Optimum conditions for intraoral roentgenograms

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Different methods for making intraoral roentgenograms have been published.[1-3] In these publications, three geometric variables in the technique can be found:

1. *Length of the cone—distance from the focal spot to the object.* The distance can be short or long as represented by the short-cone and long-cone techniques.
2. *Film placement.* The film can be placed in contact with the teeth and the soft tissues and fixed in position by the patient's fingers, or it can be placed in a position not completely determined by the contour of the soft tissues with the aid of a film holder.
3. *Angulation of the x-ray beam.* Different angulations of the x-ray beam are used, depending on the principles of the technique used. The beam may be directed at right angles to the tooth when the film is parallel with the tooth, or the beam may be at right angles to the plane bisecting the angle between the tooth and the film (bisecting-the-angle technique).

The technique utilizing the beam at right angles to the tooth is most frequently described in connection with the utilization of a long cone, whereas the bisecting-the-angle procedure is most frequently applied with a short cone.

In Part I of the present article the image formation will be studied as influenced by (a) the length of the cone, (b) the film placement, and (c) the angulation of the x-ray beam. Anatomic or other practical limitations will not be considered. In Part II the anatomic and practical limitations will be studied, and a search will be made for the best possible compromise. Part III will describe an attempt to standardize a technique that is in close agreement with the conclusion drawn from Part II.

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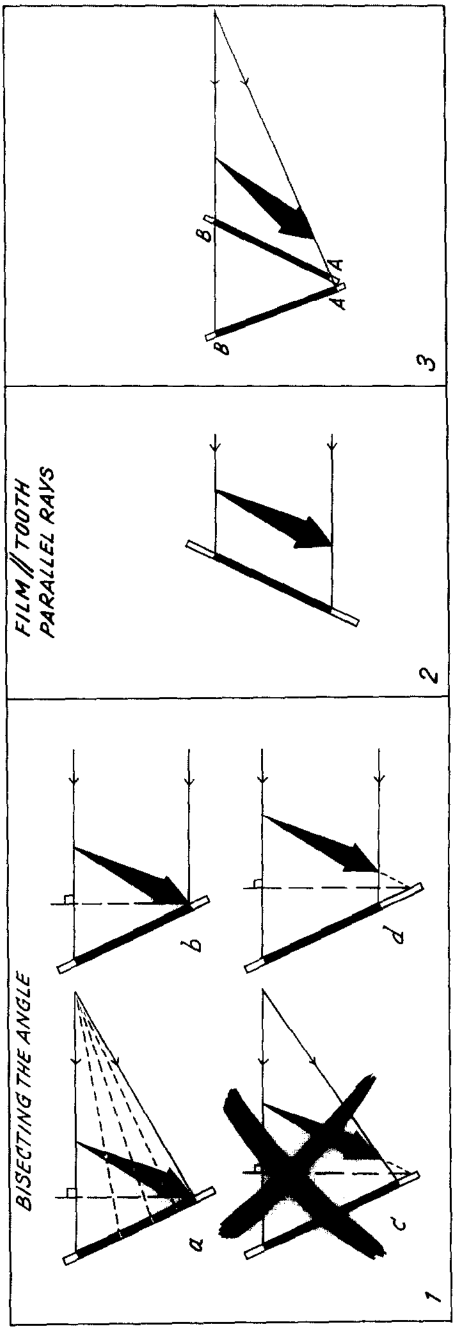


Fig. 1. All possible projections which exclude enlargement. The image has the same length as the original tooth.

PART I. THE IMAGE FORMATION AS INFLUENCED BY CONE LENGTH FILM PLACEMENT, AND X-RAY BEAM ANGULATION

Image formation is known to be influenced by cone length, film placement, and beam angulation. The images obtained with different combinations of these factors can be evaluated by the use of three criteria:

1. *Enlargement.* The ratio between tooth length and the length of the tooth image will be called "enlargement." Factors smaller than 1.0 indicate a shortening. Enlargement is called "absent" when the factor is 1.

2. *Distortion.* Apart from enlargement, there may be an uneven enlargement of different parts of the tooth. This uneven enlargement will be called "distortion." This phenomenon is shown in Fig. 1, where the four equal parts of the tooth are projected with unequal length.

3. *Distance between the projections of the buccal and palatal cementoenamel junction of the crown.* The distance between the projections of the buccal and palatal cementoenamel junction of the crown is used

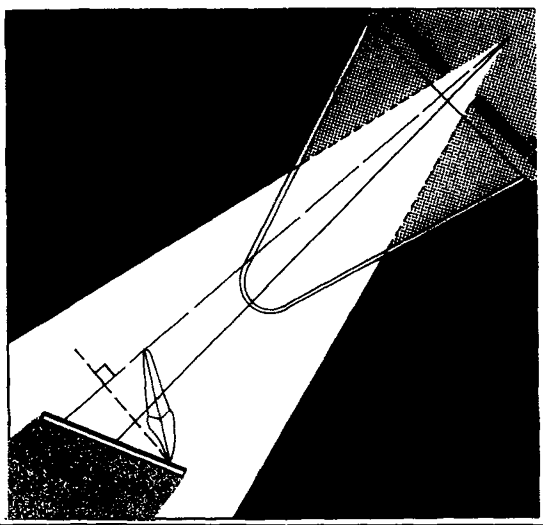


Fig. 2

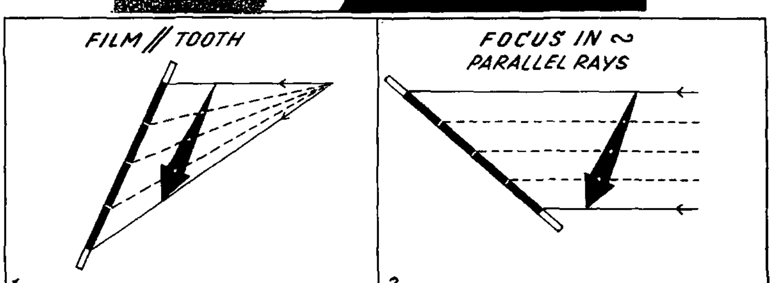


Fig. 3

Fig. 2. Projection according to the bisecting-the-angle technique when a small diaphragm is used. The central ray is directed to the center of the film, while the ray through the apex is at right angles to the bisecting line.

Fig. 3. All possible projections which exclude distortion. Equal parts of the tooth axis are projected as equal parts on the film.

as a third criterion for evaluating image formation. (See Fig. 4, shaded area, projection with dashed lines.) The smaller the distance between these two projected points, the better the results.

Requirements to exclude enlargement will be considered first. They are shown in Fig. 1. *No enlargement* is produced when one of the following conditions exists:

1. The apex is projected onto the film by a ray that is at right angles to the lines bisecting the angle between the film and the tooth. This rule has one exception, however (Fig. 1, *c*). When contact between the tooth and the film is absent and this is combined with a definite (not infinite) focal spot distance, an enlargement is produced.
2. The film is parallel to the tooth and the projection is carried out with parallel rays (focal spot at an infinite distance).
3. The terminals of distance AB (A-B equals the length of the tooth) are placed on the two divergent lines going from the focal spot through the top of the crown and the apex of the tooth. The figure shows only two of all the possible placements; an infinite number may be found by shifting the film while A and B are kept on the two projecting lines. As a matter of fact, the bisecting technique is a special case among an infinite series of positions.

It may be of interest to comment on the bisecting technique. When large diaphragms (x-ray beam collimators) are used, the axis of the beam can be directed through the apex at right angles to the bisecting line. However, with smaller diaphragms, which are to be preferred, the central ray has to be directed to the center of the film in order to avoid cone cutting. This direction of the central axis still permits the application of the bisecting technique when a ray other than the central ray goes through the apex at right angles to the bisecting line. This is illustrated in Fig. 2.

It must be remembered that distortion was defined as uneven enlargement. *No distortion* is produced when one of the following conditions exists:

1. The film is placed parallel with the tooth.
2. The rays are parallel.

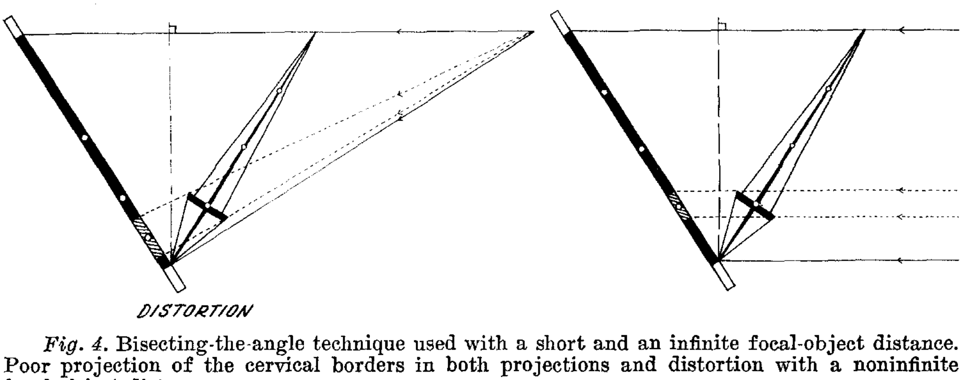


Fig. 4. Bisecting-the-angle technique used with a short and an infinite focal-object distance. Poor projection of the cervical borders in both projections and distortion with a noninfinite focal object distance.

Application of some simple geometric principles proves the above to be true (Fig. 3).

The distance between projections of the buccal and palatal cementoenamel junctions of the tooth crown can be reduced to zero by directing the ray through the cervical area at right angles to the tooth axis. It should be noted, however, that with this direction of the rays, a difference in the anatomic height of the buccal and palatal aspects of the crown will prevent the superimposition of the two respective cementoenamel junctions.

The image formation of single-rooted teeth

A comparison will be made between projections with a short and an infinite focal-object distance in combination with three different film-placement conditions.

Film placement according to the bisecting technique with the film and tooth crown in contact (Fig. 4). The use of a short focal spot distance will produce distortion because none of the requirements necessary to avoid distortion, as mentioned previously, are fulfilled. Fig. 4 demonstrates that equal distances on the tooth axis, indicated by circles, become unequal distances on the film; the resultant image is distorted. (The image is unevenly enlarged.) The use of parallel rays eliminates distortion, and enlargement also is absent. However, the projection of the cervical borders of the crown is poor in spite of the fact that some improvement is obtained when parallel rays are used. These effects are illustrated in Fig. 5; the teeth relate respectivily to the diagrams in Fig. 4. To visualize the distortion and enlargement, saw blades were placed in the root canals and a blade of the same length was placed on the film. The cervical line was demonstrated by a metal wire fixed to the cementoenamel junction.

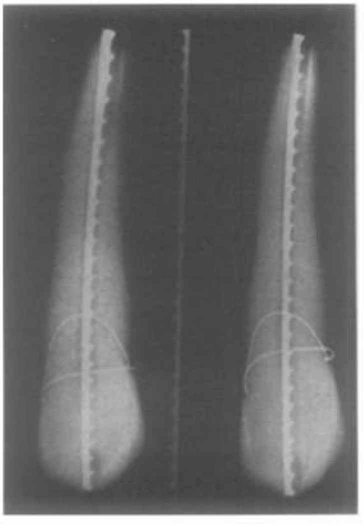


Fig. 5. Roentgenogram which illustrates the effects shown diagrammatically in Fig. 4.

Fig. 6

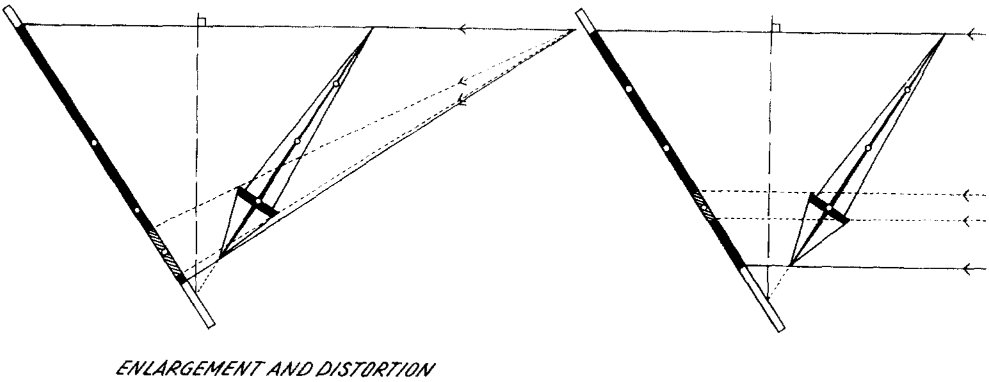


Fig. 7

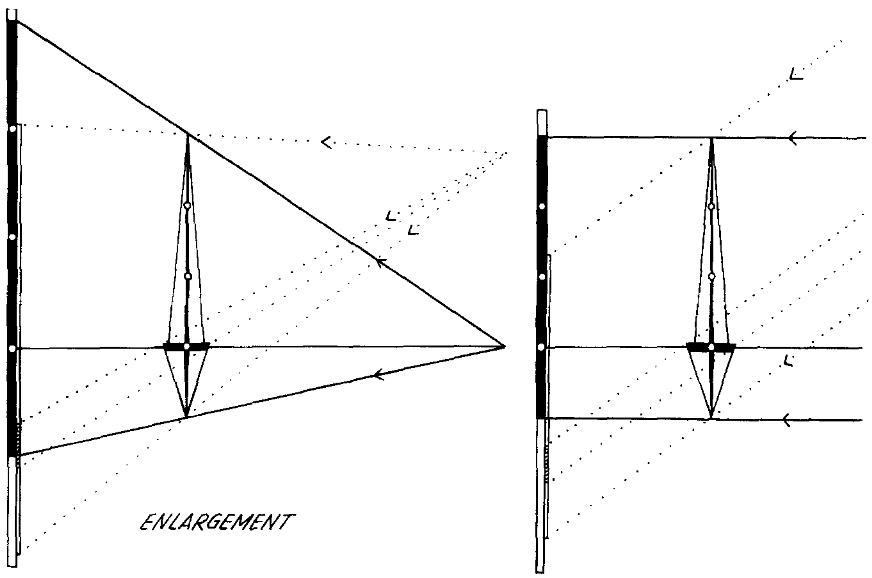


Fig. 6. Bisecting-the-angle technique when contact between tooth and film is absent. Projection with a definite and infinite focal-object distance. Poor projection of the cervical borders in both projections and distortion and enlargement with a noninfinite focal-object distance.

Fig. 7. Film parallel with the tooth. Projection with a definite and infinite focal-object distance. Enlargement when the focal-object distance is noninfinite. The quality of the projection of the cervical border can be influenced by the angulation of the beam.

All three criteria—enlargement, distortion, and the cervical line—can be judged according to the technique used.

Film placement according to the bisecting technique with the film and tooth crown not in contact (Fig. 6). Fig. 6 illustrates that enlargement and distortion occur when a short focal spot distance is used. These two effects are absent when the projection is made with parallel rays. However, the image of the cervical borders of the crown is also poor in both projections.

Film placement according to the paralleling technique—film and tooth are parallel (Fig. 7). Because of parallelism of tooth and film, neither projection

Table I

Projection technique	*Infinite focal spot distance*			*Noninfinite focal spot distance*		
	Enlargement	*Distortion*	*Cervical border*	*Enlargement*	*Distortion*	*Cervical border*
Bisecting, tooth and film in contact	–	–	+	–	+	+
Bisecting, tooth and film not in contact	–	–	+	+	+	+
Film parallel with tooth	–	–	–* +	+	–	–* +

– = Undesired effect absent.
\+ = Undesired effect present.
* = When rays through cervix are perpendicular to tooth axis.

method shows distortion. Divergent rays produce an enlargement which is absent when projecting an image with parallel rays. In contrast to the other projections previously described, all positions of the focal spot along a line parallel with the film and the tooth will neither change the magnification nor introduce distortion. Fig. 7 shows the projections from two focal spot positions (straight lines and dotted lines). This freedom in placing the focal spot can be used to alter the image of the cervical border of the crown. The projection with the solid lines superimposes the images of the buccal and palatal borders. The best projection is produced when the ray passes through the cervical borders of the crown perpendicular to the axis of the tooth.

The conclusions established thus far can also be found in Table I, where the results of the different projections are summarized. The table shows that, in general, better results are produced with parallel rays.

The image of multirooted teeth

An upper molar tooth is used as an example of a multirooted tooth. Since it can be concluded from the foregoing that infinite focal spot distances give better radiographic results, the noninfinite distances will not be given further consideration. Because of anatomic considerations, the bisecting technique using parallel rays cannot be applied simultaneously to the buccal and palatal roots. If parallel rays are directed at right angles to only one of the roots or to the axis of the tooth, enlargement of the other or of both of the roots is produced. It is equally impossible to place the film parallel with more than one diverging root. However, when the film is placed parallel with one root, the angulation of the beam can be varied without producing distortion or enlargement of the root parallel to the film (as described when single-rooted teeth were studied). This freedom to angulate can be used to apply the bisecting technique to the other root. This combination of the two techniques is illustrated in Fig. 8. Thus, the rays are perpendicular to the line bisecting the angle between the two roots. If we assume that the cervical border of the crown is perpendicular to this same line, we have also fulfilled the requirements for a good projection of the cervical border. No distortion (parallel rays), no enlargement (film parallel

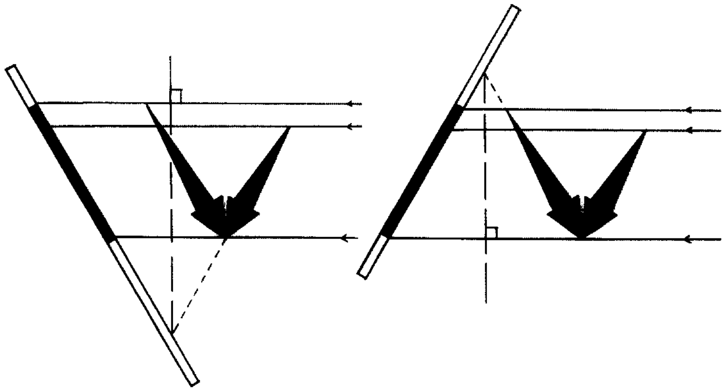


Fig. 8. Perfect projection of a multirooted tooth when the film is placed parallel with one root and the bisecting technique is applied to the other root.

to one root, bisecting technique for the other root), and, finally, a good projection of the cervical border (rays at right angles to the line bisecting the angle between the tooth roots) are achieved. The film may be placed parallel to either root as long as the bisecting rule is applied to the other root.

Conclusion

The best image of a single-rooted tooth is obtained when the object is projected with parallel rays at right angles to the tooth and the film. The best image of the multirooted tooth is obtained when the object is projected with parallel rays at right angles to the line which bisects the angle between the tooth roots while the film is positioned parallel to one of the tooth roots.

PART II. THE GEOMETRY OF THE IMAGE FORMATION IN INTRAORAL ROENTGENOGRAPHY AS INFLUENCED BY ANATOMIC AND PRACTICAL LIMITATIONS

Because the angle between the buccal and palatal roots of an upper molar is relatively small, from a practical point of view, only a small error is made when the film is placed parallel with the axis of the tooth. Acceptance of this concept has the advantage of using only one rule for the projection of single- and multirooted teeth. Thus, the most desirable projection is obtained when (1) parallel rays are used (the focal spot at an infinite distance), (2) the rays are directed at a right angle to the tooth axis, and (3) the film is placed at a right angle to the beam. This ideal projection cannot be realized because (1) the x-ray source is always at a definite (not infinite) distance from the object and (2) the anatomic structures often prevent the film from being placed in the desired position.

In order to find the best possible compromise, the influence of the above two factors was studied. Because the upper molar region is most useful in demonstrating the effects, this area is studied in greater detail.

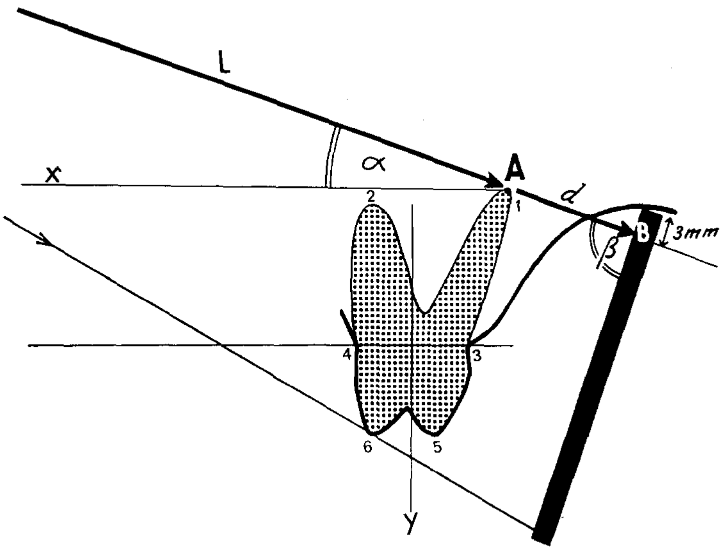


Fig. 9. Factors which influence the image formation when practical limitations are considered: *L, d, α,* and *β.*

Fig. 9 illustrates the problem and shows the four factors influencing the image formation:

1. The distance from the focal spot to the object (apex of the palatal root), indicated by *L*.

2. The angle, *α*, which is formed by the deviation of the beam from the ideal direction (at right angles to the tooth axis). A line at right angles to the connection of the buccal and palatal cervical border of the enamel and at equal distance from these borders was used as the tooth axis. This deviation, *α*, is the result of the requirement that the projection of the palatal apex, *A*, in order to be visible, should be at least 3 mm. from the border of the film, *B*. Since the border of the film cannot be placed in a position higher than the palate permits, the angle *α* visualizes the interference of the anatomic structure. In the case of an extremely high palate and a very short tooth, the line *A-B* can be at right angles to the tooth without placing the film in the highest position against the palate. In most cases, however, the situation is less favorable, and the length of the tooth and the height of the palate determine the angle *α*.

3. The distance from the palatal apex to the film, *d*. This distance depends on the placement of the film and the contour of the palate. The film placement will also influence *α*. In most cases there is only one value for *d* which produces the smallest *α*.

4. The angle, *β*, between the film and the direction *A-B*.

Table II

Landmark number	x (*mm.*)	y (*mm.*)
1	0	0
2	12.4	1.2
3	3.4	14.5
4	14.2	14.5
5	6.7	23.1
6	13.3	22.2

To summarize, the projection is defined by L, α, d, and β. The projection of six anatomic landmarks of an upper molar tooth is studied to analyze the relative importance of the four factors. The landmarks used are (1) the palatal apex, (2) the buccal apices of the roots, (3) the palatal border of the enamel, (4) the buccal-cervical border of the enamel, (5) the mesiopalatal cusps, and (6) the buccal cusps. For the sake of simplicity, the mesiodistal projections of the buccal apices as well as the buccal cusps are considered to be localized at the same point. Since the average orientation of these landmarks cannot be found in the literature on dental anatomy, an upper molar tooth of average size and representing as nearly as possible the ideal anatomic shape is used. The coordinates of the six landmarks of this tooth are given in Table II. The projection of this tooth is calculated by using the formulas given in the appendix.

The influence of the distance, *d*

From the formula, it can be concluded that the distance, d, affects only the size of the image while the proportions remain the same. From the study of Barr and Grön[4] on the shape of the palate, values for d producing the smallest possible α were selected. In the upper molar area, d was found to be approximately 17 mm.

The influence of the angle, α

To simplify the problem and to start with the most favorable condition, β is put at 90 degrees, and an extremely large focal (target)-object distance (L) is used. The only variable factor that remains is the angle α, which symbolizes the anatomic limitations. Fig. 10 shows what happens when α is changed. For dimensional comparison, the size of a dental x-ray film is shown in the background. The left side shows the picture obtained for $\alpha = 0$ degrees and the right side shows that for $\alpha = 45$ degrees. It is clear that the angle α has a decisive influence on image formation, even when an extremely long focal-film distance is used. The curves in Fig. 10 demonstrate that the buccal aspect of the molar tooth is shortened and shifted in relation to the palatal counterpart. The visual impression of the shortening of the buccal aspect is exaggerated by the shifting of the buccal roots over the image of the crown. One can conclude from the foregoing that the angle α should be kept as small as possible. Barr and Grön have shown that α can, in most cases, be kept smaller than 20 degrees.

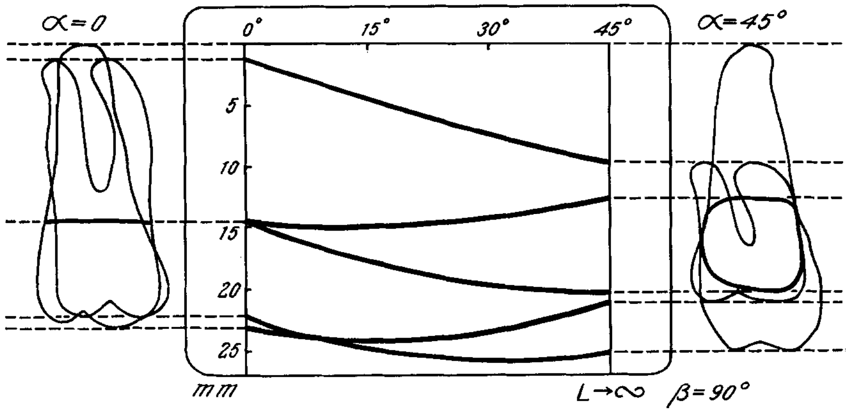
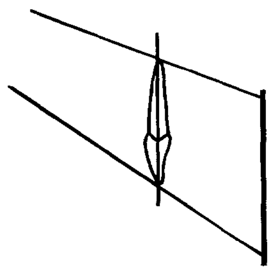


Fig. 10. Changes found in the projection of the upper molar when α is changed.



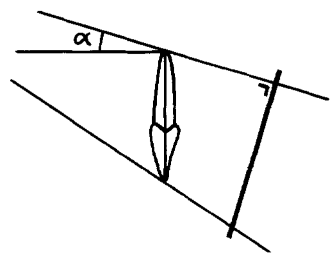


Fig. 11

L (cm)	Enlargement
∞	1.00
50	1.05
40	1.06
30	1.08
20	1.12
10	1.24

Fig. 12

L(cm)	α		
	0°	15°	30°
∞	1.00	0.97	0.87
50	1.05	1.00	0.89
40	1.06	1.01	0.89
30	1.08	1.02	0.90
20	1.12	1.05	0.92
10	1.24	1.13	0.96

Fig. 11. Enlargement found when film and tooth are parallel and L is changed (d = 24 mm.).

Fig. 12. Enlargement found for $\beta = 90$ degrees and α and L are varied ($d = 24$ mm., tooth length = 23 mm.).

It is interesting to note that, with the bisecting technique, α always will be larger than the minimum value which can be used.

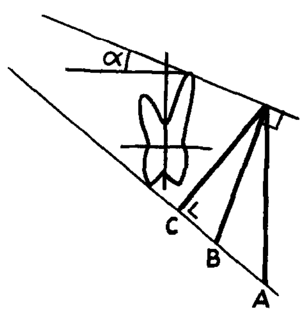
The influence of angle β and distance L

Single-rooted teeth. If the film is placed parallel to a single-rooted tooth, divergent rays will produce an elongation (Fig. 11).

It should be noted that α has no effect on this elongation. When the film is placed at right angles to the ray projecting through the apex, the elongation is partly reduced (Fig. 12). Note that for $\alpha = 0$ degrees, the position of the film is the same (parallel with the tooth) as in Fig. 11. In interpreting the table of Fig. 12, it should be remembered that α only varies between 0 and 20 degrees. When the two film positions are compared, we can conclude that less elongation is produced when $\beta = 90$ degrees.

Multi-rooted teeth (Fig. 13). Film position *A* shows a film placed parallel with the axis of the tooth. The elongation which is produced can be reduced by placing the film in position *B* at right angles to the ray projecting through the apex ($\beta = 90$ degrees). More reduction of elongation can be obtained by placing the film at right angles to the ray projecting through the tip of the buccal cusp. This position of the film will produce the smallest enlargement (Fig. 13, position *C*). This improvement is, however, of importance only for the extremely short focal distance of 10 cm. (See table of Fig. 13.) For best results, the angle β should be approximately 90 degrees.

Detailed information on the influence of *L* is shown in Fig. 14 for $\alpha = 0$ degrees, and Figs. 15 and 16 for $\alpha = 15$ degrees and $\alpha = 30$ degrees ($\beta = 90$ degrees—film perpendicular to ray as it passes through the apex). As in Fig. 10, the drawings are shown against a background having the relative size of a routine intraoral film. The two schematic drawings on each side (Figs. 14, 15, and 16) correspond with the pictures obtained with 10 cm. and an infinite focal spot (target)-object distance. These graphs can be used to select the length *L* which gives the best possible proportions. Each graph illustrates the deformations which are created when the focal-object distance is decreased. From the curves, one can conclude that the increase in the deformation is most pronounced when *L* becomes smaller than 30 cm. For practical applications, therefore, *L* should be at least 30 cm. The use of focal spot-object distances of more than 30 cm. does not improve the quality of the radiographs appreciably.



Enlargement for α=		0°	15°	30°
L= 20 cm	film pos. B	1.12	1.21	1.22
	film pos. C	1.11	1.20	1.21
L= 10 cm	film pos. B	1.30	1.36	1.32
	film pos. C	1.26	1.31	1.27

Fig. 13. Influence of *L* and α on the enlargement of an upper molar when different film positions are used.

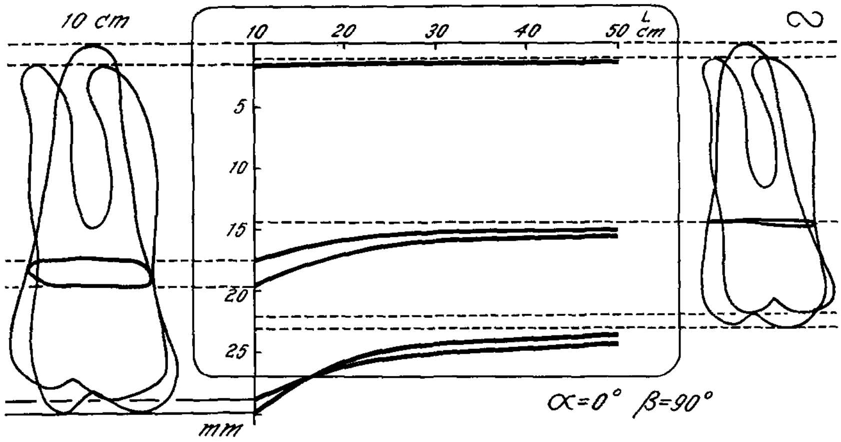


Fig.14

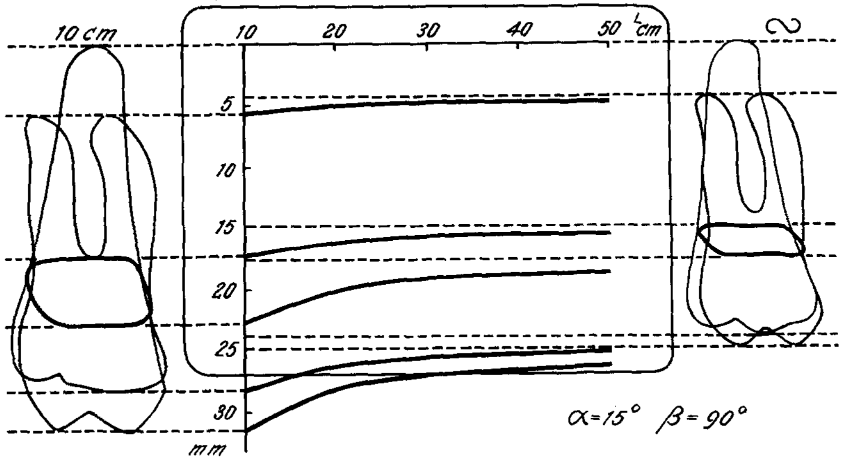


Fig. 1.

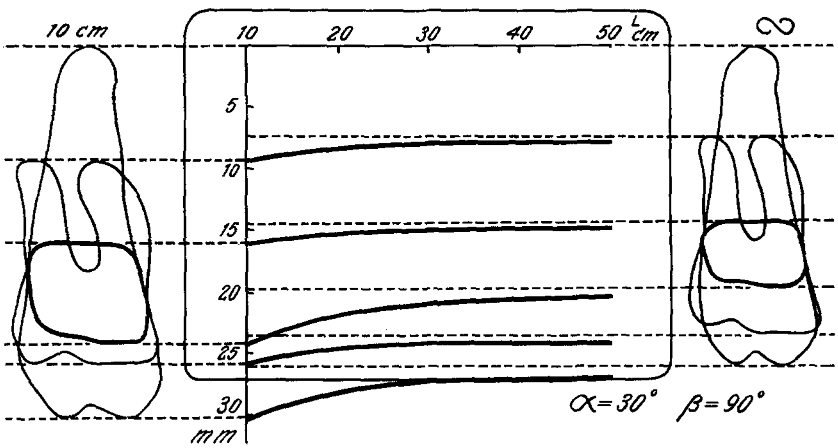


Fig. 1

Fig. 14. Changes found in the shape of the upper molar when L is changed ($\alpha = 0$ and $\beta = 90$ degrees).

Fig. 15. Changes found in the shape of the upper molar when L is changed ($\alpha = 15$ degrees and $\beta = 90$ degrees).

Fig. 16. Changes found in the shape of the upper molar when L is changed ($\alpha = 30$ degrees and $\beta = 90$ degrees).

Fig. 17

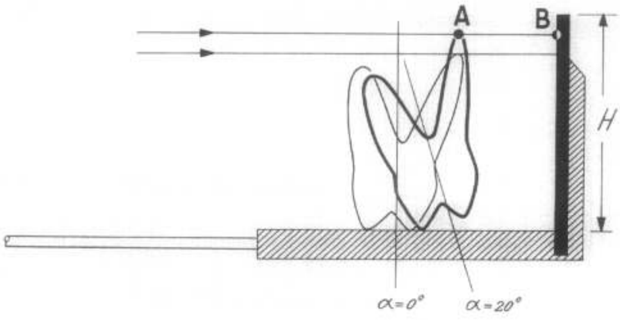


Fig. 18

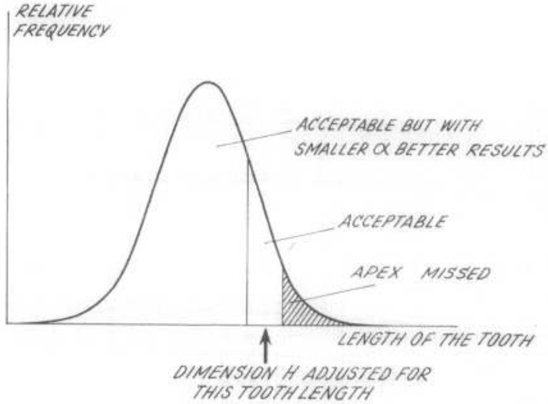


Fig. 17. Diagram showing the relation between x-ray beam, tooth, film holder, and film for two values of α ($\alpha = 0$ and $\alpha = 20$ degrees).

Fig. 18. Probability (when H is adjusted for the indicated tooth length) of (a) making a roentgenogram with an α larger than is needed; (b) making a roentgenogram with an acceptable vertical angulation (α); (c) missing the apex on the film.

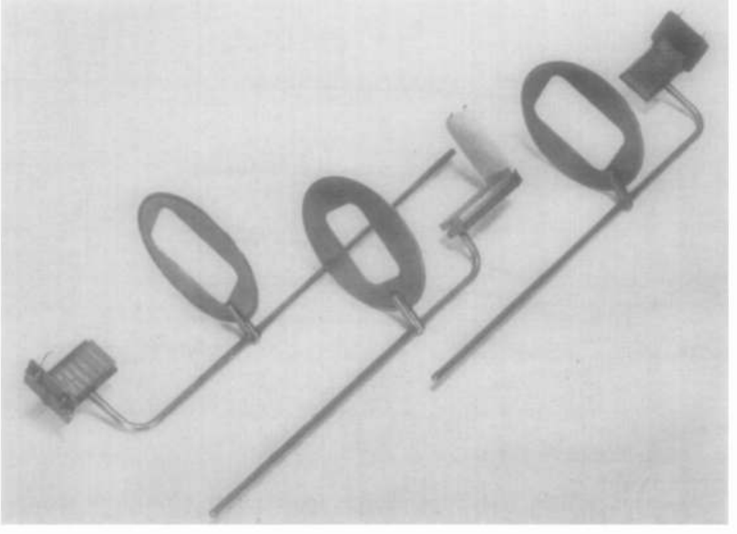


Fig. 19. Instruments used at Utrecht University Dental School.

Since longer focal spot-object distances increase the exposure time, it seems advisable to set the minimum requirement for a long-cone technique at a 30 cm. (12 inch) focal spot-object distance.

Conclusion

The best compromise for intraoral roentgenograms is obtained when (1) the prevailing importance of α dictates the value for d, (2) α is as small as possible, (3) $\beta = 90$ degrees, and (4) L is at least 30 cm. (12 inches).

PART III. A STANDARDIZED TECHNIQUE

With the use of the paralleling extension-cone (X.C.P.) instruments designed by W. J. Updegrave,[5] x-ray pictures can be made in a way that is in close agreement with the requirements found in Part II of this article. The relation between x-ray beam, tooth, and film is shown diagrammatically in Fig. 17.

The distance L can be regulated by the length of the cone, and provisions can be made to assure that this distance is at least 30 cm. The distance d is governed, as already discussed, by the anatomic configuration of the patient and the requirement of a minimum-value α. The angle β is nearly 90 degrees and is "built into" the instrument. When the film holder is positioned in the patient's mouth, the border of the film is placed in contact with the palate and the bite block against the occlusal surface. The tilting thus produced is directly influenced by the anatomic limitations (height of the palate). The tilting of the film holder relative to the tooth axis (angle α) is shown in Fig. 17, in which the molar tooth is rotated over the same angle α but in the opposite direction.

It is clear that the projection of the palatal apex cannot be kept at exactly 3 mm. from the border of the film when α changes, but the deviation is small and is acceptable for practical purposes. The dimension H in the apparatus (Fig. 17) is dictated by the length of the tooth, since A (apex of the tooth) has to be projected to B.

If the tooth is shorter than indicated in Fig. 17 and the distance H is maintained, the apex will be projected more than approximately 3 mm. from the border of the film. From Fig. 9, it is clear that this can occur only when α is larger than the desired minimum. For this shorter tooth the tilting α will consequently be larger than is needed to project A 3 mm. from the border of the film (B). If the tooth is longer than indicated in Fig. 17, the apex will be out of the picture and will give an unacceptable result. This imperfection in the technique cannot be eliminated, since the length of the tooth is unknown. The three areas under the curve shown in Fig. 18 represent the probabilities of the results when H is adjusted for the indicated tooth length. (The frequency of the length of the teeth was assumed to have a normal distribution.) If H is adjusted for a shorter tooth length, the number of cases in which the apex is missed will increase, whereas the number of teeth which could be x-rayed better with a smaller angle α will decrease. If H is increased to reduce the frequency in which the apex is missed, it will more often occur that α is larger than is required to

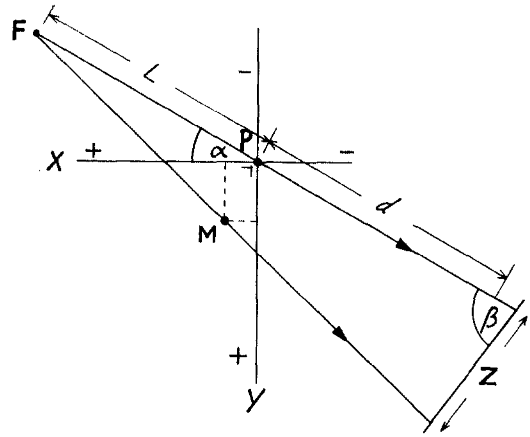


Fig. 20. Diagram of factors needed to calculate the length of the image *Z* when *L*, *α*, *d*, *β*, *x*, and *y* are known. *F*, Focal spot; *P*, palatal apex; *M*, landmarks with coordinates *x* and *y*.

give the best possible result (α as small as possible). The only solution is to construct the device for a relatively long tooth to guard against missing the apex too often.

Devices similar to the X.C.P. instruments (Fig. 19) have been used since 1959 at the Utrecht University Dental School, with good results. The main differences between the X.C.P. instruments and those used in Utrecht include the use of stainless steel (rather than plastic) and a circular collimator with a rectangular opening, which facilitates the aligning of the x-ray machine and also reduces the size of the irradiated surface to a rectangular area the size of the film (also introduced by Medwedeff and colleagues[6]).

The instruments allow for two film positions with different values for *H*. Acceptable values of *H* for the permanent dentition have been shown to be 29 mm. for upper and lower molars and premolars (film type: 1.2). The upper anterior teeth and lower cuspids require 39 mm., whereas an acceptable value for the lower incisor is 33 mm. (film type: 1.1). With the use of type 1.0 film, *H* becomes 21 mm., suitable for the deciduous molars, and 34 mm. for the deciduous cuspids and incisors.

APPENDIX

The following formulas are used to calculate the projection of the different landmarks. The symbols used are explained in Fig. 20 and previously in Fig. 9.

Let
$$\frac{y}{x} = \operatorname{tg} \delta$$

and
$$\operatorname{tg} \gamma = \frac{x \sin(\alpha + \delta)}{L \cos \delta - x \cos(\alpha + \delta)}$$

then
$$Z = \frac{(L + d) \sin \gamma}{\sin (\beta + \gamma)}$$

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