The Use of the Orthopantomograph in Longitudinal Studies

G. A. Zach, D.D.S., M.S.

O. E. Langland, D.D.S., M.S.

F. H. Sippy, B.S.

The Orthopantomograph and the Panorex are forms of curved surface laminagraphy which visualize the entire dentofacial region on a single radiograph. The simplicity of operation, the broadened scope of examination, the ability to project anatomical structures in their normal relationships with reduced superimposition of intervening parts, and the low radiation dosage are reasons for the wide acceptance of this type of radiography[1].

Curved surface laminagraphy represents laminagraphy and panoramic scanography applied to a curved surface.

Laminagraphy is a special technique of body section radiography for radiographically demonstrating a preselected plane of body structure by blurring out tissue outside the plane of interest, thus revealing details ordinarily obscured by superimposed structures.[2] This is accomplished by the simultaneous movement in opposite directions of the x-ray source and the film during exposure. The film and the x-ray tube travel parallel to each other during the entire cycle.

In panoramic scanography, a slit of radiation scans the object while the film behind the object records each portion of the image.[3]

In 1949, Paatero[4] of Finland was the first to recognize the dental application of curved surface laminagraphy to the curved surfaces of the maxilla and the mandible. His first technique used a single concentric axis of rotation. The patient and the film were simultaneously rotated on their own axes with equal velocity.

Later, Hudson, Kumpula and Dickson[5] developed a panoramic technique utilizing two eccentric axes of rotation in which the patient's head remains stationary while the cassette holder and the x-ray source rotate around it. The axis of rotation is changed from one side of the arch to the other by an automatic shift of the chair midway through the cycle. This unit is manufactured by S. S. White and is called the Panorex.

In 1959, Paatero[6] developed a panoramic technique using three axes of rotation, one concentric axis for the anterior region of the dental arch, and two eccentric axes for the right and left posterior regions. The patient is immobile while the x-ray source and a curved film cassette circulate around his head. This unit is manufactured in Finland, and distributed by Siemens of North America.

Curved surface laminagraphy equipped with a cephalostat may provide a research tool in orthodontics that cannot be supplied by any other x-ray method.

The lateral skull radiograph is used almost exclusively in cephalometry. Although this radiograph provides considerable information in craniofacial and dentofacial relationships, it does have limitations. The cephalometric lateral skull radiograph has the problem of superimposition and it is difficult to distinguish separate components of the right and left jaws at times.[7]

From the Department of Oral Diagnosis, University of Iowa.

The cephalometric lateral oblique skull radiograph has been utilized by some researchers and clinicians;[8,9] however, this radiograph reveals only one side of the jaws at a time and is limited in its scope of examination.

It was Brader[10] in 1948 who first saw the possible application of the principles of cephalometric radiography to laminagraphy. In 1953, Ricketts[11] developed a laminagraphic unit equipped with a cephalometer, which is called the Sectograph Cephalometer. It is based on the rectilinear or straight line principle of body section radiography. While this unit is an invaluable aid in diagnosis and research, it does not produce a panoramic view of the dentofacial region on a single film.

Kane[12] recently reported on the level of accuracy of a cephalostat developed for the Panorex. A comparison was made between original and duplicate Panorex radiographs taken of thirty randomly-selected patients. Of the thirty measurements of the vertical distance between the lower border of the right mandibular canal and the lower border of the right mandible, there were only seven differences between the original and duplicate radiographs greater than 0.5 millimeters. The range of variation between all original and duplicate radiographic measurements was from 0.0 to 3.2 millimeters. In the sample of thirty subjects, the range of measurements for this relatively short vertical distance varied from 4.4 millimeters to 10.3 millimeters. In Kane's study, horizontal measurements were not utilized; the reliability of the Panorex to duplicate its motion cycle was not determined.

In order to determine whether the Orthopantomograph is suitable for longitudinal studies of the teeth and jaws, a cephalostat was designed and constructed in 1964 for the Orthopantomograph at the College of Dentistry, University of Iowa.[13] This cephalostat, Figure 1, consists of: (1) a calibrated adjustable chin rest, (2) an ear rod assembly in which the individual ear rods and the anteroposterior movement of the assembly are calibrated, (3) a movable noncalibrated rest that fits snugly into the notch formed by the junction of the frontal and nasal bone (nasion), and (4) an infraorbital marker for establishing the Frankfort horizontal plane.

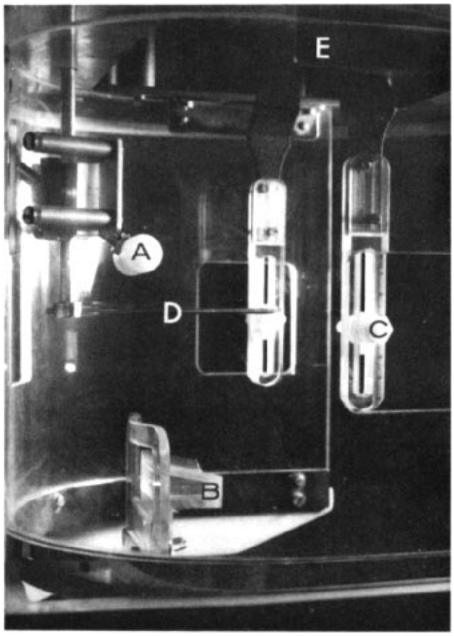

Fig. 1 Cephalostat designed for the Orthopantomograph. A, nasion rest; B, calibrated chin rest; C, calibrated adjustable ear rod assembly; D, infraorbital marker; E, mechanism to adjust ear rod assembly anteriorly, posteriorly, medially, and laterally.

Richardson[14] investigated the reliability of a repositioning technique utilizing the cephalostat constructed for the Orthopantomograph as described above. Two orthopantomograms were exposed on thirty-six patients. After the first exposure the patient was removed from the cephalostat and subsequently repositioned for the second exposure. Reference points and lines were inscribed on paired orthopantomograms. Six horizontal and two vertical measurements were obtained. Seventy two per cent (72%) of the differences between the original and duplicate film measurements were less than 1.5 millimeters. The 288 measurements ranged from 22.7 to 273.7 millimeters.

In Richardson's study the differences in the vertical measurements between paired orthopantomograms were significantly less than those found for the horizontal measurements. Of the thirty-six vertical measurements obtained in the midline, there were only five differences between the original and the duplicate orthopantomograms greater than 0.5 millimeters. The range of variation between paired orthopantomogram measurements at the midline was 0.0 to 1.8 millimeters with only one measurement difference over 1.0 millimeter. The length of these measurements varied from 43.3 to 60.9 millimeters.

Although the measurements in the horizontal plane in Richardson's study were definitely longer than the measurements in the vertical plane, other factors contribute to the significant variations found between paired orthopantomograms in the horizontal plane. Shape and size distortion of radiographic images in the vertical plane are a function of projection factors of (1) alignment of film, object, and the x-ray source, and (2) object to x-ray source and film to x-ray source distances. However, size and shape distortion in the horizontal plane are influenced by both projection and "motion" factors.

The "motion factor", which plays a part in horizontal dimensional change of radiographic images in the orthopantomogram, is dependent upon (1) the difference in velocities between the film as it rotates on its own axis and the projection of object points onto the film, and (2) the width of the x-ray beam which determines the time which the difference in velocities is allowed to exert its effect.

In the orthopantomographic technique the patient sits immobile while the x-ray source and curved film cassette circulate around his head. Also, the cassette rotates around its own axis. It takes 12.5 seconds for the Orthopantomograph to complete its exposure cycle, as compared with 22 seconds for the Panorex.

If the motion cycle of the Orthopantomograph varies during successive exposures, it follows that the horizontal dimension of the radiographic images of the immobile patient's teeth and jaws will vary accordingly. The subject of this investigation was to determine whether variations in the motion cycle of the Orthopantomograph occur during successive exposures. This problem was approached by determining the absence or presence of dimensional variation between fixed points on successive orthopantomograms. The secondary objective was to analyze image distortion in the orthopantomogram.

Materials and Methods

The source of data for this study was three wire-mesh objects, Figure 2. The wire mesh was made of steel wire 0.9 millimeters in diameter. The distance from the center on one mesh to the center of an adjacent mesh was 3.18 millimeters. The three objects were 60 millimeters in height and followed the approximate contour forms of the (A) inner surface of the image layer, the (B) basic plane of focus of the image layer, and the (C) outer surface of the image layer of the Orthopantomograph. Tammisalo[15] of Finland has defined these three basic image layer planes of the Orthopantomograph, and has mathematically determined their magnification (size distortion) values.

The objects were stabilized in plastic bases. Lead shot was affixed to the wire

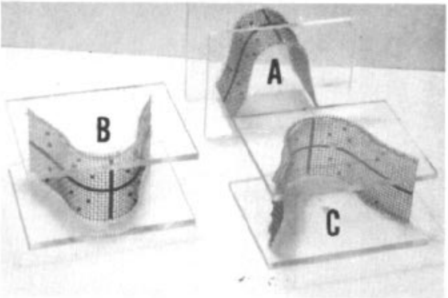

Fig. 2 Three wire-mesh objects used in study. A, contour of the inner surface of the image layer; B, contour of the basic plane of focus of the image layer; C, contour of the outer surface of the image layer.

mesh with glue. Specific lead shots were alphabetically identified as A through R, Figure 3. They were positioned to locate approximately the following reference points:

A & F The distal of the left and right mandibular third molar, respectively.

B & E The mesial of the left and right mandibular first molar.

C & D The midline of the left and right mandibular cuspid.

G & K The distal of the left and right maxillary third molar.

O & R The mesial of the left and right maxillary first molar.

P & Q The midline of the left and right maxillary cuspid.

I & M Arbitrarily placed in the vertical plane representing the midline of the dental arches.

H & L Arbitrarily placed in the same vertical plane.

J & N Arbitrarily placed in the same vertical plane.

Measurements were determined by counting the number of meshes between one identified mesh and another, inclusively. This number was multiplied by 3.18 millimeters, and 0.9 millimeters

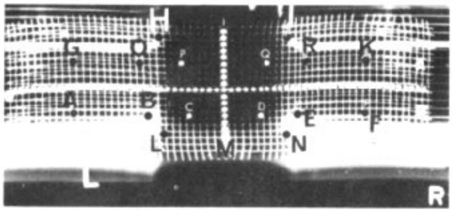

Fig. 3 Orthopantomogram illustrating reference points.

added to the product. This gave an outside-to-outside measurement of the meshes involved.

Seventeen reference lines were identified and their actual measurements are listed in Table I.

A plastic platform was constructed to support the objects in the Orthopantomograph, Figure 4. It was constructed to fit securely into the inner aspect of the face shield. When in position it was parallel to the floor.

The anteroposterior plane of focus was located by the use of a special device. It consisted of a plastic strip embedded with steel bearings, Figure 4. This was attached to the Orthopantomograph and an orthopantomogram was taken. The steel bearing which showed the least distortion on the orthopantomogram was used to represent the anteroposterior plane of focus. The vertical plane passing through the center of this steel bearing was marked on the plastic platform. The calibrations indicating the position of the ear cups were used to center the objects in a lateral position.

During the exposures object B was positioned so that the vertical plane, passing through the most anterior part of the wire mesh, coincided with the previously determined plane of focus. Object A was positioned so that the vertical plane, passing through the most anterior part of the wire mesh, was 2.1 millimeters posterior to the plane of focus. Object C was positioned so that the vertical plane, passing through the

TABLE I

Segment	Actual Length	A-x̄ (mm)	B-x̄ (mm)	C-x̄ (mm)	Segment	Actual Length	A-x̄ (mm)	B-x̄ (mm)	C-x̄ (mm)
A-B	39.1*	53.2	55.7	48.2	O-P	23.2	32.7	30.9	27.9
B-C	23.2	32.3	31.1	27.9	P-Q	42.3	60.0	56.5	50.2
C-D	35.9	50.5	48.7	43.4	Q-R	23.1	29.2	27.9	24.7
D-E	23.2	29.1	28.4	25.1	R-K	35.9	45.4	43.0	39.3
E-F	39.1	49.0	46.6	42.9	G-A	29.5	40.2	38.9	38.7
A-F	144.0*	193.3	189.6	169.9	H-L	51.8	68.8	67.7	66.9
G-K	144.0*	194.6	189.8	170.1	I-M	61.3	80.1	79.1	78.3
G-O	35.9*	48.8	50.9	43.7	J-N	51.8	68.1	66.7	66.1
K-F	29.5	39.8	38.5	38.3					

*(The actual lengths in object B were 42.2 for A-B, 147.2 for A-F and G-K, and 39.1 for G-O)

most anterior part of the wire mesh, was 2.5 millimeters anterior to the plane of focus. Thus, object B was positioned in the basic image plane, object A in the inner surface of the image layer, and object C in the outer surface of the image layer.

Kodak Royal Blue film (6 x 12) was used to obtain ten orthopantomograms of each object in its fixed position. The central beam was directed through the object at a minus eleven (—11) degrees. A setting of 63 KVP and 22 MA was used with a 12.5 seconds exposure time. A total filtration of 6 millimeters of aluminum was used. The exposed orthopantomograms were developed for two minutes and fixed for three minutes. They were then washed and dried.

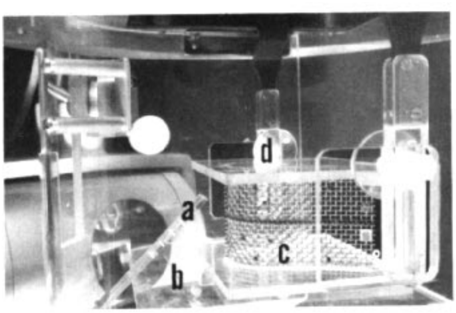

Fig. 4 a, device used to locate the anteroposterior plane of focus; b, plastic platform used to support the objects; c, wire-mesh object; d, ear cups used to center and support the objects.

The orthopantomograms were oriented on a view box so that the image representing the left side of the object was to the viewer's left.

The measurements obtained from the orthopantomograms corresponded to those previously determined on the objects. The measurements were taken between the vertical midpoints of the outside edges of the meshes containing identified lead shots. The distances between these points were independently measured to the nearest 0.1 millimeters by two investigators. When the two initial measurements agreed within 0.2 millimeters, the average of the two was used. In instances of greater discrepancy, each investigator took another measurement. The average of the two closest measurements was then used.

The millimeter ruler used in this study was examined for accuracy by comparison with an anthropometer verified by the National Bureau of Standards.

Findings and Conclusions

The actual lengths and mean radiographic lengths of the seventeen measurements on the ten orthopantomograms for each object A, B, and C are assembled in Table I.

The standard deviations of the measured distances on the ten radiographs

TABLE II

	A SD	A Var*	B SD	B Var	C SD	C Var
A-B	.18	.33	.15	.26	.12	.23
B-C	.16	.51	.12	.41	.12	.64
C-D	.35	.69	.31	.64	.28	.64
D-E	.18	.62	.19	.65	.18	.73
E-F	.14	.29	.26	.55	.09	.21
A-F	.51	.26	.48	.24	.49	.29
G-K	.95	.49	.82	.44	.50	.29
G-O	.17	.34	.17	.33	.13	.29
K-F	.21	.53	.16	.43	.27	.71
O-P	.25	.77	.10	.34	.16	.56
P-Q	.39	.65	.38	.68	.29	.55
Q-R	.28	.96	.21	.74	.25	1.00
R-K	.28	.61	.22	.51	.21	.54
G-A	.08	.20	.11	.28	.16	.42
H-L	.25	.37	.19	.27	.09	.13
I-M	.25	.31	.35	.45	.21	.27
J-N	.23	.34	.21	.32	.20	.31

*(Var = Coefficient of Variability)

are summarized in Table II. An estimate of the reliability of the orthopantomograph to duplicate its motion cycle may be obtained from these standard deviations. The true value of a measure on the radiograph would be within two standard deviations of the observed length of that measure approximately 95% of the time. For example, the true value of a measure across the anterior segment of the mandibular arch would be within .62 millimeters (2 x .31) of the observed value on the orthopantomogram approximately 95% of the time.

Variability due to machine and measurement error could be expected in general to be greater when the measurement was longer. The coefficients of variation reported in Table II are an expression of the variability relative to the length of the measurement. These coefficients are the ratio of the standard deviations of a measurement to its corresponding mean times 100. In none of the measurements was the standard deviation more than one per cent of the mean. In general, the largest values of the coefficient of variation are in the horizontal plane in the middle portion of the radiograph. This area represents the premolar and anterior portions of the dental arches. The anterior segment of the orthopantomogram is exposed while the Orthopantomograph is operating in the concentric rotational axis.

Radiographic distortion values of the horizontal and vertical measurements of objects A, B, and C are listed in Table III.

The differences in radiographic distortion values between forms A, B, and C for each horizontal measurement are consistently greater than for each vertical measurement. As mentioned previously, radiographic distortion in the horizontal plane is influenced by both "motion" and projection factors, while

TABLE III

Segment	Distortion A	Distortion B	Distortion C
Horizontal Measurements			
A-B	36%	32%	23%
G-O	36	30	22
E-F	25	19	10
R-K	26	20	10
B-C	39	34	20
O-P	41	33	21
D-E	26	22	8
Q-R	26	21	7
C-D	41	36	21
P-Q	42	34	19
A-F	34	29	18
G-K	35	29	18
Vertical Measurements			
G-A	36%	32%	31%
K-F	35	30	30
H-L	33	31	29
J-N	32	29	28
I-M	31	29	28

longitudinal radiographic distortion is influenced by projection factors only.

Therefore, in object C, where the object points are a longer distance from the center of rotation, the velocity of the projected image points will be greater than the velocity of the rotating film which results in a decrease in horizontal radiographic distortion. Conversely, in object A, where the object points are nearer to the rotational center, the horizontal radiographic distortion is increased.

In this study it was observed that there was a consistent difference in distortion between right and left sides of the orthopantomogram. As Tammisalo[15] suggests, this discrepancy could be a result of the fact that in the original prototype of the Orthopantomograph used, the position of the patient was not quite symmetrical in relation to the image layer.

It is evident from Table III that a single radiographic distortion correction factor could not be applied between patients as well as to all areas of the jaws for the same individual. Kite[16] reported similar findings in his study of image distortion in the Panorex radiograph. The explanation of these findings is based on the fact that in the Orthopantomograph and the Panorex, there is a fixed x-ray source-film relationship, while the object-film distance and the alignment of the jaws and the teeth with the film are dependent upon the anatomical variations of the patient. Of course, radiographic distortion will be exaggerated if the patient's head and mandible are incorrectly positioned.[1]

In order to use the cephalometric orthopantomogram in longitudinal studies requiring quantitative measurements in the dentofacial region, a radiographic distortion correction-factor would have to be computed for each segment of the jaws for each patient. It is possible that this could be accomplished by the use of a flexible plastic intraoral device calibrated with radiopaque material of known dimensions, or by a plastic template designed to be positioned upon the occlusal surfaces of the teeth and serve as a guide to distortion computation. However, qualitative analysis of changes in the jaws is possible without the use of distortion correction factors.

In the evaluation of cephalometric orthopantomography for use in longitudinal studies of the jaws and the teeth, it appears that the limits of error in this technique are acceptable for measurements in the vertical plane of the orthopantomogram. Although the measurements in the horizontal plane are not as reliable, the shorter horizontal measurements (those limited to one segment of the jaws) seem to be reliable enough for analysis of dental development within the jaws. However, the limits of error for the cephalometric panoramic technique (Orthopantomograph and Panorex) should be defined more precisely by further studies to determine whether these methods are acceptable for longitudinal studies of dental development.

Cephalometric orthopantomography is especially adaptable for the investigation of the following orthodontic problems:[7,12]

1. The path, rate, and sequence of tooth eruption.
2. The progress of serial extraction cases.
3. Orthodontic treatment progress and posttreatment appraisal (abnormal resorption of teeth, alteration of tooth position, angulation and root paralleling of teeth, amount of anchorage loss, degree of arch leveling and teeth involved, and excessive tipping of teeth).
4. Changes in condylar position during and after orthodontic treatment.

5. Effect of premature loss of deciduous teeth on permanent successors and adjacent teeth.
6. Postoperative appraisal of Class III malocclusions with resections.
7. Development and eruption of third molars.

Several excellent radiographic studies have been completed on the subject of mandibular third molar development and eruption.

In 1953, Ledyard[17] completed a cross-sectional study of the mandibular third molar area in subjects from the ages of eight to twenty using lateral jaw radiographs.

Three years later, Björk and associates[18] reported on a cross-sectional study of mandibular growth and third molar impactions using cephalometric lateral skull radiographs taken with the open-mouth technique.

Garn and associates[19] in 1962 reported on an interesting longitudinal study of the calcification and movement of the mandibular molars using lateral jaw and cephalometric lateral skull radiographs.

Although lateral jaw radiographs are superior to cephalometric lateral skull radiographs in the evaluation of dental development,[20] its alignment technique is difficult to reproduce and the radiograph reveals a partial, distorted view of the jaws.

Therefore, it would be interesting to utilize the cephalometric orthopantomographic technique in a longitudinal study of patterns of eruption and development of maxillary and mandibular third molars in a small group of individuals from the ages of fourteen to twenty-one.

Since the orthopantomogram provides a view of all four third molars on a single film, proportional relationships between erupting third molars and the various dentofacial structures can be observed.

Summary

The purpose of this study was to investigate the ability of the Orthopantomograph to duplicate its motion cycle. This was accomplished by ten successive exposures on three fixed objects.

Seventeen horizontal and vertical measurements were made on each of the ten orthopantomograms taken on the three objects. In none of the measurements was the standard deviation more than one per cent of the mean. In general, the largest values of the coefficients of variation were found in the horizontal plane in the anterior and premolar areas.

In analyzing image distortion in orthopantomograms, it was concluded that no single correction factor could be applied to all segments of the jaws in the same individual.

The results of this study and a previous study by Richardson[14] suggest that the Orthopantomograph equipped with a cephalostat may be sufficiently reliable within acceptable limits of error for measurements in the vertical plane and for horizontal measurements within segments of the jaws. Horizontal measurements in the molar segments seem to be more reliable than those taken in the premolar and anterior segments of the jaws.

College of Dentistry,
Univ. of Iowa,
Iowa City, Iowa 52240

References

1. Updegrave, W. J.: The Role of Panoramic Radiography in Diagnosis, *Oral Surg., Oral Med., and Oral Path.*, 22:49-57, 1966.
2. Littleton, J. T., Rumbaugh, C. L., and Winter, F. S.: Polydirectional Body Section Roentgenography—A New Diagnostic Method, *Am. J. of Roentgen.*, 89:1179-1193, June, 1963.
3. Stoneman, William, Brodeur, A. E., and Brueggemann, Irwin: A New Approach to the Radiologic Evaluation of the Mandible, *Plastic and*

Reconstructive Surgery, 39:376-381, 1967.

4. Paatero, Y. V.: A New Tomographical Method for Radiographing Curved Outer Surfaces, *Acta Radiol.*, 32:177, 1949.
5. Hudson, D. C., Kumpula, J. W., and Dickson, G.: A Panoramic X-ray Dental Machine, *U.S. Armed Forces M.J.*, 8:46-55, 1957.
6. Paatero, Y. V.: The Orthopantomograph and Its Clinical Use, *Suom. hammaslaak. toim.*, 55:172-184, 1959.
7. Graber, T. M.: Panoramic Radiography, *Angle Orthodont.*, 36:293-311, October, 1966.
8. Cartwright, L. J. and Harvold, E.: Improved Radiographic Results in Cephalometry through the Use of High Kilovoltage, *J. Canad. D.A.*, 20:261-263, May, 1954.
9. Barber, T. K.: Roentgenographic Evaluation of Growth and Development—A Review, *J. Am. Dent. Assoc.*, 67:329-339, September, 1963.
10. Brader, A. C.: The Application of the Principles of Cephalometric Laminagraphy to the Study of the Frontal Plane of the Head, *Am. J. Ortho.*, 35:249, 1949.
11. Ricketts, R. M.: Present Status of Laminagraphy as Related to Dentistry, *J. Am. Dent. Assoc.*, 65:57-64, July, 1962.
12. Kane, Edward G.: A Cephalostat for Panoramic Radiography, *Angle Orthodont.*, 37:325-333, October, 1967.
13. Langland, O. E.: The Use of the Orthopantomograph in a Dental School, *Oral Surg., Oral Med., and Oral Path.*, 24:480-487, October, 1967.
14. Richardson, James E.: Patient Positioning in the Orthopantomograph, Master's Thesis, College of Dentistry, *Univ. of Iowa,* 1966.
15. Tammisalo, E. H.: The Dimensional Reproduction of the Image Layer in Orthopantomography, *Suom. hammaslaak. toim.*, 60:2-12, 1964.
16. Kite, O. W., Swanson, L. T., Lewis, S., and Bradbury, E.: Radiation and Image Distortion in the Panorex X-ray Unit, *Oral Surg., Oral Med., and Oral Path.*, 15:1201, 1962.
17. Ledyard, B. C.: A Study of the Mandibular Third Molar Area, *Am. J. Ortho.*, 39:366-373, 1953.
18. Björk, A., Jensen, E., and Palling, M.: Mandibular Growth and Third Molar Impaction, *Acta Odont. Scand.*, 14:231-272, 1956.
19. Garn, S. M., Lewis, A. B., and Bonne, B.: Third Molar Formation and Its Development Course, *Angle Orthodont.*, 32:270-279, 1962.
20. Garn, S. M. and Shamir, Z.: *Methods for Research in Human Growth*, Springfield, Ill., Charles C. Thomas, 1958, p. 29.