By 1957, Kumpula, Hudson, and Dickson had developed a panoramic dental x-ray unit for use in mass surveys.(6) This machine was the prototype of the Panorex and is now being manufactured by S. S. White Dental Manufacturing Company and X-Ray Manufacturing Company of America.

Blackman in England followed Paatero's lead and attempted to perfect and stabilize his own apparatus (7). Blackman hoped that it would be employed throughout the country for mass dental radiography in order to obtain a comprehensive survey of tooth development from early childhood. After some modification, he developed this into the Rotograph by 1960 (3). A year later, Dr. Blackman developed the Panagraph which he called an "Anglo-Swiss development." (8) The Panagraph is a modification of an intraoral panoramic technique first developed by Dr. Walter Ott of Switzerland. Although it does not follow the tomographic principle, panagraphy produces a panoramic view of the oral cavity.

In evaluating the usefulness of panoramic radiography in orthodontics, Graber, (1) Gilbert, (9) Kane, (10) and Paatero (11) all suggested that panoramic radiography offered great potential as a diagnostic aid.

Tammisalo wrote that the orthopantomogram "offers exceptional possibilities for measurement and mutual comparison either of any individual teeth or of any other object point from a single roentgenogram." (12) In 1964, Kane described a cephalostat with three-dimensional calibrators designed for the Panorex for the purpose of duplicating original settings. (10) A serial study could thus be made to determine subsequent changes of original conditions.

Updegrave stated that "one of the greatest advantages of panoramic radiography is its scope of examination." (13, 14) Not only could the teeth and supporting tissues be seen, but also the entire mandible and maxilla. He noted that superimposition of intervening anatomic

structures are eliminated, which is important for a more accurate diagnosis. He also mentioned the value to the oral surgeon of being able to see the teeth in their correct relationship to adjacent anatomic structures and to each other.

Updegrave also stated that panoramic radiography offered other advantages to the operator and the patient. It is not necessary to place individual films intraorally. Gagging is eliminated, radiation is lowered, and this is beneficial to children and those who have anatomic abnormalities. It is also suitable for patients who are partially or completely edentulous. This feeling is shared by Kiminki and Paatero (15). Updegrave concludes that panoramic radiography is especially useful for mass screening procedures, and is applicable to certain specialities as well as general practices.

Mitchell, in 1963, reported that although panoramic radiography was of little value for revealing incipient caries, it was particularly useful for child patients (16). He suggested it as a useful supplement to conventional intraoral radiography. He concluded his report by predicting further improvements in design and operation of the equipment.

Banasik and Dean state that panoramic roentgenography is applicable to the specialty field of preventive orthodontics when studying and carrying out procedures involving serial extractions (17). They also felt that the panoramic x-rays taken during treatment could be of prognostic value.

Another important area for panoramic radiography concerns the temporomandibular joint. Tammisalo, in 1964, reported that panoramic radiograms of the temporomandibular joint taken with the

Orthopantomographs were, in many respects, superior to corresponding x-rays obtained by other methods (18). Graber concurred with this viewpoint (1). Tammisalo, Nieminen, and Paatero further demonstrated the versatility of panoramic radiography with their reports on the use of panoramic x-rays involving diagnosis of the maxillary and paranasal sinuses (19, 20).

Of great importance and concern to all health specialities is exposure to radiation. In 1955, Hudson and Kumpula reported their findings concerning the levels of radiation produced by their panoramic dental unit and by a conventional 14-film intraoral technique (21). Hudson and Kumpula used the prototype of the Panorex. They showed the total area of skin surface exposed to radiation at any point during the cycle was less than one-square inch. About 12-square inches of skin surface was covered during each individual exposure with the intraoral technique. The highest level of irradiation during the panoramic cycle was 0.42 r recorded in the cervical lymphatic region of the neck. The highest comparable measurements recorded for the conventional intraoral series of 14 exposures was 27 r in the thyroid gland region.

Blackman, in 1960, also reported very low levels of radiation emitted by his panoramic unit, the Rotograph (3). He stated that his patients received less than one-tenth the radiation compared to the patient who undergoes a full-mouth intraoral examination.

Mitchell, in his report on the Panorex in 1963, noted that the highest level of radiation at the skin surface during the Panorex cycle did not exceed 0.21 r (16). This exposure is less than that received

by the patient from exposure of a single intraoral film using ultra-speed film.

In 1964, Tammisalo and Karhuvaara reported the exposure using Paatero's Orthopantomograph was approximately one-third that compared to the conventional intraoral examination of 14 exposures (22).

Thus, it can be seen from the above mentioned reports that not only is the amount of time of taking and developing the film considerably less compared to the customary intraoral technique, but that the level of radiation to the patient is greatly minimized.

Orthopantomography

Orthopantomography (23), like pantomography (24), is a rotational tomographic technique pioneered by Paatero of Finland. His objective was to produce a panoramic view of the entire dentofacial complex on one flat surface via a single exposure of radiation. In 1948, Paatero, in search of an easier way to take full-mouth x-rays, utilized a mobile source of light (x-rays) for radiographing teeth (4). Continuing his research, the following year he published his outline of a new tomographic technique as it applied to curved outer surfaces. In 1950-1951, working for a year and a half at the Dental School of the University of Washington, he did research and experiments in this field and submitted a report of the results for publication in the United States.

Later, in Finland, he improved his method of pantomography in order to develop a reliable and useful method for recording, on an ordinary flat film of radiograms, any curved layers of a three-dimensional object.

The Pantomograph consisted of a motor-driven chair, a rotating film holder, and a stationary x-ray source (24). By revolving the object and the film at identical angular velocities but in opposite directions, a panoramic roentgenogram of any predetermined curved layer of the object was obtained. It was necessary to bend the film into the shape of the layer to be radiographed in order to obtain a suitable representation of the particular layer of interest.

Pantomography is a tomographic technique which consists of one center of rotation for the patient and film holder. This method of employing one center of rotation is known as the concentric tomographic technique. The axis of rotation for the patient is located at a point in the midsagittal plane just behind the third molars (figure 2). Blackman's Rotograph also employs the concentric tomographic principle. Graber made the comment that this method is fairly satisfactory for young children and persons with brachycephalic faces (1). He concluded that distortion and blurring occur in dolichocephalic individuals.

Paatero, in search of better definition of the jaws and teeth, developed another tomographic technique using two centers of rotation, one for each side of the face (figure 2). He called this the eccentric technique. In this method, the center of rotation is behind the third molars on the side opposite that being radiographed (24). The instrument swung over from one axis to the other as it passed the midsagittal plane. He felt that both the concentric and eccentric techniques had their advantages and disadvantages (25). He stated that the concentric pantomograms gave good overall views provided that the layer in question was cylindrical in form. However, if the layer is parabolic, like

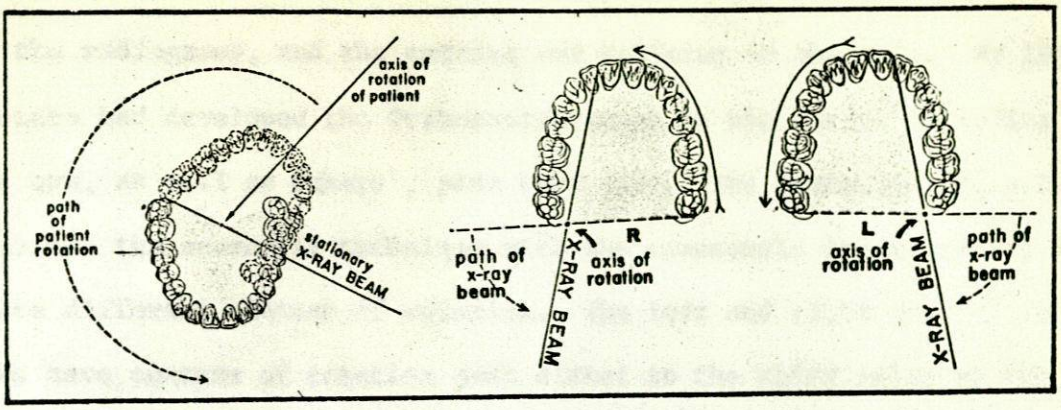


Figure 2. Left: Diagram of the concentric tomographic principle. Shaded area represents region of exposure. Patient moves while x-ray beam is stationary. Right: Diagram of eccentric tomographic principle. X-ray beam moves around stationary patient. (After Kumpula, J. W., J.A.D.A. 63:194, 1961 and modified by Graber, T. M., J. Canad.D.A. 31:158, Mar. 1965)

the human jaw, the eccentric technique is the one of choice since it produces sharper images of the molar and premolar areas on the film. Paatero stated that a drawback of the eccentric technique was the necessity of two exposures, one for each side of the jaws, and the repositioning of the patient.

It may be of interest to note that the Panorex, modeled after the prototype developed by the United States Bureau of Standards and United States Air Force, uses the eccentric tomographic technique. Although it produces excellent views of the buccal segments, the anterior segment is blurred. Furthermore, as a result of the movement caused by repositioning the patient by the shifting of the chair, overlapping occurs in the central part of the film. This necessitates cutting and splicing the two halves together.

Paatero attempted to devise a method which would improve the eccentric tomographic instrument, such as the Panorex. He wished to eliminate repositioning the patient, the blurring in the middle part

of the radiograms, and the cutting and splicing of the film. By 1959, Paatero had developed the Orthopantomograph in his search to refine his own, as well as others', past work (26). The Orthopantomograph combines the eccentric technique with the concentric technique and has three different centers of rotation. The left and right side of the jaws have centers of rotation just distal to the third molar on the opposite side to that being radiographed. The anterior segment has its center of rotation located posterior to the incisors and approximately at the bicuspid region (Figure 3). In order to produce an orthopantomogram with a single exposure, the procedure is outlined as follows:

1. The x-ray head and synchronized-film holder moves from position 1 to position 2 on the center of rotation O_1 to provide an image of the left side of the jaws on the film.
2. When the x-ray beam reaches point P, which approximates the left second bicuspid locale, the x-ray head and film holder glides to a new center of rotation, O_2, to radiograph the anterior segment.
3. As soon as point N is reached, the x-ray beam begins rotation about axis O_3; and the right side of the jaws is reproduced on the film.

The Orthopantomograph takes about 15 seconds to complete its cycle and produces a remarkable panoramic view of the dentofacial complex.

Professor Paatero has contributed an excellent instrument for obtaining panoramic views of the stomatognathic system. Dentistry, as well as other allied specialities, are indebted to him. His

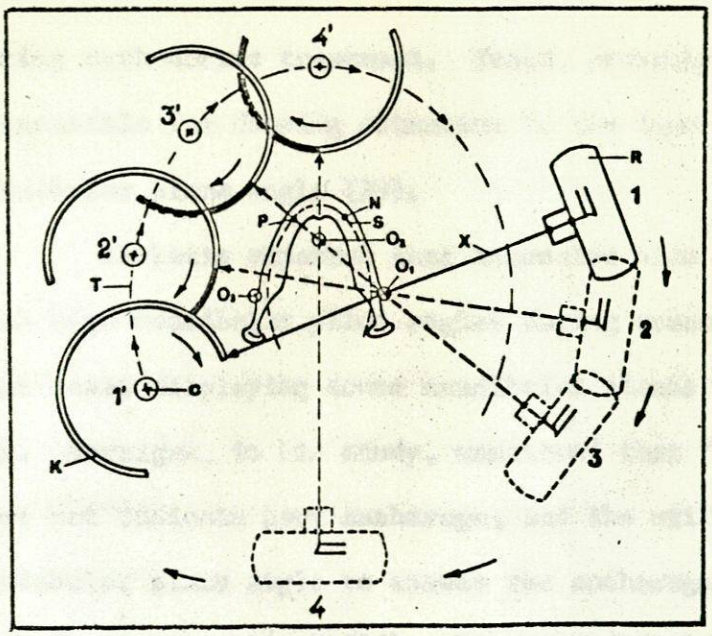


Figure 3. Diagram of the combined concentric and eccentric tomographic principle. The x-ray beam glides around the axis O_1 to radiograph the left side of the face, and about axis O_2 to radiograph the anterior region (P-N) of the face. The image of the right side of the jaws is projected on the film when axis O_3 is in use as the rotation center. (after Paatero)

untimely death in 1963 has deprived us of a great researcher.(27). Now it is up to others to continue his work in panoramic radiology, a field in which he pioneered.

Frankfort-Mandibular Plane Angle

The Frankfort-mandibular plane angle was established by the intersection of the Frankfort-horizontal plane and mandibular plane. The Frankfort-horizontal plane was constructed by drawing a line from orbitale tangent to the superior part of mechanical portion. The mandibular plane was erected by drawing a line from menton to a point tangent to the lower border of the mandible just posterior to the antegonial notch.

Very little has been written concerning the Frankfort-mandibular plane angle and its importance in bite opening and migration of teeth

during orthodontic treatment. Tweed, probably more than anyone else, is responsible for drawing attention to the importance of the Frankfort-mandibular plane angle (28).

Ricketts reported that excessive bite opening occurs in cases with high mandibular plane angles during treatment. (29). He stated that cases displaying acute mandibular planes tend to resist bite opening. Horrigan, in his study, mentioned that "a steep mandibular plane does not indicate poor anchorage, and the utilization of the Frankfort-mandibular plane angle to assess the anchorage value of the mandibular arch is questionable." (30). He concluded that a case presenting a steep mandibular plane does not suggest an increased tendency for the bite to open during orthodontic treatment.

Schudy, in his study of the importance of the occlusal plane, contends that the occlusal-mandibular plane angle is significantly related to overbite (31). He maintains those cases with high occlusal-mandibular plane angles have a greater tendency for the bite to open. Cases exhibiting occlusal-mandibular plane angles below 8 degrees tend to resist bite opening.

METHODS AND MATERIALS

Sixteen patients who are undergoing treatment at the Orthodontic Department, Western Reserve University School of Dentistry served as subjects. The sample consisted of twelve females and four males. All of the subjects were Caucasians and their ages varied from eleven to fifteen years of age.

These children were specifically selected because they were classified as having Angle Class II malocclusions and were diagnosed as needing the removal of dental units. One patient, although she had an Angle Class I malocclusion, was included in the study because her twin sister was in the group. This author felt that a comparison of the twins might reveal some points of interest. The patients were divided into three groups according to their Frankfort-mandibular plane angle as shown in Table 1. These patients were classified as high, low, or middle Frankfort-mandibular plane angle cases.

Treatment Procedure

I. Initial records were taken before treatment was started.

   A. Study models.

   B. Complete intraoral roentgenograms.

   C. Lateral and frontal roentgenographic cephalometer

TABLE 1

CLASSIFICATION OF PATIENTS IN THE THREE GROUPS

Patient	Age	Sex	Division of Angle Class II	(FMA) Frankfort-Mandibular Angle
			Group I	**Low (FMA)**
1	13	F	1	22.0
2	15	F	1	22.5
3	11	M	2	22.5
4	13	M	1	22.5
5	12	F	1	20.75
			Group II	**Middle (FMA)**
6	12	F	1	28.75
7	12	F	1	25.5
8	14	F	1	29.0
9	12	M	1	23.5
10	14	F	1	26.5
			Group III	**High (FMA)**
11	12	M	1	31.0
12	12	F	1	30.5
13	11	F	1	31.0
14	12	F	1	31.0
15	13	F	1	29.75

II. Band Placement

Bands were fitted and cemented on all teeth deemed necessary for treatment except those which were indicated for removal. This procedure was carried out by the junior students in the Orthodontic Department at Western Reserve University.

III. Second set of models, lateral and frontal cephalometric roentgenograms, and the first orthopantomograms

These records were taken before extraction of teeth and measurements were made from them which will be described in detail later in this chapter.

IV. Removal of Dental Units

V. Standardized Leveling Method Was Initiated

VI. After seven weeks of leveling, the final records for this study included: orthopantomograms, frontal and lateral cephalograms, and study models.

Radiographic Procedure

I. Equipment

A. The Broadbent-Bolton cephalometer was utilized for all cephalograms

B. The Orthopantomograph, designed by Paatero of Finland is manufactured by Siemens' Medical X-Ray of Germany and Sarjavilmiste of Finland (figures 4 and 5).

C. A special head positioner was designed to be used in the Orthopantomograph specifically for this study (figure 6).

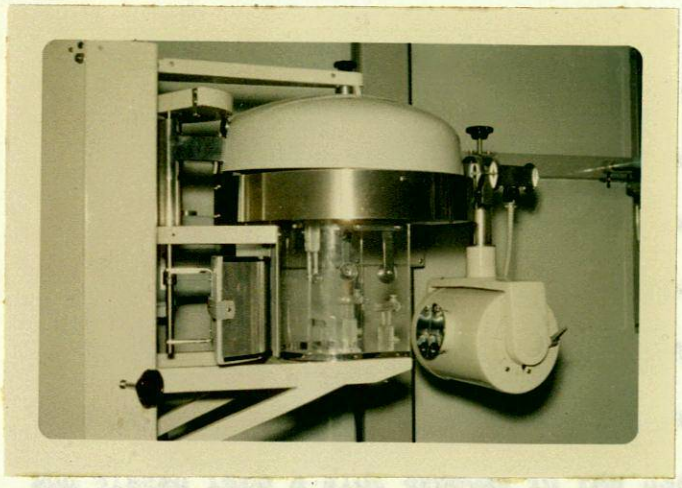


Figure 4. Orthopantomograph

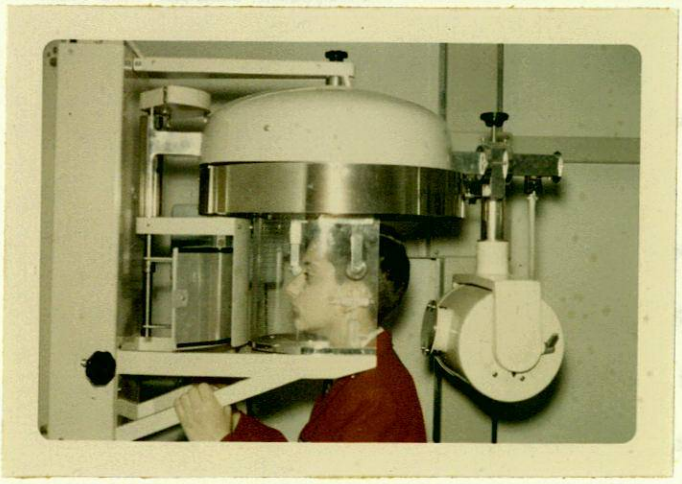


Figure 5. Patient positioned in Orthopantomograph

This cephalostat was made completely of plexiglass in order to minimize superimposition of its image on the orthopantomogram. There are eight adjustable parts to allow for the vertical, horizontal, and depth movements. The nasal rest apparatus was suspended from the Orthopantomograph as illustrated in figure 6. It allowed for anteroposterior movement as well as up and down. Two vertical columns (figure 7) housed vertical structures which support horizontal structures from which vertical and horizontal measurements could be made. These vertical columns were in turn supported and placed into a slot grooved in the base of the cephalostat which would allow medial and lateral movement. This U-shaped base was affixed to the Orthopantomograph via two metal screws.

Metal washers were modified and fitted snugly on each ear-rod. The purpose of these metallic rings was to reveal the position of mechanical porion. They were used as reference points on the tracing.

Clear plastic millimeter rules with black figures were mounted on the cephalostat in the appropriate areas and red lines inscribed in the plastic permitted measurements to be read easily. Thus, by proper procedure, the ear rods could be readily placed into the external meati of the patient.

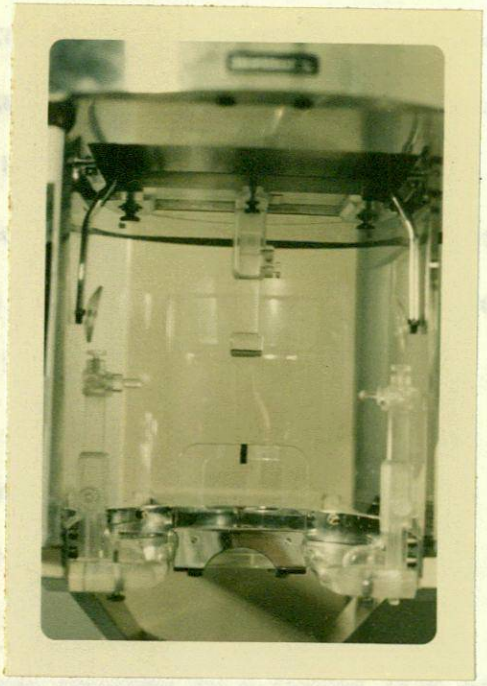


Figure 6. Special cephalostat used in this study.

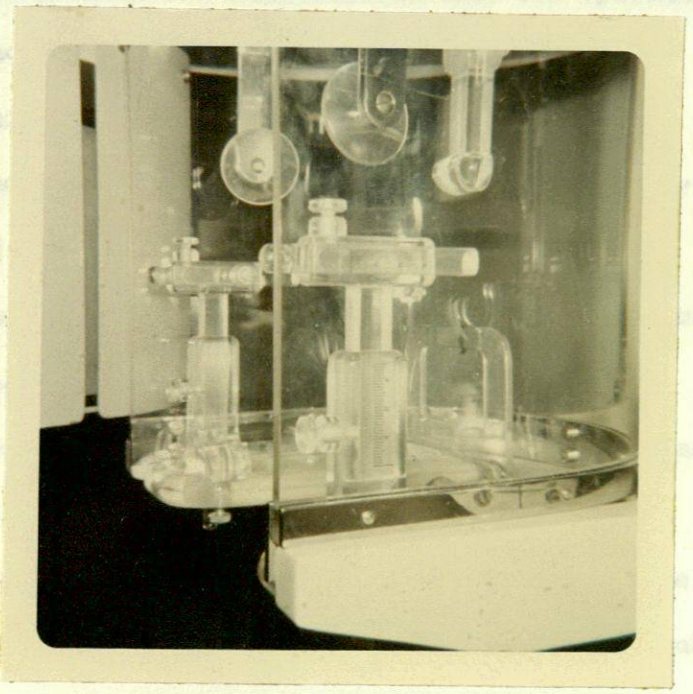


Figure 7. Close-up of vertical and horizontal structures of the head positioner.

II. Procedure

A. All cephalograms were taken in the conventional manner at the the Bolton Study of Dentofacial Developmental Growth, School of Medicine, Western Reserve University.

B. All orthopantomograms were taken at a private practitioner's office by the author. The procedure is described as follows:

1. A 6 x 12 inch Kodak Blue-Brand film was placed in a plastic cassette.
2. The patient's name and date was printed on X-rite Opaque Label tape and placed on the lower left side of the cassette for identification.
3. The film was mounted on a curved film holder which was then affixed to the Orthopantomograph.
4. The patient was familiarized with the operation of the machine and instructed how to place his chin against the chin positioner.
5. The nasal rest was then adjusted, followed by the placement of the ear rods.
6. The head was further stabilized by plastic holders placed near the temple region.
7. The patient was then told to "close on his back teeth and hold everything steady."
8. Exposure of 80 Kv. and 20 Ma. for approximately 15 seconds was made. During this exposure cycle, the author attempted to detect any movement of the already well-stabilized head.

9. Measurements of the settings on the cephalostat were recorded after exposure.
10. After approximately seven weeks of leveling, each patient was repositioned according to his original readings for the final orthopantomograms.

Modification of Equipment

After taking a few orthopantomograms, it became apparent that a more controlled method was needed to insure proper placement of both condyles on the 6 x 12 inch Kodak Blue-Brand film.

A dry skull was used for this purpose. The loaded cassette was placed at a certain distance from the end of the cassette holder and an exposure of the skull was made. After several trials and errors, the correct location for the cassette was determined and a reference point was inscribed on the cassette holder for future reference. This modification of the equipment provided the means by which one could adequately take a panoramic x-ray of the dentofacial complex from one temporomandibular joint around the arch to the opposite temporomandibular joint (figures 8 and 9).

Leveling Procedures

In order to diminish discrepancies, all patients were to undergo a seven-week period of leveling treatment. A series of three round arch wires of .016, .018, and .020 diameters were used. The schedule required each patient to wear the .016 arch wire for three weeks, and the .018 and .020 arch wires for a period of two weeks each.

The maxillary and mandibular arches were bent ideally in form. Bayonet bends were placed in each arch far enough mesially to the molars

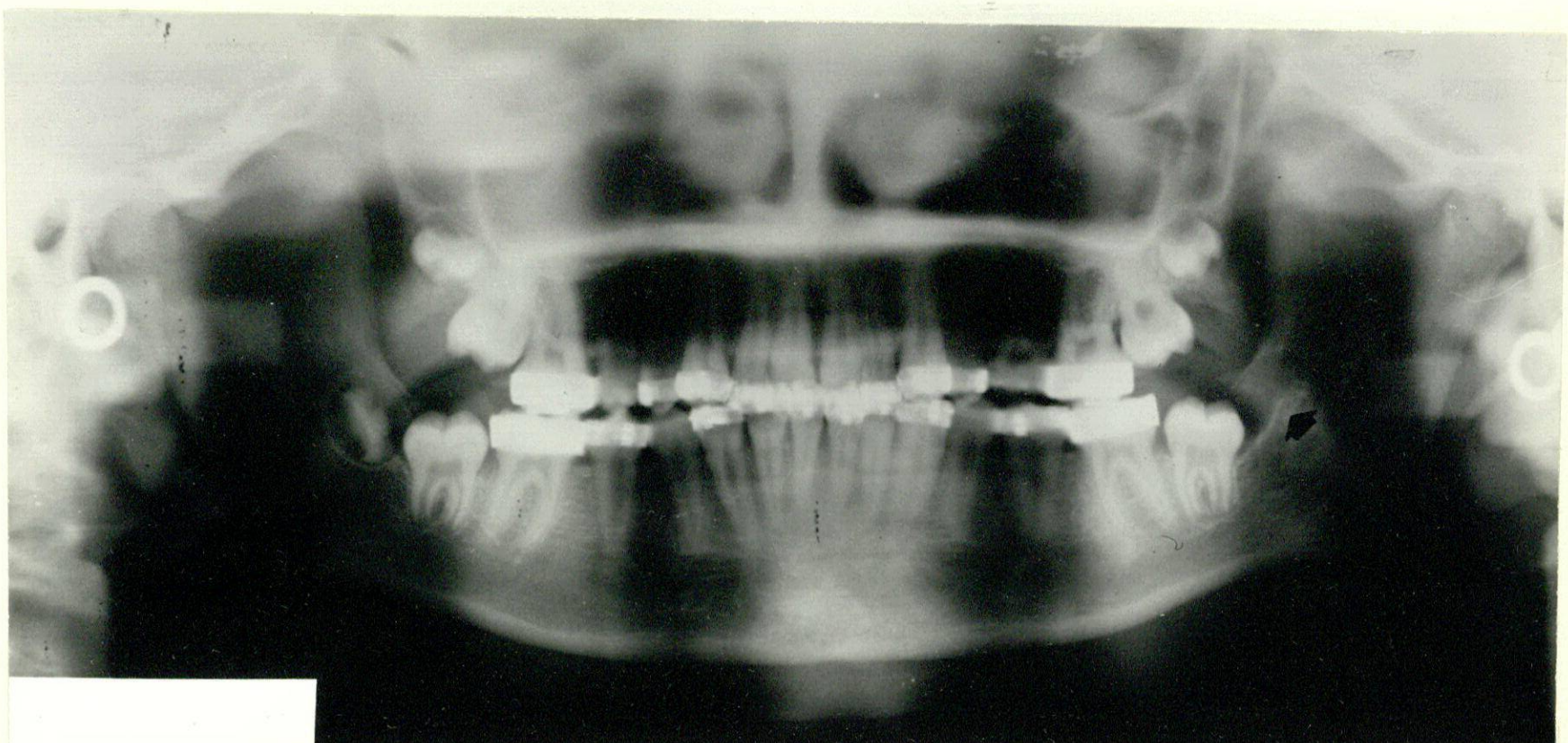


Figure 8. Panoramic x-ray showing the dentofacial complex from one temporomandibular joint around the arch to the opposite temporomandibular joint. Arrow shows follicular cyst in the mandibular third-molar region.

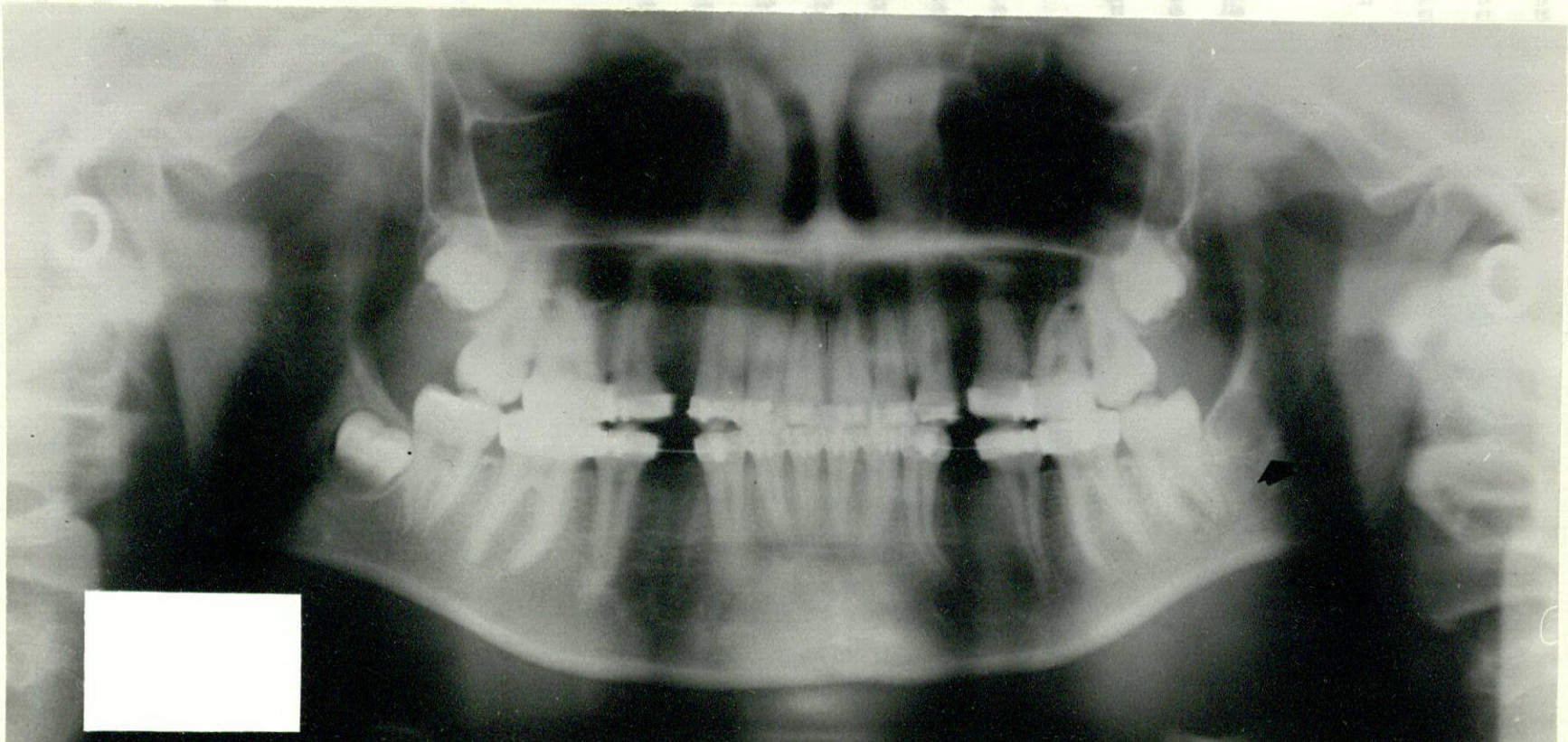


Figure 9. Panoramic x-ray of a twelve-year-old orthodontic patient. Note follicular cyst in mandibular third-molar region.

not to interfere with tooth migration. No reverse curves of Spee, lateral insteps, or stops were incorporated into the arch wires. All the arch wires were formed and placed by three graduate orthodontic students in the junior class.

Measurements

I. Study models:

A. Magnification

The mesiodistal width of each mandibular tooth from first molar around the arch to the opposite first molar was measured after banding. These measurements were used to determine the degree of magnification these teeth showed when measured on the orthopantomograms. All measurements on the models were made with a Boley gauge to the nearest .1 of a millimeter. Measurements were made near the incisal edge of the band close to the contact point as illustrated in figure 10.

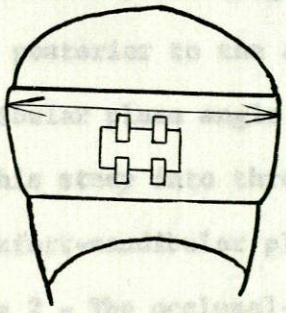


Figure 10. Mesiodistal measurement from study models and orthopantomograms.

B. Amount of space closure

The distance between the mesial of the first molar and distal of the cuspid, the mesial of the first molar and distal of the second bicuspid, and the mesial of the second bicuspid and distal

of the cuspid were measured and recorded from the models taken after banding and leveling. These measurements were made to determine if there were any difference in tooth migration in those patients with high, low, or middle Frankfort-mandibular plane angles.

II. Lateral Cephalometric Roentgenograms

A. All tracings were done on .003-inch matte acetate. Whenever bilateral structures were involved, the right and left sides were traced separately and an average tracing made. Figure 11 illustrates structures traced.

B. The following linear and angular measurements were made:

1. Angle 1 - The Frankfort-mandibular plane angle. This angle was established by the intersection of the Frankfort-horizontal plane and mandibular plane. The Frankfort-horizontal plane was constructed by drawing a line from orbitale tangent to the superior part of mechanical porion. The mandibular plane was erected by drawing a line from menton to a point tangent to the lower border of the mandible just posterior to the antegonial notch. The Frankfort-mandibular plane angle was used to classify the patients in this study into three groups of high, low, and middle Frankfort-mandibular plane angle.

2. Angle 2 - The occlusal-mandibular plane angle. The occlusal-mandibular plane angle was established by the intersection of the mandibular plane and the occlusal plane. The occlusal plane was constructed by drawing a line that bisected the crown portions of the maxillary and mandibular central

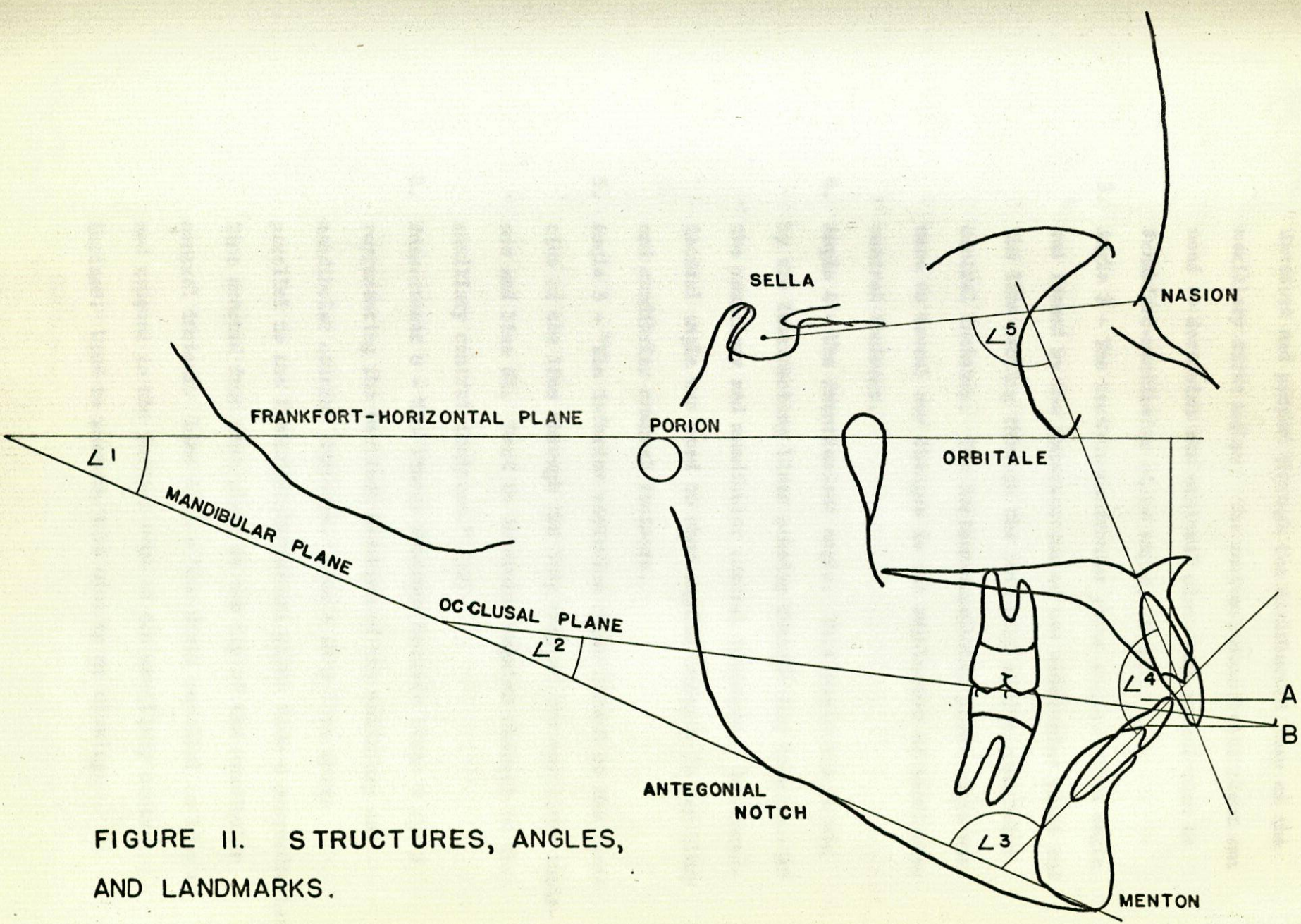


FIGURE II. STRUCTURES, ANGLES, AND LANDMARKS.

incisors and passed through the distobuccal cusp of the maxillary first molar. The occlusal-mandibular plane was used to determine the occlusal plane and correlation to Frankfort-mandibular plane angle, if any.

3. Angle 3 - The incisor-mandibular plane angle. This angle was formed by the intersection of the mandibular plane and the line passing through the long axis of the mandibular central incisors. The incisor-mandibular plane angle was used to reveal any changes in the angulation of mandibular central incisors.
4. Angle 4 - The interincisal angle. This angle was formed by the intersecting lines passing through the long axes of the maxillary and mandibular central incisors. The interincisal angle was used to show angular changes in maxillary and mandibular central incisors.
5. Angle 5 - "The inferior posterior angle formed by the junction of the line through the long axes of the maxillary incisors and line SN. Used to determine angular changes in the maxillary central incisors." (32)
6. Measurement 6 - The linear distance between lines A and B representing the vertical overbite of the maxillary and mandibular central incisors. Line A is a line drawn parallel to the Frankfort-horizontal plane from a perpendicular line erected from that plane to the tip of the mandibular central incisor. Line B is a line drawn parallel to line A and tangent to the incisal edge of the maxillary central incisor. Used to measure bite opening or closing.

III. Orthopantomogram Measurements

A. All tracings were done on .003" x 6" x 12" matte acetate. Since there is no superimposition of bilateral structures on the orthopantomograms, the necessity of drawing an average tracing was eliminated.

B. Mesial-distal migration

An attempt to determine the mesiodistal movement of the mandibular first molar, second bicuspid, and cuspid was made. Since the orthopantomogram presents a panoramic view of the entire dentition spread out on a flat surface, it was believed that the mesiodistal migration of teeth could be determined. In order to accomplish this, reference landmarks were established as follows:

1. Porion line - a line drawn tangent to the superior aspect of right and left porion.
2. Center line - a line erected perpendicular to porionic line and through the maxillary incisal suture.
3. Utilizing porionic line as a base from which perpendicular lines could be erected, the following measurements were used to determine mesiodistal migration of the mandibular cuspid, second bicuspid, and first molar (figure 12):
   a) Cuspid measurement - The linear distance between the center line and a line erected perpendicular from line porion and tangent to the distal of the cuspid.
   b) Second bicuspid measurement - Linear distance between the center line and a line erected perpendicular from line porion and tangent to the mesial of the second bicuspid.

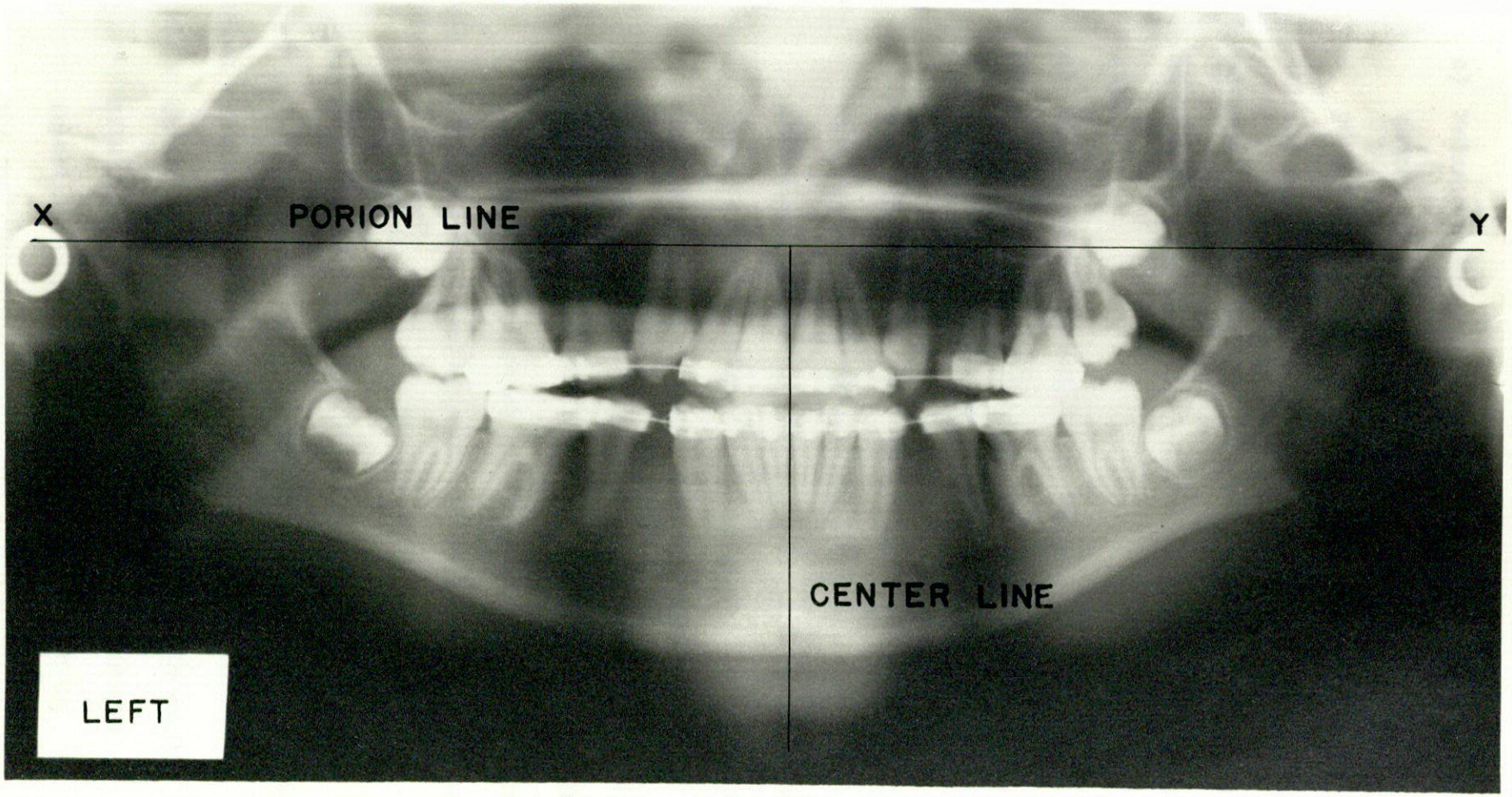


Figure 12. Orthopantomogram showing porion line and center line. Perpendicular lines were erected from porion line to mandibular teeth to determine mesiodistal migration.

c) Molar measurements - The linear distance between the center line and a line erected perpendicular from line porion and tangent to the mesial of the first molar.

4. All the above measurements were used to evaluate mesiodistal movement and to determine if there is any difference in tooth migration in high, low, and middle Frankfort-mandibular plane angle.

a) Magnification of mandibular teeth

An attempt was made to determine the magnitude of the enlargement of mandibular teeth as measured on the orthopantomogram. The purpose of this portion of the study was to discover if magnification was uniform throughout the orthopantomogram or if it varied according to different segments of the arch. To accomplish this, the following measurements were taken:

(1) The mesiodistal width of all mandibular teeth from first molar to first molar was measured at the incisal portion of each band on the orthopantomogram.

(2) Corresponding measurements were taken from the study models and a comparison made.

b) Repositioning measurements

Initially, eight measurements were recorded when the patient was positioned in the special cephalostat designed for the Orthopantomograph in this study. After seven weeks of leveling, the patient was repositioned in the cephalostat according to the original reading, and the final orthopantomogram

was taken. The reliability of repositioning the patient in the cephalostat was determined as follows:

(1) The inner surfaces of the metallic rings which identify porion were traced. The superior aspect of the left one was marked X and the other, Y.

(2) A line connecting points X and Y was drawn. (figure 12)

(3) The linear distance between X and Y as recorded from the original and final orthopantomograms. The linear measurement X-Y was used to evaluate reliability of repositioning rather than superimposing anatomical landmarks due to:

(a) A small sampling indicated that some anatomical landmarks would superimpose on the right side, but not on the left unless a shifting of the tracings was made; and

(b) If anatomical landmarks did not superimpose well, we wanted to be able to measure the variance and attempt to explain the cause.

Determination and Recording of Measurements

Tracing procedures, illustrations, and the various methods of measurements have been described on pages 19 to 33. To minimize the amount of error, all orthopantomograms and cephalograms were traced twice on separate occasions. The observed data, statistical analyses, and the results may be noted in the Appendix.

FINDINGS AND DISCUSSION

I. Orthopantomograph Characteristics

A. Magnification

The question arises as to the degree of Orthopantomograph magnification. Since the Orthopantomograph x-rays and the corresponding models were available, it was possible to make a comparison. Preliminary measurements were made by comparing mesiodistal dimensions of x-ray images of teeth and those on corresponding models. The x-ray distance was then divided by the model distance yielding a magnification factor.

The magnification factors derived from pretreatment data were found to cover a relatively wide range. When the factors for the incisors, cuspids, second bicuspids, and first molars were plotted, an association was indicated between magnification and tooth location.

The magnification factors seemed to group into a roughly W- or M-shaped pattern. Consistently high values were found in the region of the second bicuspid and consistently low values were found in the location of the cuspid. Values between these extremes were found in the areas of the incisors and center line. Also, the magnification values on the left side of the x-ray had a consistently wider range than those on the right side. This asymmetrical distribution would indicate some inherent characteristic of the Orthopantomograph that caused changes in magnification on one side more than the other. On the basis of these findings, it was reasoned that an

association could probably be found between the center of the tooth-to-center-line distance on the Orthopantomograph x-ray and the tooth magnification.

When these preliminary data were revised, it appeared that the relationship between distance from the center line and magnification was far more complex than a simple linear association. Accordingly, it was decided to attempt to fit the magnification to a multiple regression of the first six powers of the linear distance from the center line.

If the distance of a given tooth from the center line is called x, then the proposed equation relates magnification to x, x^2, x^3, x^4, x^5, and x^6. Such an equation will allow us to predict for any given distance from the center line, the expected magnification in this area on the x-ray film.

The above described multiple linear regression was done on pretreatment data. The magnification factors as raw data ranged from .78 to 2.32 with a corresponding standard deviation of .224. We found that before fitting the regression equation the mean magnification value was 1.55 and that the most likely range of values was .89 to 2.21.

The computerized program used to treat the 189 data observations first added into the regression equation all the independent variables, powers of x, and then deleted, one by one, all those independent variables that were not significant at the 5 per cent level. Under this procedure, the final regression contained x, x^2, and x^6. This means that these variables can be considered significant sources of explanation of the variance of magnification

values. Thus the following regression equation was derived:

$$MAG = 1.40 - 1.6 \cdot 10^{-3}x + 2.9 \cdot 10^{-4}x^2 - 2.63 \cdot 10^{-6}x^6$$

This equation was plotted on a graph (figure 13). It has associated with it, a coefficient of multiple determination of .347; that is, 34.7 per cent of the variance in magnification is explained. Also, the standard error of the estimate is reduced to .183. This is reflected in the upper and lower confidence limits shown on the graph. For any given distance from the center line, the most likely value for the magnification in that area of the x-ray film is given by the regression equation. However, we can also expect some values to range as high as the upper confidence limit and some to range as low as the lower confidence limit. This still leaves much of the variance in these magnification values unexplained. The most likely explanation is that there are other factors; for example, mandibular morphology, which determine magnification for a given patient. Thus, the magnification factor for any given x-ray film is quite likely a unique function of the individual being x-rayed. Also, it is quite possible that magnification as a function of machine characteristic does not correspond to individual center lines as a reference point. Furthermore, each patient will present a different center line with respect to machine geometry. It is doubtful that such intrinsic sources of error could ever be delineated or eliminated.

B. Reliability

One object of the study was to test the reliability of repositioning subjects in the cephalostat. For this reason, the only comparative data available came from the x-rays taken

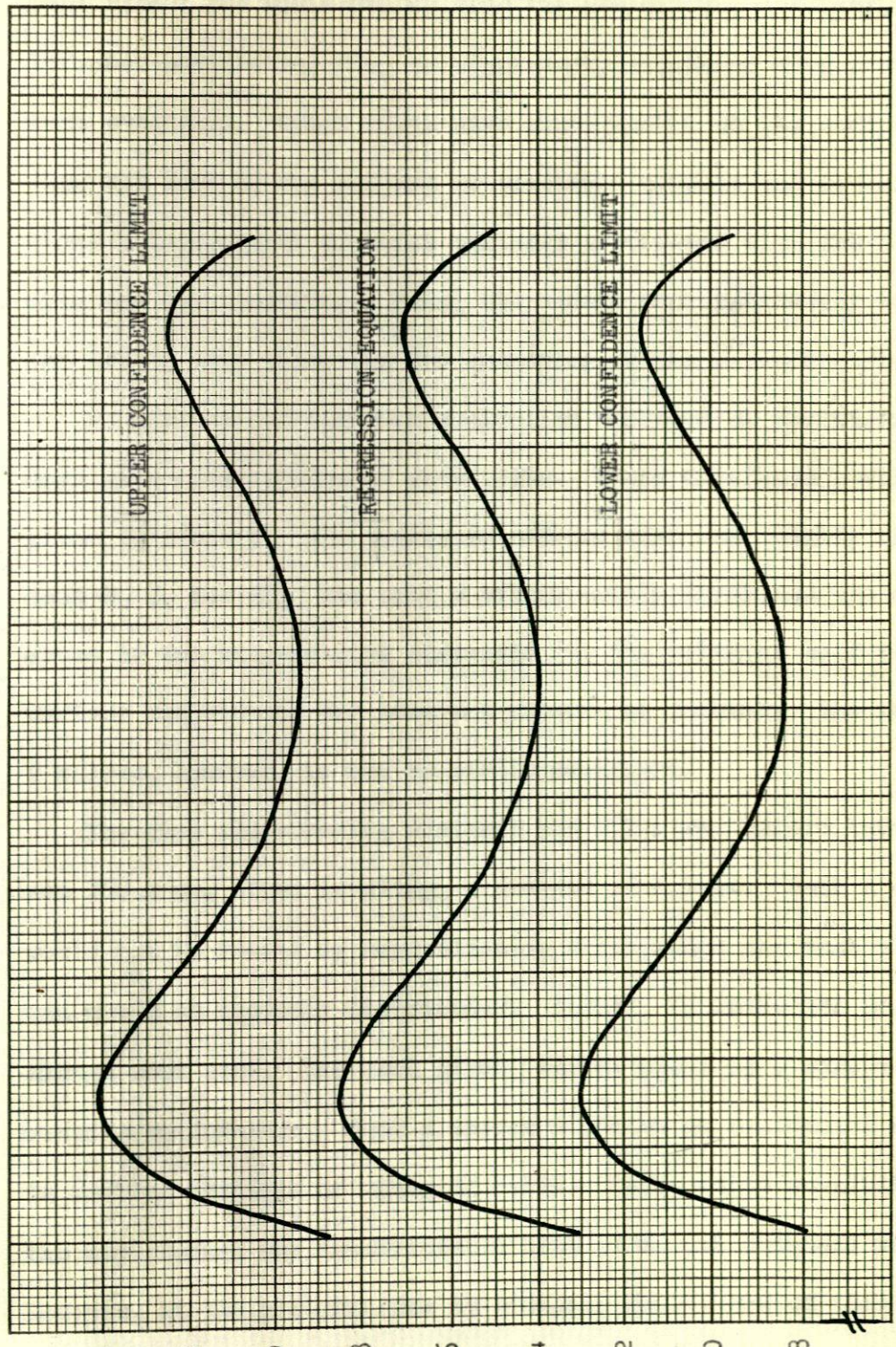


Figure 13 Orthopantomograph Magnification Versus Distance from the Center Line on the X-ray

before and after the seven weeks of leveling. This meant that the tooth-to-center-line distances were confounded with treatment effect and could not be used for comparison. However, the left-ear-positioning ring to right-ear-positioning ring distances were available. Since these were measurements on the equipment, they are free of any patient or treatment effects and contain only those contributions to total variance associated with the equipment and its resetting. Also, the values were relatively large and should thus allow for the detection of the maximum differences.

An analysis-of-variance evaluation was used on the recorded data with observations of each value. These tabulated results are given in Table 2. The indicated effects were very highly significant N, T, and NT. The real N effect merely indicates the differences in the ring-to-ring distances for the settings used with various individuals and need not concern us further. The real T effect, however, is not so easily explained.

The mean ring-to-ring distance was 272.4 mm. before leveling and 266.2 mm. after leveling, a decline of 6.2 mm. Such a change would not be caused by repositioning error since any such phenomenon would be randomly distributed. Rather, it indicates some real change over time. The most likely source would be a change in machine performance. Such a change might be an accidental change in machine settings or aging of parts. It is quite possible that the cephalostat was inadvertently moved from its original position. However, at the present time of writing, the source of this change must remain unassigned.

The very highly significant NT effect indicates that particular individuals produce reductions in ring-to-ring distances over time that were significantly larger or smaller than the mean decline. These unexplained sources of variation are quite likely the result of repositioning errors. If this is assumed to be their source, then the components of variance of the repositioning error can be analyzed. The mean-squared variance associated with any NT distance that can be attributed to repositioning error is 1.23. This yields a standard deviation of 1.1 mm. However, because of cross-correlated effects the possibility remains that shorter distances within the x-ray might have larger repositioning errors associated with them.

II. Tooth Migration into the Extraction Site

A. Measurement and design

The determination of the amount and nature of tooth movement into the extraction site following the extraction of the mandibular first bicuspid was based on two sets of data. The first set consisted of measurements taken from models which represented the alignment of the teeth before and after the seven weeks of leveling. These raw data were produced by taking linear measurements from the distal of the cuspid to the mesial of the second bicuspid, and from the distal of the cuspid to the mesial of the first molar for each extraction site. To measure the accuracy of the measurements or "reading error," repeat measurements were taken on each value.

The second set of readings was taken from the orthopantomograms. For each site, three values were taken: (1) center line

to the distal of the cuspid, (2) center line to the mesial of the second bicuspid, and (3) center line to the mesial of the first molar. The intention was that these data taken with respect to a standard reference line would be used to measure mesiodistal movement of the various teeth during treatment. This information would be then related to the information obtained from the model measurements.

For both of these sets of data the same technique and model design were used: analysis of variance and split-error terms. The analysis of variance approach allows all main effects and their interactions to be tested and examined with one experiment. The main effects or factors considered in this particular design were as follows: G, the three groups into which the subjects were classified according to their respective Frankfort-mandibular plane angles; N, the individual patients; S, the side of the mandible on which the particular measurements were taken; L, the specific location or distance being measured; and T, the treatment effect produced by the seven weeks of leveling.

Each main effect or factor in the experiment consists of two or more horizons or levels. Thus, the levels in T_1 treatment, are before and after; the levels in G, groups, are the three classifications of Frankfort-mandibular plane angles, etc. When main effects are tested, the presence of a significant or "real" effect indicates that real differences across the levels of the factor do occur. Thus, a significant T would indicate consistent differences in before and after values. Such general conclusions have application across all the other factors in the experiment.

First order (two factor) and higher order interactions indicate that certain combinations of factors interact with each other to produce values that are higher or lower than would otherwise be expected. The general assumption of the model equation is that results are linearly additive. Thus, for example, a specific expected NT value would, in part, be due to its T component and, in part, due to its N component. However, if the observed NT differs from this by a sufficient amount, a significant NT interaction will be detected. This conclusion that a real NT effect exists would mean that certain individuals react under treatment quite differently than others and that this phenomenon is unique for particular NT combinations.

For both sets of data, the same model equation and assumptions were used. Assumptions relating to the individual factors were as follows:

G-crossed fixed
N-nested random
S-crossed fixed
L-crossed fixed
T-crossed fixed

The error terms were derived on the basis of N being nested within G by splitting the error term N(LSTG). Thus each G grouping was considered to be a random sample of individuals possessing that particular characteristic. The design was balanced by making all the G groups of the same size.

B. Model measurement analysis

Table 3 gives the analysis of variance results of the width migration study on values taken from models. The L and T effects were found to be very highly significant ($\alpha = .001$) and

the TL interaction was found to be highly significant ($\alpha = .01$). The first half of the table might be considered a description of the experimental population, while the second half may be considered as the effect of treatment on that population. Thus, the very highly significant L effect merely points up the fact that the cuspid-to-first-molar distance, L_1, is intrinsically larger than the cuspid-to-second-bicuspid distance, L_2. These are actual characteristics of the population. The absence of any G effect or G interactions in the first half of the table indicates that no G-associated differences were found in the sample studied.

The real T effect indicates a general change in the measured distances with treatment. As shown in Table 4, the mean value went from 10.79 mm. to 9.59 mm., an average decrease for all distances of 1.20 mm. Further, the TL effect indicates that this reduction was not the same for each measurement location. Again, reference to Table 4 shows the cuspid-to-second-bicuspid distance, L_2, declined from a mean value of 7.13 mm. to 5.63 mm., a reduction of 1.50 mm. However, the L_1 measurement declined from 14.45 mm. to 13.54 mm., a change of only .91 mm. Since the cuspid reference point was the same for both measurements, this would indicate that the first molar is (relatively) less mobile than the second bicuspid.

Finally, there were no TG-associated interactions. This indicates that no discernible effect on treatment changes could be found associated with G characteristics.

C. Orthopantomograph measurement analysis

Table 5 gives the analysis-of-variance results for the orthopantomogram measurements when analyzed using the same experimental

design as was used in the model's case. The L, SL, and LT effects were found to be very highly significant, and the ST and SLT effects were found to be significant ($\alpha = .05$). The L effect has exactly the same meaning as in the previous case and indicates the inherent differences in the distances associated with various locations. The absence of any G effect or interaction again indicates the absence of any discoverable G-associated differences. The real SL effect is a new phenomenon and requires some explanation.

It was noted previously, that the Orthopantomograph produces an asymmetric-magnification pattern. The presence of a real SL effect is an indication of that asymmetry, a characteristic of the population of orthopantomograms that were studied. This real effect is then the product of a machine characteristic rather than a characteristic of the population of subjects used in the study.

The above indicates that machine characteristics and population characteristics have become confounded in the study. Thus, the presence of the SL and SLT effect is in all likelihood, the result of machine characteristics interacting with real changes rather than changes in population attributes, as such. Unfortunately, the real source cannot be assigned definitively because of the confounding of these two sources of variants. One measurement can never provide two pieces of information.

Table 6 gives the ST and SLT mean values. Of more interest is the very highly significant LT effect. Examination of the Table 6 would indicate that the cuspid is moving distally, the second bicuspid is moving mesially, and that the first molar is

essentially not moving at all. This may be the results of the second bicuspid tipping into the extraction site or rotating and thus presenting a wider mesiodistal measurement.

D. Comparison of findings

When comparing the results of these two experimental procedures, the general conclusions agreed rather well. In terms of population characteristics, both methods were found to exhibit very highly significant differences for location differences. The SL interaction found in the orthopantomogram data can be considered a unique characteristic of that apparatus.

When considering the T-associated effects, the absence of an overall T effect for the orthopantomogram data can be attributed to the fact that the location measured produced opposite directionality for changes with treatment, whereas, the model measurements produced codirectionality. The orthopantomogram-associated-ST-and-SLT effects must, again, be considered as byproducts of that unique apparatus.

The general area of agreement for the two techniques is the very highly significant T and the highly significant TL interaction. When evaluated, both indicate that the cuspid-to-second-bicuspid distance closes faster with treatment than the cuspid-to-first-molar distance. In addition, the Orthopantomograph provides directionality information on these changes. Also of interest, is the fact that no instance of either method provided any indication of any G-associated effect on interaction.

III. Overbite and Related Factors

A. Overbite opening

One of the areas to be examined in the study was the

relationship, if any, between Frankfort-mandibular plane angle and the degree of change in overbite with leveling. To test this relationship, the patients were sorted into three groups on the basis of their Frankfort-mandibular plane angles. Given this classification, it was decided that analysis of variance would be the best method of testing for significance.

The analysis-of-variance design chosen, assumed that both G, the Frankfort-mandibular plane angle groups, and T, the treatment, were crossed and fixed variables. However, N, the individual patient effect, was considered to be a random variable nested within G. Thus, each group consisted of a random sample of patients. This led to a split-plot design in which G was tested against N(G) and T and TG were tested against TN(G).

The before-and after overbite data were recorded in millimeters. These data were then analyzed, yielding the analysis-of-variance results shown in Table 7. Here, a T effect significant at the 5-per-cent level is found. When the mean values are examined, we find a $\bar{T}_1$ of 4.33 mm. and a $\bar{T}_2$ of 3.70 mm. Since smaller values indicate an opening of the bite, this indicates an average bite opening during the seven weeks of leveling of .63 mm. Also of particular interest, is the absence of any G or TG effect. This indicates that within the accuracy of the study, the Frankfort-mandibular plane angle was not found to effect either the amount of overbite or the rate of change of overbite.

In association with the study of overbite, the maxillary-incisal angle, mandibular-incisal angle and interincisal angle were also examined. Tables 8, 9, and 10 give the analysis-of-

variance results for these three examinations. All three indicate very highly significant N effects, but this patient-to-patient variability is of no particular interest here. Also, all three analyses indicate real NT effects. This, however, signifies the variability of individuals to treatment and need not concern us.

What is of interest are the very highly significant and highly significant T effects for the maxillary-incisal angle and the mandibular-incisal angle. These mean values, as affected by treatment, are compared in Table 11. Here, we find the maxillary-incisal angle decreasing 2.56 degrees with treatment and the mandibular-incisal angle increasing 2.09 degrees with treatment. These counterposed effects probably explain the fact that no indicated significant effect with treatment was found for the interincisal angle.

B. Frankfort-mandibular plane angle and occlusal-mandibular plane angle with treatment

Another focus of the study was the change, if any, in Frankfort-mandibular plane angle with treatment. For this purpose, an analysis of variance was run on Frankfort-mandibular plane angle data using the same format as with overbite. These results are given in Table 12. The very highly significant G effect exists, by definition, since this is how the data was grouped. However, the absence of any T-related effects would seem to indicate that Frankfort-mandibular plane angle is a constant function of head morphology and is relatively unaffected by treatment.

A similar study was made using occlusal-mandibular plane angle data. We see from Table 13 that a highly significant G effect exists. This indicates that perhaps some cross correlation exists between Frankfort-mandibular plane angle and occlusal-mandibular plane angle. Also, there is a highly significant T effect. When examining the mean values, we find that the average occlusal-mandibular plane angle increases from 18.36 degrees to 19.50 degrees with treatment. Since overbite also changes with treatment, this leads us to suspect that perhaps changes in overbite values may be related to changes in occlusal-mandibular plane angle values. Such investigation, however, must remain for some further study.

C. Overbite versus Frankfort-mandibular plane angle--multiple regression

A final area of investigation was to determine if the amount of overbite or changes in overbite were associated, in any way, with the Frankfort-mandibular plane angle or the occlusal-mandibular plane angle. For this purpose, a computerized multiple-regression program was used. The first regression fit was made using overbite values as the dependent variables and values of the Frankfort-mandibular plane angle and the occlusal-mandibular plane angle as the independent variables.

All the data used in the first fit were before treatment observations. When both dependent variables were added to the regression equation, the coefficient of determination was a very low .199. This means that about 20 per cent of the total variance was explained. Also, when tested for significance, neither Frankfort-mandibular plane angle nor occlusal mandibular plane angle remained in the fit. Neither Frankfort-mandibular

plane angle nor occlusal-mandibular plane angle can be considered a significant variable in explaining the variation in overbite values. Of some interest is the fact that the partial correlation of Frankfort-mandibular plane angle with occlusal-mandibular plane angle was .70. This confirms the previously mentioned possibility that Frankfort-mandibular plane angles and occlusal-mandibular plane angles are related.

Following this, the relationship between changes in overbite as a function of Frankfort-mandibular plane angle and occlusal-mandibular plane angle was investigated. For this purpose, the same procedure as above was used save that the change in overbite value with treatment was used as the dependent variable rather than the absolute value of overbite before treatment. For this regression fit, the coefficient of multiple determination, R^2, was .068. Thus only about 7 per cent of the total variance was explained. Needless to say, neither of the independent variables were found to be significant. We conclude from this that essentially neither Frankfort-mandibular plane angle nor occlusal-mandibular plane angle correlate with the degree of change in overbite.

SUMMARY AND CONCLUSION

Summary

This investigation was conducted to evaluate the use of panoramic radiography in orthodontics and the importance of the Frankfort-mandibular plane angle in relation to bite opening and tooth migration. Two points of discussion in orthodontics concern the following:

1. Is there any difference in tooth migration in those patients with high, low, or middle Frankfort-mandibular plane angle?

2. Does the bite open more readily in high Frankfort-mandibular plane angle cases than in low Frankfort-mandibular plane angle cases?

It was decided the Orthopantomograph would be a most useful instrument in seeking the answers to these particular questions. A special cephalostat was designed at Western Reserve University to be used in the Orthopantomograph for this study.

The study group consisted of sixteen Caucasian patients who were undergoing treatment at the Orthodontic Department, School of Dentistry, Western Reserve University. Fifteen of these children had Class II malocclusions and one had a Class I malocclusion. The sample was sorted into three groups consisting of high, low, and middle Frankfort-mandibular plane angles as shown in Table 1. All patients were diagnosed as requiring the removal of one or more teeth.

All patients were to undergo a seven-week period of leveling treatment after the teeth were extracted. During this time, each patient was to wear the .016 round arch wire for three weeks, and the .018

and .020 arch wires for a period of two weeks each.

It has previously been mentioned that panoramic radiography is a useful aid in many phases of dentistry. During our routine panoramic radiography, two dental anomalies were detected in the orthopantomograms which would probably have been missed by conventional radiography.

It was felt that the panoramic x-rays offered an excellent way to determine linear measurements, as well as, directional ones. Therefore, an attempt was made to determine if there were any difference in the amount of migration in high, low, or middle Frankfort-mandibular plane angle cases and in what direction the mandibular cuspid, second bicuspid, and first molars moved.

The degree of magnification found in the orthopantomograms of the mandibular teeth from first molar to first molar was investigated. Haataja and Somer in their study showed the magnification in various locations in dental segments deviate somewhat from each other (33). This study confirms that finding and also reveals a magnification range of values between .78 and 2.32 with a mean magnification value of 1.55.

Analysis-of-variance test was used to determine the reliability of repositioning the patients in the special cephalostat. Unfortunately, this could not be effected in this study due to either the change in machine performance or the inadvertent movement of the cephalostat from its original position during the course of the study.

Data from tracings of the roentgenographic cephalograms were used to examine the existence of any relationship between Frankfort-mandibular plane angle and the degree of change in overbite with leveling. A computerized multiple-regression program was used to investigate whether the amount of overbite or changes in the overbite were associated in any way with the Frankfort-mandibular plane angle or

the occlusal-mandibular plane angle.

This study indicates that the steepness of the Frankfort-mandibular plane angle does not influence the amount of tooth migration into the extraction site. Also, the tendency for the bite to open or close more readily in high Frankfort-mandibular plane angle cases compared to low Frankfort-mandibular plane angle cases could not be shown during the seven-week period of leveling. Perhaps, if the study were conducted over a longer period of time, evidence contrary to the above mentioned findings would have evolved.

The study, also, showed that the direction of the migrating teeth can be determined from the orthopantomogram. The cuspids moved distally, second bicuspids moved mesially, while the first molars remained essentially stationary. It was also shown that the second-bicuspid region gave the highest magnification values, while the cuspid region showed the lowest.

The Orthopantomograph not only produces an asymmetric magnification pattern with the left side showing a consistently wider range than the right, but also produces a wide range of magnification throughout the dental segments. It is felt that the panoramic device used in this study must be improved and developed further before it can be a useful instrument for deriving precise measurements.

All the observed data of this study were submitted to the Statistics Department of Western Reserve University for analysis.

Conclusions

It is hoped that this study will serve as a stimulus for further investigations. The following conclusions were made:

1. Higher values of magnification were consistently found in the location of the second-bicuspid region, while low values were found in the cuspid region.
2. The Orthopantomograph produces an asymmetric magnification pattern with the left side showing a consistently wider range than the right side.
3. The mean magnification value is 1.55 and the magnification range is .78 to 2.32.
4. Magnification for any given x-ray is quite likely a function of the patient being x-rayed. It is also possible that magnification as a function of machine characteristic does not correspond to individual center lines as a reference point. When different individuals are treated, their center lines will be located in different places with respect to machine geometry.
5. The cuspid moved distally, the second bicuspid moved mesially, and the first molar essentially did not move.
6. The cuspid-to-second-bicuspid distance closes faster with treatment than the cuspid-to-first-molar distance.
7. No discernible differences in the amount of tooth migration during treatment could be found in those patients with high, low, or middle Frankfort-mandibular plane angles.
8. The steepness of Frankfort-mandibular plane angle was not found to affect either the amount of overbite or the rate of change of overbite.
9. The Frankfort-mandibular plane angle appears to be a constant function of head morphology and is relatively unaffected by treatment during the seven-week period of leveling.

10. This study showed that a partial correlation of Frankfort-mandibular plane angle with the occlusal-mandibular plane angle was .70.

11. Essentially, neither the Frankfort-mandibular plane angle nor occlusal-mandibular plane angle reveals any correlation with the degree of change in overbite during the seven-week period of leveling.

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APPENDIX

TABLE 2

ANALYSIS OF VARIANCE TO DETERMINE
RELIABILITY OF REPOSITIONING

S.V.	S.S.	df	M.S.	F	Fc	Conc.
N	2841.75	13	218.60	2180.00	2.90	.001
T	541.88	1	541.88	380.00	9.07	.001
NT	18.49	13	1.42	14.95	2.90	.001
R(NT)	2.67	28	.095	-----	---	----
Total	3404.79	55				

$T_1 = 272.46$ $T_2 = 266.24$

Notes:

Measurements in millimeters
S.V. - Source of variance
S.S. - Sum of squares
df - Degrees of freedom
M.S. - Mean squares
F - F test
Fc - F critical
Conc. - Conclusion
N.S. - Not significant

TABLE 3

ANALYSIS OF VARIANCE TO DETERMINE TOOTH MIGRATION
USING MEASUREMENTS FROM MODELS

S.V.	S.S.	df	M.S.	F	Fc	Conc.
G	29.48	2	14.74	1.02	4.26	N.S.
N(G)	129.94	9	14.44	----		
L	2763.37	1	2763.37	3255.00	10.6	.001
LG	3.25	2	1.62	1.91	4.26	N.S.
LN(G)	7.64	9	.85	----	----	----
S	4.56	1	4.56	< 1	5.12	N.S.
SG	24.36	2	12.18	2.25	4.26	N.S.
SN(G)	48.79	9	5.42	----	----	----
SL	.63	1	.63	1.06	5.12	N.S.
SLG	.77	2	.39	< 1		N.S.
SLN(G)	5.36	9	.60	----	----	----
T	66.27	1	66.27	33.6	10.6	.001
TG	1.52	2	.76	< 1		N.S.
TN(G)	17.76	9	1.97	----	----	----
TL	3.36	1	3.36	11.47	10.6	.01
TLG	.52	2	.26	< 1		N.S.
TLN(G)	2.64	9	.29	----	----	----
TS	.18	1	.18	< 1		N.S.
TSG	.82	2	.41	< 1		N.S.
TSN(G)	5.50	9	.61	----	----	----
TSL	.27	1	.27	2.03	5.12	N.S.
TSLG	.07	2	.04	< 1		N.S.
TSLN(G)	1.20	9	.13	----	----	----
R(TGNSL)	1.31	96	.0136			
Total	3119.56	191				

TABLE 4

MODEL TOOTH MIGRATION MEAN VALUES IN MILLIMETERS FOR SIGNIFICANT EFFECTS

LT	T_1	T_2	$T_2 - T_1$
L_1	14.45	13.54	- .91
L_2	7.13	5.63	- 1.50

T	T_1	T_2	$T_2 - T_1$
	10.79	9.59	- 1.20

L	L_1	L_2
	14.00	6.38

TABLE 5

ANALYSIS OF VARIANCE TO DETERMINE TOOTH MIGRATION USING MEASUREMENTS FROM ORTHOPANTOMOGRAMS

S.V.	S.S.	df	M.S.	F	Fc	Conc.
G	703.36	2	351.68	2.43.	4.26	N.S.
N(G)	1301.52	9	144.61	----	----	----
L	15073.03	2	7536.51	855.00	6.01	.001
LG	56.78	4	14.20	1.61	2.93	N.S.
LN(G)	158.73	18	8.81	----	----	----
S	199.33	1	199.33	2.62	5.12	N.S.
SG	80.90	2	40.45	< 1		N.S.
SN(G)	684.10	9	76.01	----	----	----
SL	173.26	2	86.63	23.0	6.01	.001
SLG	20.21	4	5.05	1.34	2.93	N.S.
SLN(G)	67.82	18	3.77	----	----	----
T	5.12	1	5.12	< 1		N.S.
TG	19.53	2	9.77	< 1		N.S.
TN(G)	99.47	9	11.05	----	----	----
TL	68.54	2	34.27	17.14	6.01	.001
TLG	5.36	4	1.34	< 1		N.S.
TLN(G)	36.09	18	2.00	----	----	----
TS	60.68	1	60.68	6.23	5.12	.05
TSG	2.30	2	1.15	< 1		N.S.
TSN(G)	87.62	9	9.73	----	----	----
TSL	8.95	2	4.47	5.39	3.55	.05
TSLG	6.92	4	1.73	2.08	2.93	N.S.
TSLN(G)	15.02	18	.83	----	----	----
R(TGNSL)	13.03	144	.0905			
Total	18947.67	287				

TABLE 6

ORTHOPANTOMOGRAPH TOOTH MIGRATION
MEAN VALUES IN MILLIMETERS
FOR SIGNIFICANT EFFECTS

LT		T_1	T_2	$T_2 - T_1$
	L_1	23.52	25.11	+1.59
	L_2	30.38	29.62	-1.20
	L_3	41.71	41.68	- .03

ST		T_1	T_2	$T_2 - T_1$
	S_1	35.43	34.70	- .73
	S_2	36.28	37.61	+1.33

SLT			T_1	T_2	$T_2 - T_1$
L_1	S_1		24.11	25.02	+ .91
	S_2		22.95	25.19	+2.24
L_2	S_1		29.87	27.70	-2.17
	S_2		30.89	31.54	+ .65
L_3	S_1		40.51	39.82	- .69
	S_2		42.90	43.55	+ .65

TABLE 7

ANALYSIS OF VARIANCE TO DETERMINE THE RELATIONSHIP BETWEEN FRANKFORT-MANDIBULAR PLANE ANGLE AND THE DEGREE OF CHANGE IN OVERBITE AFTER LEVELING

S.V.	S.S.	df	M.S.	F.	Fc	Conc.
G	6.47	2	3.23	< 1		N.S.
N(G)	201.87	12	16.82	----	----	----
T	6.02	1	6.02	6.02	4.75	.05
TG	3.22	2	1.61	1.61	3.87	N.S.
TN(G)	12.05	12	1.00	----	----	----
R(TNG)	7.30	30	.24	----	----	----
Total	236.93	59				

$\overline{T_1} = 4.33$ $\overline{T_2} = 3.70$

TABLE 8

ANALYSIS OF VARIANCE TO DETERMINE THE CHANGES IN THE MAXILLARY INCISAL ANGLE AFTER LEVELING

S.V.	S.S.	df	M.S.	F	Fc	Conc.
N	1552.75	15	103.52	57.00	2.70	.001
T	105.06	1	105.06	23.20	8.68	.001
NT	67.94	15	4.53	2.49	2.01	.05
R(NT)	58.25	32	1.82	-----	----	----
Total	1784.00	63				

TABLE 9

ANALYSIS OF VARIANCE TO DETERMINE CHANGES IN THE MANDIBULAR INCISAL ANGLE AFTER LEVELING

S.V.	S.S.	df	M.S.	F	Fc	Conc.
N	2305.44	15	153.70	102.00	2.70	.001
T	70.14	1	70.14	11.5	8.68	.01
NT	138.11	15	9.21	6.1	2.70	.001
R(NT)	48.25	32	1.51	----	----	----
Total	2561.94	63				

TABLE 10

ANALYSIS OF VARIANCE TO DETERMINE CHANGES IN THE INTERINCISAL ANGLE AFTER LEVELING

S.V.	S.S.	df	M.S.	F	Fc	Conc.
N	4114.44	15	274.30	83.00	2.70	.001
T	.0156	1	.0156	< 1		N.S.
NT	191.48	15	12.77	3.84	2.70	.001
R(NT)	106.50	32	3.33	----	----	----
Total	4412.44	63				

TABLE 11

MAXILLARY AND MANDIBULAR INCISAL ANGLE MEAN VALUES IN DEGREES

	T_1	T_2	$T_2 - T_1$
Maxillary Angle	107.03	104.47	-2.56
Mandibular Angle	95.11	97.20	2.09

TABLE 12

ANALYSIS OF VARIANCE TO DETERMINE CHANGES IN THE FRANKFORT-MANDIBULAR PLANE ANGLE WITH TREATMENT

S.V.	S.S.	df	M.S.	F	Fc	Conc.
G	1128.21	2	564.10	56.35	12.97	.001
N(G)	120.02	12	10.01	----	----	----
T	3.94	2	1.97	< 1		
TG	.66	4	.17	< 1		
TN(G)	127.49	24	5.31	----	----	----
R(TNG)	6.25	45	.139	-----	----	----
Total	1386.66	89				

TABLE 13

ANALYSIS OF VARIANCE TO DETERMINE CHANGES IN THE OCCLUSAL-MANDIBULAR PLANE ANGLE WITH TREATMENT

S.V.	S.S.	df	M.S.	F	Fc	Conc.
G	348.96	2	174.48	9.42	6.92	.01
N(G)	222.15	12	18.51	----	----	----
T	11.27	1	11.27	16.70	9.33	.01
TG	.76	2	.379	< 1		N.S.
TN(G)	8.10	12	.675	----	----	----
R(TNG)	14.50	30	.483	----	----	----
Total	605.73	59				

$\overline{T_1} = 18.63$ $\overline{T_2} = 19.50$

TABLE 14

MESIODISTAL WIDTH OF MANDIBULAR TEETH - MODELS

	Right		Left		Right		Left		Right		Left	
	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2
Patient Number	$\overline{1}$				$\overline{2}$				$\overline{3}$			
1	4.7	4.8	5.0	5.0	6.3	6.3	6.0	6.0	6.4	6.4	6.5	6.5
2	6.2	6.2	5.9	5.9	6.3	6.3	6.6	6.6	6.6	6.5	6.8	6.9
3	6.2	6.2	5.9	5.8	6.6	6.5	6.8	6.7	6.6	6.6	7.3	6.7
4	5.1	5.1	4.7	4.7	5.6	5.7	5.9	6.1	7.3	7.3	6.7	6.5
5	5.6	5.6	5.6	5.6	5.6	5.6	5.7	5.7	6.8	6.9	6.9	6.9
6	5.5	5.5	5.4	5.4	6.2	6.2	6.3	6.3	6.4	6.4	6.6	6.4
7	5.5	5.5	5.3	5.3	6.5	6.5	6.1	6.1	6.9	7.1	7.2	7.2
8	5.8	5.7	5.8	5.8	6.7	6.7	6.6	6.6	6.9	7.1	7.0	6.8
9	5.4	5.4	5.5	5.5	6.3	6.3	5.9	5.7	7.1	6.9	7.3	7.4
10	5.4	5.4	5.4	5.4	5.8	5.9	6.1	6.1	6.4	6.3	6.5	6.4
11	6.3	6.3	5.7	5.7	6.3	6.3	6.4	6.4	7.3	7.4	7.6	7.6
12	5.8	5.7	5.8	5.7	5.7	5.7	6.3	6.3	6.7	6.6	7.3	7.3
13	4.8	4.6	5.4	5.4	6.3	6.3	6.4	6.4	6.4	6.4	7.0	7.1
14	5.3	5.3	5.6	5.5	6.4	6.4	5.9	5.9	6.4	6.3	6.8	6.9
15	5.9	5.8	5.9	6.0	5.7	5.7	6.6	6.6	6.9	6.9	7.2	7.2
16	5.0	5.0	5.2	5.2	6.3	6.4	5.7	5.7	6.5	6.4	6.8	7.0
	$\overline{4}$				$\overline{5}$				$\overline{6}$			
1	7.1	7.2	6.8	6.8	8.4	8.3	7.2	7.3	11.9	11.8	11.4	11.4
2	6.7	6.5	6.6	6.6	6.8	6.9	7.2	7.0	11.2	10.8	11.3	11.3
3	7.7	7.7	7.7	7.5	7.4	7.4	7.2	7.1	11.5	11.5	11.7	11.7
4	7.3	7.2	7.5	7.3	6.9	6.8	8.1	7.6	11.1	11.0	10.8	10.5
5	6.6	6.6	7.3	7.3	6.7	7.1	7.4	7.2	10.6	10.8	10.9	11.1
6	6.3	6.5	6.8	6.7	8.1	8.1	6.9	6.9	10.7	10.6	10.0	10.2
7	7.3	7.3	6.8	6.9	7.5	7.3	7.6	7.6	11.5	11.4	11.3	11.4
8	7.3	7.2	6.9	6.9	E	E	7.5	7.3	11.5	11.6	11.8	11.4
9	7.7	7.6	7.3	7.2	7.6	7.4	7.4	6.9	11.5	11.6	11.5	11.5
10	7.3	6.8	6.4	6.4	7.3	7.1	7.5	7.3	11.2	11.3	10.8	10.8
11	7.3	7.3	7.4	7.3	UE	UE	UE	UE	13.5	13.4	13.2	13.2
12	7.0	7.0	7.3	7.2	7.7	7.7	7.1	7.1	11.6	11.6	11.6	11.7
13	6.6	6.7	6.9	6.7	7.1	7.1	7.2	6.9	11.4	11.2	11.0	11.4
14	7.4	7.3	7.2	7.3	7.1	7.1	7.7	7.8	10.9	10.8	10.8	10.7
15	7.7	7.6	7.4	7.3	8.3	8.3	7.6	7.4	11.3	11.3	11.2	11.1
16	7.1	7.0	7.5	7.3	7.5	7.7	7.7	7.8	11.6	11.5	10.4	10.7

Note: $\overline{1}$ - central incisor $\overline{4}$ - first bicuspid Measurements in millimeters
$\overline{2}$ - lateral incisor $\overline{5}$ - second bicuspid UE - unerupted tooth
$\overline{3}$ - cuspid $\overline{6}$ - first molar E - extracted prior to study

TABLE 15

MESIODISTAL WIDTH OF MANDIBULAR TEETH - ORTHOPANTOMOGRAMS

	Right		Left		Right		Left		Right		Left	
	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2
Patient Number		$\overline{1}$				$\overline{2}$				$\overline{3}$		
1	7.5	6.5	7.2	6.9	9.4	9.0	9.0	9.0	8.2	8.2	7.6	7.4
2	8.3	8.2	8.1	8.0	9.0	9.0	9.0	8.8	9.0	9.0	9.3	9.5
3	8.9	9.2	8.9	9.2	9.1	9.0	10.5	10.6	10.2	10.0	11.0	11.5
4	7.1	6.6	7.2	7.4	7.9	8.1	8.1	8.0	8.0	8.0	5.0	5.3
5	8.7	8.7	8.3	8.3	9.0	9.1	9.7	10.3	8.5	10.0	10.0	9.5
6	8.0	7.2	8.0	8.1	7.5	7.8	9.0	9.6	10.0	8.0	9.6	9.5
7	9.0	8.6	7.4	8.0	10.3	10.4	9.0	9.0	8.5	9.2	10.5	11.3
8	8.0	7.8	7.5	7.1	9.5	9.5	9.4	9.5	8.5	8.0	8.5	8.0
9	9.0	9.1	10.4	9.8	10.2	9.4	10.8	10.4	10.1	9.8	11.5	11.5
10	7.2	7.2	7.8	7.2	8.4	8.3	8.6	8.5	9.0	8.2	7.6	7.7
11	8.6	8.6	8.7	8.5	9.7	10.0	9.5	9.7	9.4	9.6	9.5	9.6
12	8.5	9.0	8.8	9.2	9.2	9.5	8.8	8.7	8.4	8.0	8.3	8.2
13	7.1	7.2	7.5	8.1	7.6	8.7	9.4	9.6	9.2	8.6	10.0	9.4
14	7.5	7.4	7.1	7.2	8.5	8.2	8.8	8.8	7.5	7.7	8.5	8.5
15	8.2	8.5	7.8	8.0	10.4	9.9	10.5	10.0	9.1	10.6	9.2	9.5
16	6.5	6.8	7.0	7.3	8.2	8.9	8.0	8.0	8.1	8.6	8.8	8.8
		$\overline{4}$				$\overline{5}$				$\overline{6}$		
1	10.3	10.5	9.8	10.7	12.3	12.1	16.8	17.1	16.6	17.0	20.5	17.2
2	10.5	10.2	11.0	10.7	10.0	10.5	12.0	12.0	18.5	18.5	17.5	20.0
3	13.5	13.5	13.3	13.0	13.5	14.2	15.0	15.6	19.5	20.0	20.1	18.0
4	9.5	10.2	11.4	11.4	13.1	13.4	12.2	12.4	18.8	18.5	16.8	19.9
5	10.5	10.5	10.8	11.5	11.5	11.4	13.8	13.5	16.5	16.0	20.0	18.0
6	11.0	10.9	10.5	11.5	14.8	15.4	12.5	13.2	18.6	18.3	18.5	23.0
7	10.0	10.2	12.0	12.4	12.3	12.5	15.7	16.0	17.5	17.5	23.4	19.7
8	11.4	10.5	10.3	10.5	E	E	12.5	13.5	22.6	22.4	19.7	17.6
9	11.0	11.2	12.5	12.4	11.6	12.0	14.0	13.5	17.7	17.6	17.6	18.2
10	10.0	10.8	10.0	10.5	12.3	12.7	12.5	13.0	17.5	18.7	18.0	21.0
11	12.5	12.5	14.0	14.2	UE	UE	13.8	13.6	20.0	20.0	20.5	18.7
12	10.6	10.5	10.2	11.1	13.6	14.2	13.1	13.5	20.5	21.6	19.3	18.5
13	10.2	10.0	10.5	10.5	14.8	15.5	12.5	12.0	16.5	1616	18.5	20.5
14	9.2	9.3	12.0	13.9	11.8	13.0	16.0	16.5	14.5	15.4	20.2	18.5
15	11.2	12.5	10.8	12.0	12.0	12.5	12.5	12.5	17.5	18.5	18.0	20.2
16	11.6	12.0	10.0	10.0	14.6	14.5	12.8	13.5	20.5	20.5	17.5	17.0

Note: 1 - central incisor 4 - first bicuspid Measurements in millimeters
2 - lateral incisor 5 - second bicuspid UE - unerupted tooth
3 - cuspid 6 - first molar E - extraction prior to study

TABLE 16

MANDIBULAR MEASUREMENTS FROM THE CENTER LINE TO THE DISTALS OF THE INCISORS - ORTHOPANTOMOGRAMS

	Right $\overline{1}$		Left $\overline{1}$		Right $\overline{2}$		Left $\overline{2}$	
Patient Number	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2
1	6.4	7.6	7.4	7.1	15.0	15.3	15.7	15.4
2	6.4	5.3	9.8	10.1	14.1	13.4	17.5	18.2
3	11.1	11.0	5.3	5.2	20.0	19.7	15.0	15.1
4	7.1	7.4	6.1	6.4	14.9	15.1	13.6	13.6
5	9.7	9.5	6.1	7.1	17.9	17.7	15.6	15.4
6	9.4	9.8	5.1	5.2	16.1	15.9	14.0	14.0
7	12.2	12.2	3.3	3.5	20.7	20.2	8.0	9.0
8	4.0	3.6	10.6	10.6	10.4	10.1	16.3	16.9
9	10.0	9.6	7.8	7.9	18.6	18.5	16.8	17.6
10	6.1	6.8	7.9	7.6	13.2	12.7	15.1	14.8
11	10.2	10.3	5.9	6.0	18.7	19.0	14.2	14.8
12	4.6	5.3	12.0	11.6	11.1	11.3	18.8	18.5
13	7.2	7.0	7.2	7.0	15.2	14.6	15.3	15.3
14	6.2	6.7	7.7	7.9	14.0	14.1	15.0	14.8
15	11.6	12.3	4.0	4.2	18.6	18.9	13.0	12.5
16	10.3	10.0	2.5	2.8	16.0	15.6	10.2	10.1

TABLE 17

MANDIBULAR MEASUREMENTS FROM THE CENTER LINE TO THE DISTAL OF THE CUSPID, MESIAL OF THE SECOND BICUSPID, AND FIRST MOLAR - ORTHOPANTOMOGRAMS

Patient Number	$\overline{6}$ RIGHT R_1	$\overline{6}$ RIGHT R_2	$\overline{6}$ LEFT R_1	$\overline{6}$ LEFT R_2	$\overline{5}$ RIGHT R_1	$\overline{5}$ RIGHT R_2	$\overline{5}$ LEFT R_1	$\overline{5}$ LEFT R_2	$\overline{3}$ RIGHT R_1	$\overline{3}$ RIGHT R_2	$\overline{3}$ LEFT R_1	$\overline{3}$ LEFT R_2
	Before Leveling											
1	42.6	43.2	40.0	40.7	31.5	31.4	23.6	23.7	21.9	21.9	19.5	19.6
2	37.5	37.6	44.8	44.6	29.6	29.6	34.4	34.5	21.5	21.7	26.0	26.1
3	44.9	45.1	47.6	47.5	34.4	34.0	34.2	34.2	27.8	28.5	24.5	24.1
4	38.5	38.4	43.1	42.0	29.2	29.0	31.6	31.5	22.8	22.8	20.1	29.3
5	40.2	40.7	42.9	43.4	30.9	31.0	30.6	31.0	23.8	23.5	23.4	23.6
6	45.2	45.9	42.1	42.5	33.0	32.8	29.9	30.0	25.6	25.9	23.4	23.3
7	42.6	42.8	39.0	39.6	32.1	32.2	26.4	26.0	27.6	28.0	19.3	19.4
8	27.9	28.6	35.8	35.8	E	E	27.2	26.6	17.6	17.7	23.2	22.7
9	46.1	46.2	52.5	52.4	35.0	35.1	38.9	39.3	27.8	28.0	29.1	28.8
10	38.6	37.5	39.8	40.0	28.1	28.1	29.4	29.5	22.4	21.9	22.5	22.9
11	39.5	39.3	42.7	43.5	UE	UE	32.5	32.6	26.6	26.6	23.5	23.4
12	33.2	32.5	39.4	40.1	22.3	21.9	28.5	28.5	19.7	19.4	22.1	22.5
13	41.8	41.5	44.1	44.7	28.7	28.0	33.0	33.2	23.6	22.8	24.1	24.2
14	36.3	35.6	39.1	39.1	25.0	24.5	24.8	25.0	20.1	19.8	20.6	21.1
15	42.2	41.4	39.5	39.8	31.3	31.1	28.5	28.4	26.8	26.9	19.4	19.9
16	31.9	32.2	34.6	34.6	24.1	24.4	23.0	22.6	22.4	22.8	18.2	18.0
	After Leveling											
1	44.6	43.6	37.9	37.9	30.1	29.6	24.9	25.1	25.1	25.1	20.1	20.1
2	36.5	36.6	45.2	45.3	27.2	27.6	35.4	35.7	23.1	23.2	28.7	28.5
3	40.1	40.2	43.0	43.3	28.0	28.1	31.9	31.6	26.7	26.8	21.6	21.8
4	36.6	36.2	40.7	41.1	26.3	25.3	31.0	31.1	22.4	22.4	21.2	21.4
5	39.8	40.0	43.9	43.4	26.5	26.1	30.9	30.9	27.1	24.9	26.0	25.5
6	45.5	44.1	42.6	42.8	33.3	33.2	31.0	31.3	25.9	26.9	24.2	24.4
7	40.5	40.0	42.2	42.2	27.4	27.0	27.4	27.4	17.8	25.5	27.1	26.5
8	27.9	27.7	36.8	37.2	E	E	29.3	29.1	26.8	28.4	24.9	25.2
9	45.3	44.5	50.6	50.8	30.6	30.9	37.4	37.4	23.9	26.7	29.4	29.3
10	39.2	39.4	41.3	40.2	27.2	27.1	29.6	29.5	25.4	23.3	24.5	24.7
11	35.8	35.6	42.8	43.1	UE	UE	32.9	33.1	24.4	25.2	25.9	26.0
12	29.6	29.2	43.1	42.5	22.2	21.2	31.7	31.5	19.8	20.0	27.2	27.2
13	41.9	41.8	43.5	43.6	28.7	28.8	24.8	31.6	25.8	25.7	23.2	24.3
14	33.3	33.4	34.9	35.1	23.5	23.6	28.0	24.6	21.8	21.5	22.3	22.1
15	40.1	39.9	40.3	39.7	25.2	24.9	25.8	26.8	26.3	26.3	20.1	20.6
16	34.5	34.4	39.2	39.3	24.2	23.9	31.6	25.5	22.9	23.0	20.9	21.1

TABLE 18

MANDIBULAR MEASUREMENTS FROM THE CENTER LINE TO THE MESIALS OF THE FIRST BICUSPIDS - ORTHOPANTOMOGRAMS

	Right		Left	
Patient Number	R_1	R_2	R_1	R_2
1	22.2	22.0	19.6	19.7
2	21.4	21.7	25.5	25.5
3	23.6	23.7	24.5	24.1
4	22.9	22.9	22.4	22.5
5	22.7	22.6	22.2	21.8
6	24.3	25.0	22.2	21.0
7	24.5	24.4	21.2	20.4
8	12.7	13.4	18.7	19.0
9	24.5	24.6	28.2	27.0
10	20.3	19.5	20.5	21.1
11	24.6	25.0	21.3	21.5
12	17.6	17.3	22.1	22.4
13	20.9	21.0	23.1	23.3
14	17.9	18.2	17.0	16.9
15	26.9	25.5	17.8	17.3
16	16.2	16.0	17.1	17.2

TABLE 19

MESIODISTAL WIDTH BETWEEN MANDIBULAR FIRST MOLARS TO CUSPIDS, FIRST MOLARS TO SECOND BICUSPIDS, AND CUSPIDS TO SECOND BICUSPIDS - MODELS

	Before Leveling											
	Right		Left		Right		Left		Right		Left	
	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2
Patient Number	$\overline{6}$ to $\overline{3}$				$\overline{6}$ to $\overline{5}$				$\overline{5}$ to $\overline{3}$			
1	NE	NE	15.1	15.4	NE	NE	c	c	NE	NE	7.8	8.0
2	14.1	14.0	14.3	14.2	c	c	c	c	7.1	7.1	7.0	6.8
3	15.6	15.4	16.3	16.5	c	c	c	c	8.0	8.0	8.2	8.2
4	14.5	14.5	15.7	15.6	c	c	c	c	7.3	7.1	8.4	8.7
5	14.0	14.1	13.7	13.7	c	c	c	c	7.2	7.0	6.5	6.5
6	15.2	15.3	14.6	14.6	c	c	c	c	6.8	6.7	6.7	6.8
7	14.5	14.9	13.3	13.3	c	c	c	c	7.1	6.7	6.3	6.2
8	14.4	14.3	14.2	14.1	E	E	c	c	E	E	6.8	6.8
9	15.5	15.3	15.4	15.4	c	c	c	c	8.2	8.4	7.6	7.4
10	14.7	14.9	14.8	14.9	c	c	c	c	8.0	8.0	6.6	6.7
11	10.6	10.9	14.3	14.4	UE	UE	c	c	UE	UE	8.1	8.0
12	12.3	12.3	14.5	14.5	c	c	c	c	4.3	4.5	6.4	6.4
13	14.6	14.5	14.4	14.3	c	c	c	c	7.7	7.4	7.3	7.0
14	15.8	15.6	14.8	14.7	c	c	c	c	8.3	8.6	7.8	8.1
15	10.1	10.1	14.4	14.3	c	c	c	c	5.5	5.5	7.2	7.1
16	14.7	14.6	12.6	12.6	c	c	c	c	6.5	6.5	5.3	5.2
	After Leveling											
1	NE	NE	14.3	14.4	NE	NE	c	c	NE	NE	6.6	6.7
2	13.4	13.4	13.3	13.3	c	c	c	c	6.5	6.4	5.8	6.1
3	13.5	13.7	15.3	15.3	c	c	c	c	5.4	5.4	7.5	7.4
4	13.8	14.2	15.4	15.4	c	c	c	c	6.9	7.0	8.4	8.6
5	13.3	13.5	13.2	13.3	.7	.6	c	c	4.8	5.1	5.6	5.4
6	15.3	15.3	13.6	13.7	.7	.7	.3	.3	5.8	5.8	5.1	5.3
7	13.1	12.8	11.3	11.3	c	c	.6	.5	5.1	4.7	3.7	4.0
8	14.0	14.0	13.2	13.4	E	E	c	c	E	E	6.1	5.9
9	13.8	13.8	14.4	14.4	c	c	.2	.5	6.1	6.0	5.8	5.7
10	14.6	14.4	14.1	14.1	c	c	c	c	6.5	6.7	5.8	5.8
11	10.1	10.2	14.4	14.0	UE	UE	c	c	UE	UE	6.4	6.3
12	11.8	11.8	12.5	12.5	c	c	c	c	3.7	3.7	4.2	4.4
13	14.4	14.6	15.1	15.0	c	c	c	c	7.0	7.1	7.1	7.0
14	13.5	13.6	13.1	13.1	c	c	c	c	6.2	6.4	5.5	5.6
15	9.3	9.3	13.6	13.7	c	c	c	c	2.1	2.3	5.4	5.4
16	14.5	14.1	14.1	14.1	c	c	c	c	6.7	6.9	6.2	6.3

TABLE 20

INTERINCISAL ANGLE MEASUREMENTS

Patient Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Before Leveling	R_1	124.0	113.0	149.0	115.5	127.0	120.0	132.5	115.0	134.5	119.5	124.0	126.0	114.0	120.0	119.0	117.0
	R_2	123.0	115.5	142.0	115.5	126.5	117.5	125.5	115.5	134.0	118.0	126.0	128.0	114.0	121.0	114.5	115.0
After Leveling	R_1	124.5	119.0	139.0	108.0	125.0	122.5	127.5	110.0	135.0	119.5	123.0	128.0	117.0	120.0	121.0	113.5
	R_2	125.0	119.5	140.0	112.5	126.0	123.5	128.5	110.5	139.5	119.5	121.5	132.0	116.5	119.0	120.5	114.0

Note: Measurements in degrees

TABLE 21

RELIABILITY OF REPOSITIONING IN ORTHOPANTOMOGRAPH
X TO Y MEASUREMENT

Patient Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Before Leveling	R_1	273.0	NA	NA	271.7	268.2	267.8	267.0	286.1	267.2	270.0	290.7	266.8	270.0	273.4	273.4	268.6
	R_2	273.0	NA	NA	272.6	268.8	267.8	266.7	286.0	266.3	270.0	290.7	266.8	270.0	273.4	273.5	268.7
After Leveling	R_1	268.6	283.0	268.3	267.2	261.2	261.3	259.2	279.0	259.5	263.0	285.9	261.4	265.5	267.4	266.4	260.8
	R_2	269.3	282.7	268.5	266.5	261.2	261.5	260.0	278.7	259.6	263.0	285.7	261.7	265.6	267.6	267.1	260.5

Note: NA - measurements not available
measurements in millimeters

TABLE 22

MANDIBULAR PLANE ANGLE MEASUREMENTS

		Group I					Group II					Group III					
Patient Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Frankfort-Mandibular Plane Angle																	
Before Banding	R_1	22.0	22.5	23.0	22.5	20.5	28.5	25.0	29.0	23.5	26.0	31.0	31.0	31.5	31.0	30.0	27.0
	R_2	22.0	22.5	22.0	22.5	21.0	29.0	26.0	29.0	23.5	27.0	31.0	30.0	30.5	31.0	29.5	27.0
Before Leveling	R_1	21.0	23.5	25.0	19.0	21.0	28.0	27.5	25.5	28.0	25.5	30.0	29.0	31.0	33.0	30.5	27.5
	R_2	21.0	24.5	25.0	19.0	20.5	27.5	28.0	25.5	27.5	26.0	29.5	29.5	30.5	32.5	31.0	26.5
After 7-wks. Leveling	R_1	22.0	24.0	25.0	20.0	20.5	26.0	28.5	26.5	29.0	27.0	30.0	32.0	30.0	35.5	27.5	28.0
	R_2	22.0	25.0	25.0	20.5	19.5	26.0	28.0	27.0	29.0	27.0	30.0	32.0	29.5	35.5	28.0	28.0
Occlusal Mandibular Plane Angle																	
Before Leveling	R_1	19.0	17.0	13.0	12.5	18.5	17.0	18.5	14.0	16.0	19.0	20.0	21.0	23.0	25.0	21.5	22.0
	R_2	19.0	17.0	14.5	12.5	19.0	18.5	20.5	16.0	16.5	20.0	20.0	22.5	21.0	25.0	22.0	22.0
After Leveling	R_1	20.0	19.0	14.5	14.5	18.5	19.0	20.0	15.5	17.0	20.5	22.0	23.0	22.5	25.0	21.0	22.5
	R_2	20.5	18.5	14.5	14.5	19.0	19.5	19.5	17.0	15.5	21.0	21.5	23.0	23.0	24.0	22.0	22.0

Note: Measurements in degrees

TABLE 23

MANDIBULAR INCISAL ANGLE MEASUREMENTS

Patient Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Before Leveling	R_1	90.0	111.5	83.5	105.5	93.0	97.0	93.0	103.0	94.0	97.0	93.5	88.0	96.5	95.5	90.0	93.0
	R_2	89.0	108.0	85.5	104.0	92.5	98.5	95.0	100.5	91.5	96.5	94.0	87.0	96.5	93.5	92.5	95.0
After Leveling	R_1	91.0	106.5	88.0	111.5	98.0	96.5	98.0	107.0	90.0	100.0	100.0	88.0	96.0	98.0	93.0	99.5
	R_2	91.5	106.0	88.0	107.5	98.0	95.0	99.0	105.5	89.5	100.0	96.0	87.0	95.5	99.5	92.5	99.0

Note: Measurements in degrees

TABLE 24

MAXILLARY INCISAL ANGLE MEASUREMENTS

Patient Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Before Leveling	R_1	106.0	106.0	98.0	116.0	115.0	107.0	98.0	106.0	103.5	107.0	103.5	103.5	107.0	102.5	115.5	109.0
	R_2	109.0	106.0	102.0	116.5	116.0	107.0	101.5	107.0	105.5	108.0	102.0	101.5	108.0	103.5	117.5	110.5
After Leveling	R_1	104.0	102.0	102.5	117.0	111.0	104.0	97.5	106.0	107.0	103.5	98.0	100.0	105.5	99.5	111.0	106.5
	R_2	104.0	102.0	100.5	115.5	110.0	104.0	95.0	106.5	104.0	103.5	103.0	97.5	107.0	98.5	111.0	106.0

Note: Measurements in degrees

TABLE 25

OVERBITE MEASUREMENTS

		Group I					Group II					Group III					
Patient Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Before Leveling	R_1	2.0	4.8	8.1	1.5	5.0	5.1	5.1	3.7	3.8	3.0	7.5	1.0	4.0	1.1	5.5	4.0
	R_2	2.4	4.8	9.0	2.7	6.0	6.3	5.5	3.6	4.4	3.5	7.3	0.9	4.4	3.3	4.6	3.1
After Leveling	R_1	2.3	4.5	5.6	1.0	4.4	7.2	4.2	3.4	3.7	4.1	5.6	0.4	3.7	0.4	5.5	2.1
	R_2	2.6	4.2	5.6	0.5	4.2	6.7	4.8	2.5	3.4	3.8	6.1	1.1	3.8	0.6	5.0	1.9

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