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An 'anatomic' projection method for dental radiography.

By

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Two factors commonly recognized as being responsible for distortion in dental radiographs are the divergence of the X-ray bundle and the difficulty of keeping the root of the tooth and the film plane parallel. For the production of radiographs that are correct in at least some respects, it has long been the practice to follow as closely as practicable some pre-determined geometrical rules for the mutual positioning of the X-ray components and the cranium. The disadvantages inherent in this approach lie in its essentially theoretical nature in virtue of which it is impossible to judge with any confidence how near the actual setting is to the ideal.

Neither is the final radiograph of any assistance in this respect. Not only will it give no indication whether or no an accurate setting has been accomplished; in many cases it will be impossible to observe how large a deviation has been incurred. The practised dentist, in virtue of his general perception of the tooth dimensions, is in a position to make a rough estimate of whether an image of a tooth is too long or too short, but an accurate interpretation is still extremely unlikely.

The technical procedure will, of course, be instrumental in determining to some degree the chance of an accurate setting, and this fact has led to the application of a number of setting methods. These may be considered to fall into three groups:

- free-hand setting,
- mechanical setting of the central beam,
 - employing various appliances, and
- the 'anatomic' method.

The majority of these procedures have not been subjected to any systematic investigation in respect of their properties under practical conditions. It might in general be said that, whatever the method used, the result will ultimately depend much on the practitioner's familiarity with the variations in the anatomy and on his experience in the application of one or another of the methods. Since all dentists are unpractised to begin with, the problem is almost entirely an academic one: it might be stated thus: Is there any method that, while being easy to teach, is at the same time practically independent of the personal equation associated with the majority of the methods?

Free-hand setting is beyond all doubt the most widely practised method. The geometric theory determined, an attempt is made to apply it in practice by directing the ray cone with no other assistance than the operator's conception of the three-dimensional conditions in the skull, the length of the teeth, the position of the root apices, etc. This is undoubtedly the most difficult of the methods to master, but it has, on the other hand, the great advantage that one has the opportunity of taking into consideration the proportions of the individual jaw — *i. e.* the anatomic variations.

A previous investigation by the present author (1940) was concerned with the reliability of the free-hand setting method when applied by both practised and inexperienced dentists. It was found that the random errors of both categories were of roughly equal magnitude: the systematic deviations, however, were more than three times as great for beginners as for the trained operators. This would seem to lend support to the assumption that the difficulties encountered by the unpractised are inherent in the method itself.

A question of fundamental importance in this connection is whether deviations from the true measurements in the radiographs are in fact of any real significance in practical dental care. Several authors have expressed the opinion that a variation of about 10 % is normal and of no practical importance. This, however, was at the beginning of the century, but nowadays the demands on the accuracy of dimensional representation of the radiograph in several fields of odontology are probably considerably greater, especially in the case of marginal diseases of the jaw-bone and numerous prosthetic appliances.

The present author has also conducted an investigation with jaw preparations containing teeth, with the purpose of deter-

mining the radiograph image distortion when the personal equation has been eliminated. To this end the teeth were extracted, prepared with a net of metal reference lines and reset in the alveolars, Fig. 1 and Fig. 2. The jaw preparations were then set up in the projection device illustrated in Figs. 3 (a) & 3 (b) which permits a controlled and systematic variation of all the stereometric factors involved in the projection.

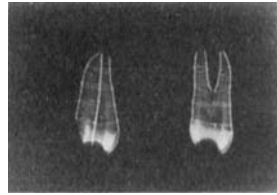


Fig. 1.

In the latter investigation an impression was thus gained of the variation in the 'theoretical' structure of the picture, while

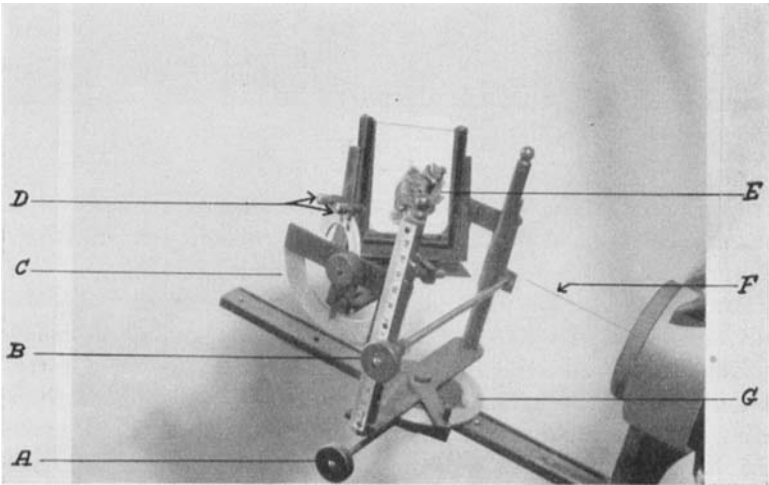


Fig. 3 (a). The projection arrangement (HERULF) for the study of the positional changes of the anatomic details for various projection relationships when X-raying the jaw and teeth.

- A = horizontal adjustment of target distance.
- B = vertical adjustment of incidence point of central beam.
- C = inclination mechanism by which central beam is set at various angles of incidence to the preparation and film packet.
- D = screws by which the preparation and film packet are set at various angles to one another.
- A base screw, unmarked in the illustration, permits rotation of horizontal plane of preparation and film packet.
- E = preparation fastened on a pin stuck into the root canal.
- F = central beam represented by a thin steel needle that appears on the radiograph as a white spot.
- G = mechanism for rotation of the complete carriage to give oblique beam directions in combination with changed point of incidence of central ray.

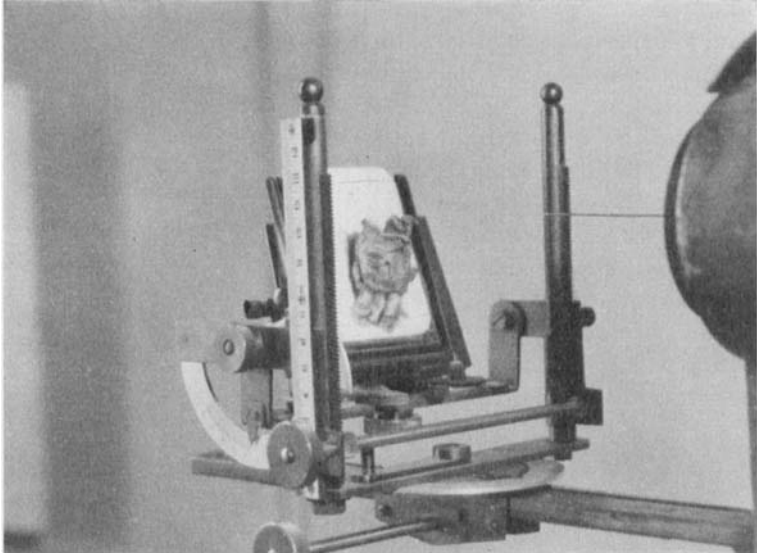


Fig. 3 (b).

the former was concerned with *in vivo* conditions when operators of varying experience attempt to realize certain prescribed projection conditions by the free-hand method.

An attempt was subsequently made to overcome the disadvantages of free-hand setting by the *application of various mechanical aids*. In the first place attention was devoted to the elimination of the personal setting error — *i. e.* such errors as arise through incorrect calculation of the relationship between the X-ray cone, the tooth and the film. The approach consisted in computing the mean of the anatomic characteristics for various persons. This provided a general impression of the best position of the film packet in relation to the teeth and the structure of the jaw. On the basis of this information it was possible to calculate the angle of the central beam in relation to, for example, the Frankfort horizontal and the level at which it should intersect the tooth to give bisector radiographs. The theoretical values thus obtained were then applied practically, using mechanical devices such as linear scales, protractors and spirit levels to construct the required beam directions.

In this way it should be possible to eliminate some of the systematic and accidental personal errors. The disadvantages from

the clinical and academic points of view are that the dentist works as a robot, paying no regard to the individual jaw characteristics of the patient.

The *anatomic setting technique* "beruht auf den unbewussten Lagebeziehungen zwischen dem Centralstrahl und der plastischen Schädelanatomie" (PARMA, 1929). Such methods are mentioned by several authors. They have generally reached certain formulated rules for the ray direction by analysing cranium radiographs, and then set the ray path by a known orientation in relation to various anatomic features. They work backwards, as it were, in so far as an attempt is made to satisfy the theoretical claims of the devised projection system by finding identifiable anatomic details that might serve as reference points. The angle as well as the point of incidence of the central beam should be specified: of a reference line in relation to which the angle may be expressed, the bridge of the nose may be mentioned as an example. The crux of the anatomic method lies, however, in finding and defining distinct orientation points for all the teeth, and facial contours that will provide a tolerably reliable definition of the direction of incidence of the ray. The majority of the authors who deal with such methods have restricted themselves to those teeth where the chance of successful orientation was favourable. Individual attempts to work out a method for the complete dentition have, in the opinion of the present author, resulted in too many detailed instructions, that serve only to confuse the beginner who desires to acquire the method for routine application.

These procedures are founded on the principle of a definite relation between the structure of the skull and the characteristics of the teeth. It is, moreover, a question of anthropological and anatomical conditions; certain aspects of the main problem have been resolved by the Swedes THOURÉN, SEIPEL, LUNDSTRÖM, BJÖRK, *et al.*, but a comprehensive account that might form the basis for systematic X-ray methods of the type suggested probably still remains to be written.

Starting from the assumption that an anatomic method should, by its very nature, have more regard to the anatomic variability than do the mechanical methods, and that it is, moreover, easier to acquire than the free-hand setting method, an attempt was made to realize an anatomic method that might be applied to the whole dentition and that is not concerned with a superabundance of details.

Basic principles.

It should first be borne in mind that the bisector rule gives a dental radiograph in which the total length is correct, independent of the target distance. (That, on the other hand, the inner distortion in the same image varies with the target distance is a circumstance that will be disregarded in this connection.) It is thus possible to place the focus at any desired point along the theoretical path of the central ray that has been calculated to give the bisector radiograph. It might be noted that a number of different planes have been suggested as the most convenient references for orientation of the cranium. The occlusal plane, the Frankfort, the Chandler and the Camper planes have all been proposed as the most suitable for horizontal setting.

Suppose the cranium to be fixed so that the longitudinal axis of the tooth is vertical and the technical central ray in the horizontal plane, while the X-ray tube can be raised and lowered in this position. When the theoretical bisector ray is drawn it is immediately evident that when the tube is raised so that the focus lies on this line a bisector radiograph is obtained, even if the horizontal central beam is incident at a point some distance above the tooth. (Fig. 4.) If the diaphragm aperture is sufficiently large it is clear that some ray in the cone other than the horizontal one will lie on the theoretical central ray path.

It is then found, moreover, that for a given target distance a bisector setting with a horizontal tube can be obtained by raising the tube to the point where the focus lies on the theoretical bisector ray path.

Assume now that instead a certain point of incidence is prescribed for the horizontal central ray path. Is it still possible to obtain a bisector projection? In the case where there is a horizontal point of incidence somewhere above the tooth, it is clear that if the tube is moved horizontally, retaining the same point of incidence, there will still be some position of the tube where the focus lies on the theoretical bisector ray path.

Here, then are the two basic conditions, and the object is now to combine them with the architecture of the skull in such a manner as to provide clear skeletal details that will serve as means of orientation of the horizontal ray. Put in another way, if clearly identifiable skeletal features are made the point of departure

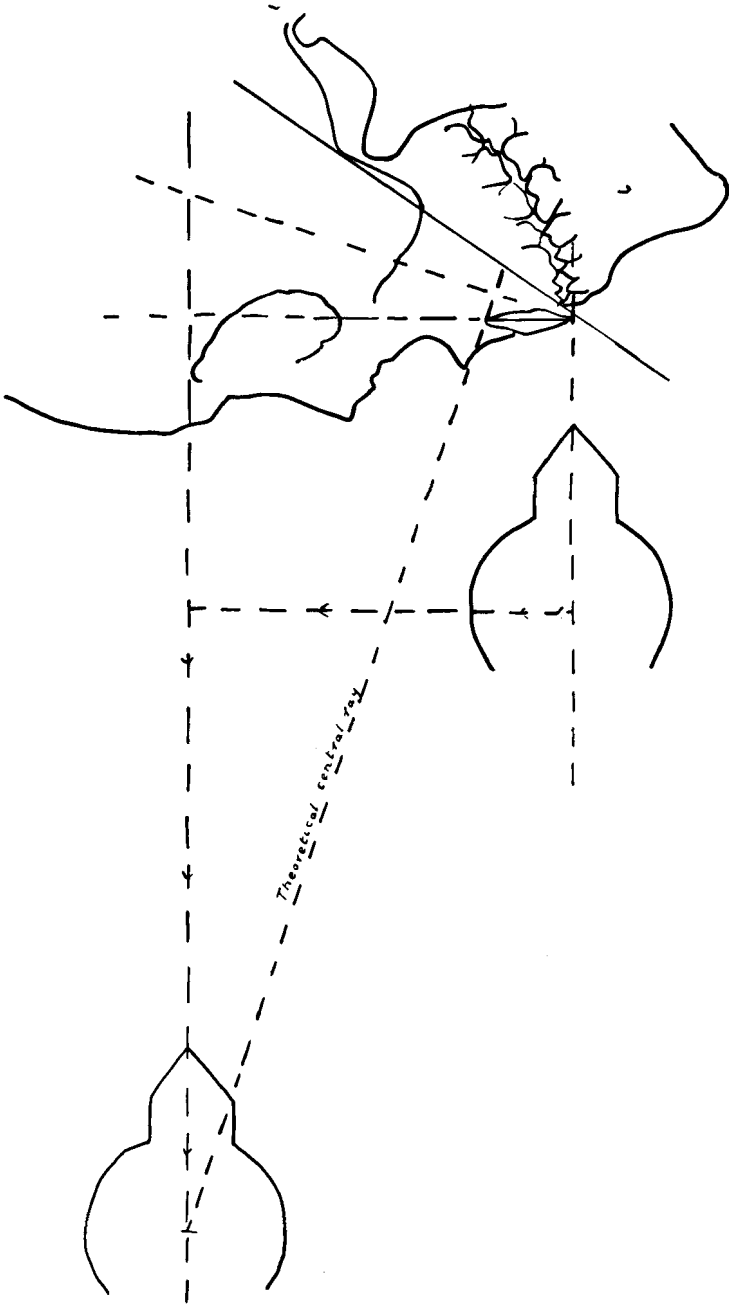


Fig. 4. The horizontal and vertical displacements when the focus lies in the theoretical ray path.

the problem will be to manipulate the target distance and the point of incidence so as to obtain a bisector radiograph of the various teeth.

Excellent orientation features are provided by, for example, the supra- and infraorbital ridges and the median line through the orbit. If now the position of the tube is such that the horizontal ray path meets the upper ridge of the orbit, there are three possibilities in respect of the total radiograph of, say, the canine: the root apex is projected by a ray of varying inclination and the length of the image will be correct, too large or too small, depending on the inclination of the projecting ray. If the length of the image is correct it is clear that the focus will be located on the theoretical path of the bisector; in the other cases the focal distance will be too large or too small, respectively. If it is desired to retain a certain level for the sake of good orientation as, for example, just when the horizontal central ray is directed towards the supra-orbital ridge, it can be calculated how large the target distance must be in order to give the bisector setting; this, of course, on the condition that the theoretical central ray path can first be established — which, however, is possible only when the actual length of the tooth and the angle between the tooth and the plate are known. If a practical method is desired on the basis of these theoretical considerations, a knowledge would be required (from a sufficiently large material) of the average anatomic characteristics in respect of the lengths of the various teeth and their location in relation to those facial features that would conveniently serve as direction points.

It might be thought that one could use the same details (for example, the continuation of a horizontal line through the supra- or infraorbital ridges for the orientation in respect of *different* kinds of teeth, on the condition that the target distance were adjusted to the characteristics of the individual teeth.

This is, to all intents and purposes, a question of an analysis of the mean values and variability in anthropological measurements.

The theoretical method outlined here requires, of course, a point focus and a means of rotating the tube that should ensure that the focus lies on the axis of rotation. Since the direction setting of the ray bundle is effected through the horizontal ray, the cone with its primary aperture should be rotated to the tooth so that the central part of the bundle is effective in the exposure — this condition requiring of course no change in the theoretical conditions.

The formula for the calculation of the target distance. (Fig. 5.)

- v = angle between the longitudinal axis of the tooth and the film
- $\frac{v}{2}$ = angle between horizontal and theoretical ray paths
- a = distance from the cusp of the tooth to the supra-orbital ridge
- l = length of the tooth
- $(a-l)$ = distance from apex to supra-orbital ridge
- x = target distance to the root plane.

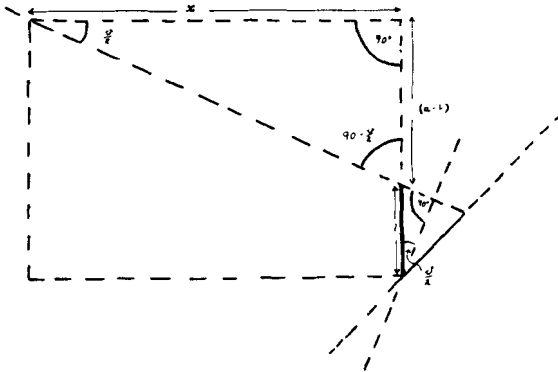


Fig. 5. The basic theory for the calculation of the target distance when the horizontal beam is incident on the supraorbital ridge.

Reference to the sketch shows the relationship between the known quantities a , l , and v , and the unknown target distance, x

$$x = \frac{a - l}{\tan \frac{v}{2}}$$

Introductory experiments.

In order to obtain a preliminary idea of the result that might be expected from such a method, experiments were performed with the upper canines of a number of subjects who were X-rayed by students with no previous technical practice. The teeth in question were for one reason or another due for extraction.

A plastic impression of the jaw was first taken, after which the tooth was X-rayed, the central ray being horizontal and inci-

dent on the supra-orbital ridge. The tooth was extracted for measurement of its actual length and to enable a positive cast of the jaw and tooth to be obtained with the extracted tooth set in the plastic impression: this was expected to facilitate measurement of the angle between the longitudinal axis of the tooth and the film plane.

These primary experiments had to be based on the assumed positions of the plate and longitudinal axis, and the distance from the cusp to the supra-orbital ridge. The angle was estimated to be 35° and the distance 8 cm. An average tooth length of 26 mm was chosen, a figure obtained in a previous investigation (1940) on upper canines. A rough calculation on the basis of these figures showed that a target distance of somewhat more than 17 cm should result in a bisector radiograph where the focus was at the level of the supra-orbital ridge.

It was desirable even at that early stage to obtain an idea of the extent to which complete absence of practice in dental radiography was of significance to the results — just as it was earlier found that training played a great part in free-hand setting.

In connection with the statistical treatment of these preparatory experiments Professor G. DAHLBERG was kind enough to provide instructions. 180 unpractised students divided into groups of 9 took radiographs using a prescribed procedure but without controls. Each group had one subject and each member of the group took one radiograph of the canine. The 20 groups thus examined 20 teeth and each canine was X-rayed by 9 observers. The actual measurements of 4 of these teeth were omitted because the patient changed his or her mind about allowing extraction or because the tooth was broken on extraction. The average of the X-ray measurements was obtained by taking the average of the 9 means of the X-ray series.

The principal result of this investigation was that the X-ray image was found to be, on the average, 1.3 mm larger than the actual size; *i. e.* a difference of about 5 %, which was interpreted as quite an encouraging result when compared with the 10 % that was taken as the normal figure. The error of the method was $10\frac{1}{2}$ %, which is surprisingly low in view of the fact that these experiments were based on estimated tooth — film angles and the distance of the cusp from the incidence point on the supra-orbital ridge.

The students later made measurements with a large number of

patients in order to obtain an approximation of the average of this distance and the variability when unpractised persons perform palpation and measurements. For 180 men the average cusp—incidence point distance was 9.70 ± 0.039 cm and for 376 women 8.16 ± 0.026 cm, with standard deviations of 0.54 and 0.50 respectively. The distance had been estimated as 8 cm. The difference between males and females is statistically significant and it is surprising that the standard deviation within the sexes is so small. This information might of course have been obtained equally well before the X-rays were performed. It was, however, not feasible on account of the other important factor — the angle between the tooth axis and the film plane.

The result of this preparatory investigation was interpreted as indicating that an anatomic method on the lines described and based on more voluminous and more thoroughly worked material would provide a step in the right direction.

Cranial investigation.

It is clear that one cannot expect to assemble in a reasonable period of investigation a large enough number of persons willing to place themselves at the disposal of the dentist for necessary extractions and other treatment. There is, moreover, the fact that much of the necessary information is not readily available from living material. It is hardly to be expected, for example, that root canals shall be available for insertion of direction indicators purely for the purpose of research.

From the very large collection of skulls belonging to the Institute of Anatomy of the University of Uppsala a selection was made that yielded 200 that were suitable for the investigation in respect of existing teeth and similar factors.

It should be pointed out that it was the upper teeth that were of interest in association with the anatomic setting methods. One reason is that it is difficult to find identifiable direction references in the mandibular architecture. A further, and perhaps the more important reason, lies in the fact, that in the mandible there is more chance of getting the film plane parallel to the plane of the roots, and thus ensuring near enough ideal projection, since one is then fairly independent of the point of incidence and ray direction. As far as the lower anterior teeth are concerned a modifica-

tion of the usual manner of fixing the film packet has been given in an earlier paper (HERULF 1951) in which a parallel film position is provided for these teeth as well. For the reasons stated this investigation was limited to the maxillary teeth.

MATERIAL.

The selection of the skulls was made with regard to the presence of teeth and their condition as well as to other details that might assist in evolving the projection method. The material is therefore heterogeneous from several points of view. The journals of the Institute concerned with the collection of skulls, which are in some cases over 200 years old, are frequently incomplete in respect to age and sex data. There are of course certain criteria in the architecture of the cranium by which the sex is indicated, and these were in each case discussed with the anatomist, but the element of doubt was rarely absent. For this reason no sex grouping that could be claimed as reliable was attempted.

Foreign races are most probably not represented, and all the skulls are from adults, some of them clearly having lived to a great age. Heavy abrasion is a striking feature of this material. This can be easily established from the details of the lengths of the teeth and the heights of the crowns. The condition is pointed out at this stage since it influences the practical application of the projection method — to what extent is a question that might well be debated.

Complete rows of teeth in a skull occur but rarely. For this reason it has been impossible to perform consistent examinations of the teeth in any one jaw; it has instead been necessary to make use of teeth of a particular type irrespectively of their placing in one jaw. The third molars have not been included, nor, as a rule, have the anterior premolars.

With a few isolated exceptions, the teeth examined were: anterior incisors, canines, posterior premolars and first and second molars.

METHOD.

In order to obtain a conception of the skull structure a number of the ordinary craniometric dimensions were taken (by Martin's procedure). They comprised: the traverse diameter of the skull

(euryon—euryon), its length (glabella—opisthion) and height (basion—bregma), the height of the face (gnathion—nasion), and its breadth (zygion—zygion). For this purpose use was made of the slide gauge and calipers.

In addition a number of measurements were taken with the cubic craniofor and a craniofor constructed by the present author to which reference will later be made. With the cranium in the norma parietalis position the distances from the base plate to the supra- and infraorbital ridges were noted, and from the base plate to the following points: the incisal mid-point of the +1+, the cusp of the +3+, the buccal cusp of the +5+, the distobuccal cusp of the +6+, the mesiobuccal cusp of the +7+ and the lowest point of the zygoma. By subtracting the last-mentioned distance from each of the others the distances (= a in the formula) were obtained from these points to the lines through the orbital ridges and to the horizontal mid-line of the orbit. (Fig. 6.)

It is highly desirable that the molars should be projected free of the shadow of the zygoma. To this end, the lateral distance be-

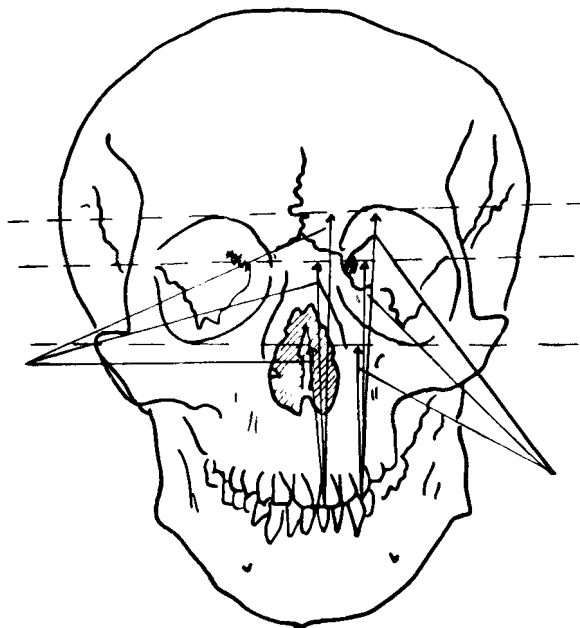


Fig. 6. The distances (a in the formula) from the various teeth to the three orbital planes.

tween teeth and zygoma should be known. Measurements were therefore made of the distances from the base plates to the mesio-buccal cusp of the +7+ and to the lower edge of the zygoma, the cranium being in the norma lateralis position.

For the measurement of *the length of the teeth* they were removed from the skull. Where this was impossible without the risk of damage the root tip was carefully exposed *in situ*. Consideration was then given to the conditions governing the *position of the film* and its relation to the inclination of the teeth. Measurement was therefore made of the palatal height — from the line joining the occlusal mesial fossae of the second molars — and the width of the dental arch — between the palatal surfaces of the crown of the same teeth. An excellent measuring instrument suitable for this purpose has been constructed by ANDERS LUNDSTRÖM.

The inclination of the root was determined in the following manner. The pulp cavity and the first part of the root canal were opened so that a specially treated piece of piano wire (0.25 mm diam. and 10 cm long) could be inserted some 10 mm into the canal. If the crown is prepared so that the wire is supported without tension by the cavity walls the wire gives the principal direction of the canal. With the craniofor and the skull in the norma lateralis position the wire was projected on to a paper screen by means of an ordinary hair cross tube. In this way a reproduction was obtained of the inclination of the roots in relation to the median plane. With the cranium in the norma frontalis position the inclination of the tooth was obtained in relation to the median plane. Direct measurements were also made of the angle between tooth and film packet by placing the latter in position and laying a rigid pin on the back roughly in the ortho-radial position. It will generally fall across the root canal pin and the angle can be measured with a protractor. One of the sources of error when attempting to reproduce practical conditions was of course that the soft parts were absent. To what extent this can affect the position of the film is difficult to decide with any degree of certainty unless experiments are performed to determine the thickness of the gingiva.

To provide an estimate of the effect of *abrasion* on the lengths of the teeth constituting this material the crown height was measured from the buccal cemento-enamel junction to the occlusal edge of the crown.

It should be mentioned in connection with the cranifor measurements that the usual cubic type proved very difficult to use for registering the inclination of the roots. It was found that the bulky clamping arrangement for securing the cranium frequently concealed the pins. The author therefore designed a cranifor (Fig. 7) that was suitable for cephalo-dental measurements (p. 90, 91).

The apparatus consists of a stand on a large heavy base plate in the horizontal plane. The most time-consuming operation associated with the cubic cranifor is the orientation and horizontalization — for example, of the Frankfort plane. In the new apparatus this is easily effected by allowing the adjustable metal rods to rest against the upper wall of the external auditory canal; it then remains only to bring the frontal Frankfort point to the same level. The cranium is secured by firm pressure applied through sponge cushions. Devices with pivots and stop screws provide the means for changing the skull planes by simple manual adjustments. This permits reliable setting of the planes at 90° or any other desired angle. Further details are illustrated in the figures.

The *magnitude of the error of measurement* was estimated from independent control measurement of 20 crania performed by another person.

Dental radiographs were taken using 20 crania to test the suitability of the orbital lines mentioned as direction references for a horizontal central beam. The root tips were covered with a contrast medium, and all three exposures were made on the same plate. Direct measurements were then possible and comparison could be made between the measurements relating to one or another of the projection directions. One could also be reasonably certain that the generally most variable source of error — the differences in the position of the film packet — was eliminated. (Fig. 8.)

A commentary on the tables follows. The reader is referred to the formula for the calculation of the target distance.

With the cranium placed in the norma parietalis position the distances were measured from the base plate to a number of points so as to obtain the distance a in the formula. In other words the distance was obtained from the incisal and the occlusal points of the various types of teeth to the supra- and infra-orbital ridges to the median line between the ridges.

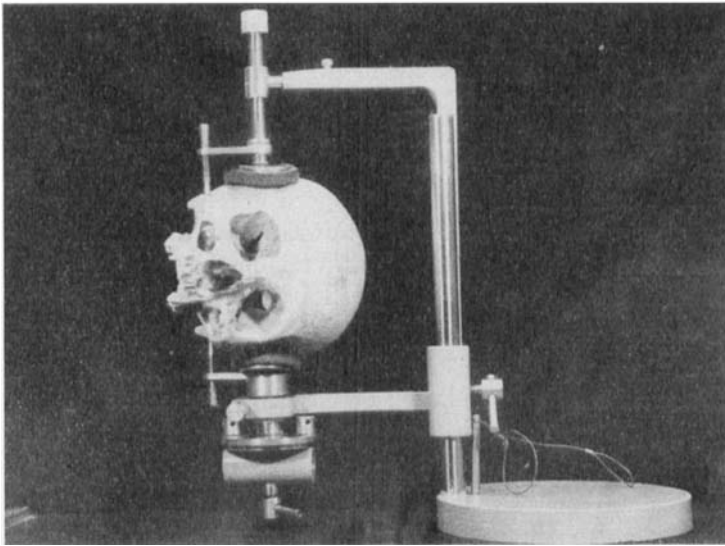
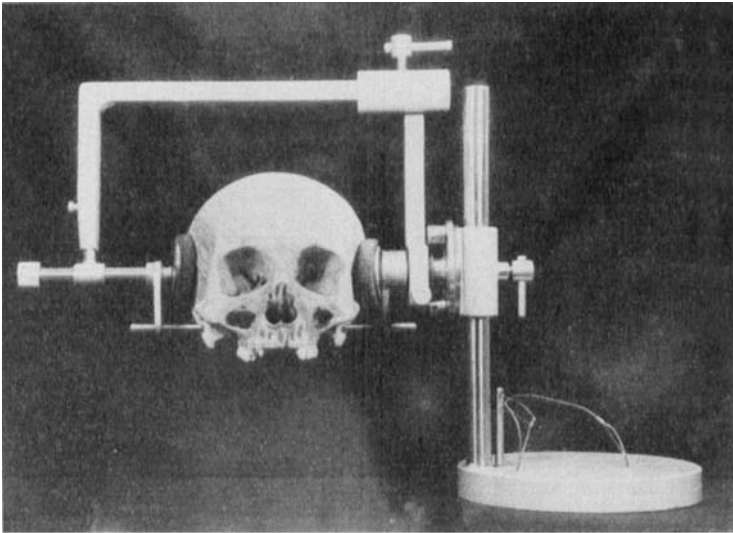
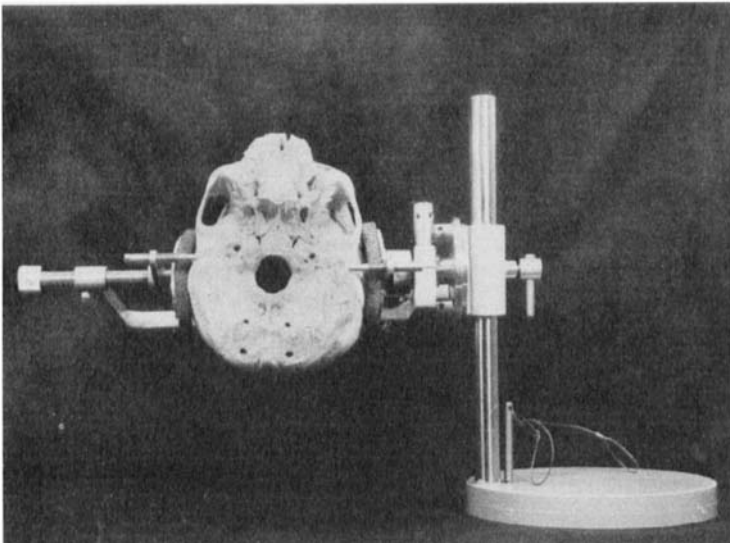
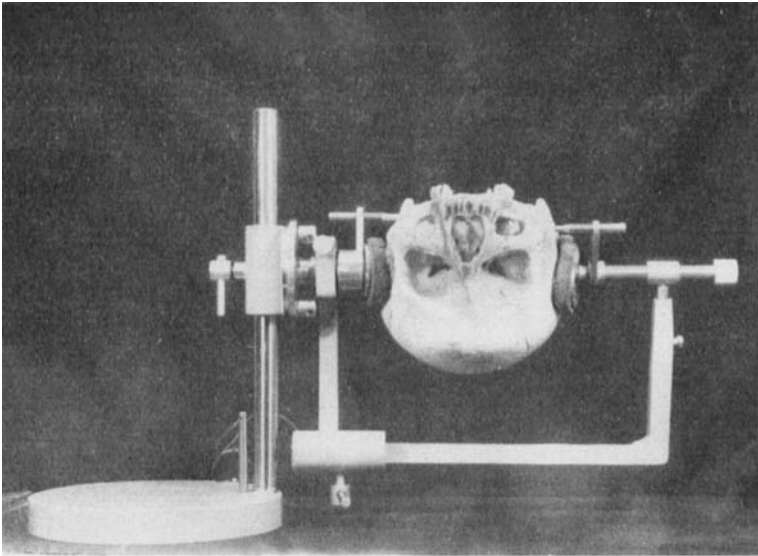


Fig. 7. The "Cranifor" (HERULF) for measurement of particular jaw regions.



The crania are shown in various positions in relation to the base plate.

It has been suggested above that the zygomatic arch is of great importance in the projection of the upper posterior molars. This of course depends largely on the architecture of the skull. A number of races — and quite a few individuals in others — are characterized by an outstanding zygomatic arch and perhaps at the same time a very low alveolar process. In such cases it is impossible to project the apices apart from the shadow of the zygomatic arch. This of course offers no great difficulty so long as one is aware of it, since the ray can be corrected subsequently. To provide some detailed information concerning the zygomatic arch and its relation to the molar teeth a number of measurements were made.

The average height of the orbit (the distance between the upper and lower ridges) was about 36 mm. It was 10 % greater for females than males in this material, but this should not be made a point of in scientific discussion, since the number of women was so small compared with men and was, moreover, not precisely known.

The distance a.

For the *canines* the mean distance was 8.4 cm. Corresponding figures have been quoted above for the subjects concerned in the measurements performed by the students. The material comprised 564 persons, of which about two-thirds were women. The average was 8.45 cm — a very close agreement.

Anterior teeth.

From the supra-orbital ridge the distance was 8.4 cm.

Second premolars.

From the buccal cusps to the supra-orbital ridge the distance was 8.3 cm.

Second molars.

From the mesiobuccal cusp to the supra-orbital ridge the distance was 8.1 cm.

To sum up it might be said that there is but little variation in the average perpendicular distance from the occlusal points of the various types of teeth to the plane through the supra-orbital ridge.

Zygomatic arch.

This material showed that if one starts from the average length of a second molar (= 2.0 cm) the lower border of the zygoma lies

0.4 cm cranially of the plane of the root apices. This is a remarkably small difference in level and will involve difficulty in projection that will be more pronounced the greater the lateral distance between the mid-root plane and the lower border of the zygoma. This point receives further treatment in the next table

With the cranium in the norma lateralis position, measurements were made of the horizontal distance between the plane of the molars and the zygoma; thus the distances between the base plate and the second molar's mesiobuccal cusp and between the base plate and the lower border of the zygoma were obtained. It was found that the border of the zygomatic arch lay on an average 1.7 cm laterally of the molar plane through the mesiobuccal cusp.

With the cranium in the same position measurements were taken of the angle between the Frankfort horizontal and the 'bite plane'. The definition of 'bite plane' is not uniform throughout the literature. In the present case the bite plane line is taken as that obtained by joining up the occlusal contact points of the teeth.

The angle had an average value of 5.5° .

Table III gives a comparison between the actual and image lengths of the various teeth when a horizontal central ray was incident on the supra- and infra-orbital ridges and the mid-line of the orbit in turn. The table gives the X-ray measurements from series of intraoral radiographs of 20 crania. To facilitate the taking of dimensions the root tips were covered with a contrast medium. The three exposures, one for each incidence point, were made on the same undisturbed film. One can therefore take the reference points for the various ray directions on the same picture, the advantage being that some of the error sources were eliminated, foremost among them being that due to the different relative positions of film and tooth. (See the large standard deviation in these values. Table IV.)

A study of the table will reveal immediately that for all the teeth the image lengths gradually decrease as one passes from the point of incidence on the supra-orbital ridge, over the median line to the lower border. It can be seen, moreover, that the images from all the ray positions are larger than actual size.

It should be remembered that the length of the image is determined partly by the size of the angle between tooth and film and partly by the position of the focus. The latter can be considered

Table I.

The distances from the occlusal reference points of the teeth to the three orbital planes (a in the formula).

Tooth	Males		Females		Sex unknown			Total		
	No.	$M \pm E (M)$	No.	$M \pm E (M)$	No.	$M \pm E (M)$	σ	No.	$M \pm E (M)$	σ
Plane through supra-orbital ridge										
+1+	84	84.98 ± 0.48	14	80.32 ± 1.39	43	83.06 ± 0.75	4.90	141	83.93 ± 0.41	4.85
+3+	101	84.43 ± 0.47	17	79.62 ± 1.03	47	82.70 ± 0.67	4.60	165	83.44 ± 0.38	4.86
+5+	97	83.72 ± 0.43	18	79.22 ± 1.02	48	81.89 ± 0.73	5.05	163	82.68 ± 0.37	4.73
+7+	97	81.63 ± 0.43	16	77.16 ± 1.18	45	80.08 ± 0.70	4.67	158	80.74 ± 0.37	4.60
Plane through orbit centre.										
+1+	84	67.53 ± 0.45	14	63.07 ± 1.33	43	65.60 ± 0.64	4.22	141	66.50 ± 0.37	4.43
+3+	101	66.98 ± 0.51	17	62.47 ± 0.94	47	65.27 ± 0.59	4.02	165	66.03 ± 0.38	4.89
+5+	97	66.20 ± 0.35	18	61.97 ± 0.94	48	64.46 ± 0.63	4.35	163	65.22 ± 0.31	4.00
+7+	97	64.38 ± 0.39	16	59.97 ± 1.11	45	62.65 ± 0.64	4.28	158	63.44 ± 0.34	4.25
Plane through infra-orbital ridge										
+1+	84	49.77 ± 0.42	14	45.68 ± 1.26	43	48.08 ± 0.58	3.80	141	48.85 ± 0.35	4.12
+3+	101	49.33 ± 0.38	17	44.76 ± 1.08	44	47.81 ± 0.54	3.70	165	48.43 ± 0.32	4.07
+5+	97	48.63 ± 0.34	18	44.50 ± 0.83	48	47.01 ± 0.56	3.87	163	47.71 ± 0.29	3.76
+7+	97	46.63 ± 0.35	16	42.59 ± 1.02	45	45.01 ± 0.58	3.89	158	45.76 ± 0.31	3.84
Plane through zygomaticus										
+7+	98	24.69 ± 0.35	16	23.59 ± 0.66	44	44.44 ± 0.49	3.22	158	24.51 ± 0.27	3.34

Table I (continued).
Male-female difference

Tooth	Supra-orbital ridge	Orbit centre	Infra-orbital ridge	Zygomatius
+1+	4.66±1.48	4.46±1.40	4.09±1.33	—
+3+	4.81±1.14	4.51±1.07	4.57±1.15	—
+5+	4.50±1.11	4.23±1.00	4.15±0.90	—
+7+	4.47±1.26	4.41±1.18	4.04±1.08	1.10±0.75

Table II.

The lateral positions of the lower border of the zygomatius and the buccal edge of the second molar in relation to the base plate.

	Males			Females			Sex unknown			Total		
	No.	$M \pm E (M)$	σ	No.	$M \pm E (M)$	σ	No.	$M \pm E (M)$	σ	No.	$M \pm E (M)$	σ
7's mesio-buccal cusp ...	102	108.96±0.46	4.61	16	111.44±1.41	5.62	48	110.18±0.87	6.03	166	109.55±0.40	5.19
Zygom. lower border ...	106	92.60±0.53	5.44	19	95.34±1.18	5.15	49	92.99±0.94	6.58	174	93.01±0.44	5.78
7's mesio-buccal cusp lat. to zygom. lower border	98	16.47±0.43	4.24	16	16.00±0.93	3.73	45	16.92±0.78	5.21	159	16.55±0.35	4.47
Angle between Frankfort horiz. & bite plane ...	96	5.81±0.39	3.81	12	4.96±0.75	2.61	47	4.86±0.45	3.10	155	5.45±0.28	3.54

as defined by two 'co-ordinates' — a vertical, represented by the distance from the given points in the cusps or incisal edges to the orbital lines, and a horizontal, the target distance from the imaginary extension of the teeth. In the special group of 20 crania the position of the film was constant for the three projections, since they were taken on the same film with points of incidence for the horizontal central beam in the three lines of the orbits. Further, the target distance is similarly constant for the three projections — about 25 cm.

The table thus reflects the effect on the image length of moving the point of incidence from a line through the infra-orbital ridge through the median line of the orbit to a line through the upper border. Since all the positions of the points of incidence give too large image dimensions — decreasing with height, as the theory requires — an accurate image length would be obtained if a point of incidence were chosen that was situated still higher than the supra-orbital ridge. There are, however, no easily identifiable points in this part of the skull.

From what has already been said it will be seen that it is possible to influence the length of the image by varying the target distance — a shorter distance giving a steeper inclination to the beam projecting the root apex, and thus a shorter image. On account of the identifiable character of the supra-orbital ridge, this was retained as the point of incidence for the central beam and it then remained to find some target distance that would give the correct image length. As the statistical analysis of the larger material was at this stage still incomplete the target distance used in the radiograph series was determined by the length of the X-ray tube, and by the estimated thickness of the soft tissues in living subjects.

With the aid of the formula it is a simple matter to calculate the target distance required to give a theoretically correct image length.

It now appears that the real tooth sizes of the 20 crania deviated appreciably from the mean value of the larger material, the teeth in the former being longer.

It can be seen from the table that the 'enlargement' when the central beam was incident on the supra-orbital ridge varies some one or two millimetres from one tooth to another, a value that is less than 10 % of the actual length, and thus within the permissible limits set up by previous authors.

If the formula is used to calculate the target distance required

Table III.

A comparison between the actual and image lengths of the various teeth, measured with the horizontal central beam incident on one of the three orbital planes. The root apices were coated with contrast medium; the three exposures were made on the same film (see Fig. 8; plate II).

Tooth No.	Actual length		Infra-orbital ridge			Orbit centre			Supra-orbital ridge		
	M ± E (M)	σ(M)	Mean	D + E (D)	σ(D)	Mean	D ± E (D)	σ(D)	Mean	D ± E (D)	σ(D)
+1+	23.89 ± 0.55	2.48	28.49	— 4.60 ± 0.45	2.02	27.04	— 3.15 ± 0.40	1.79	25.61	— 1.72 ± 0.35	1.56
+2+	22.72 ± 0.44	1.99	26.57	— 3.85 ± 0.43	1.93	25.33	— 2.61 ± 0.36	1.61	24.20	— 1.48 ± 0.32	1.42
+3+	27.65 ± 0.55	2.47	32.71	— 5.06 ± 0.36	1.60	31.00	— 3.35 ± 0.40	1.77	29.41	— 1.76 ± 0.42	1.87
+5+	22.18 ± 0.47	2.06	25.88	— 3.70 ± 0.39	1.72	24.75	— 2.57 ± 0.37	1.61	23.64	— 1.46 ± 0.36	1.58
+6+	19.78 ± 0.38	1.69	22.35	— 2.57 ± 0.45	2.00	21.52	— 1.74 ± 0.41	1.82	20.72	— 0.94 ± 0.40	1.79
+7+	20.30 ± 0.37	1.63	24.09	— 3.79 ± 0.37	1.59	23.31	— 3.01 ± 0.35	1.53	22.47	— 2.17 ± 0.37	1.61

to give correct image lengths, the values for the 20 crania group are, for

- anterior teeth 16—17 cm,
- canines 17 cm,
- premolars (single root) 23—24 cm, and
- molars (single root) 27—28 cm.

If on the other hand the mean of the actual lengths *for the whole material* is taken (Table VII) the corresponding figures for the target distances are: 17—18, 17—18, 23—34 and 27—28 cm.

It should therefore be possible to evolve a refined technique — on a theoretical basis — for example by making a telescopic view finder, that would give the ideal distance for each sort of tooth. In practice, however, the sources of error are large, and some of them inevitable; for example, the varying position of the film packet in routine examinations, the anatomic variability of the tooth length, and the shapes of the roots. For this reason there is perhaps little to be gained by going too thoroughly into the details of target distance. It might be better, perhaps, to choose a fixed mean distance of, say, 22 cm and in routine work to take the deviations that arise and that are perhaps smaller than with other methods.

Table IV shows the angle between the long axis of the tooth in question and the film packet obtained in the method described. The position of the film, which is determined by the anatomical conditions of the jaw, by the operator's knack in placing the film packet and by the patient's ability to hold the film in the proper position, involves many sources of error which could prejudice any result obtained from a satisfactory method of directing the beam. A low palate gives a large angle while a high vault will tend to give parallel film and tooth. It depends in both cases on the level at which the film is placed, and again on how it is secured with the finger: the pressure ought not to be applied so that the film bends in the axial direction, as this will incur distortion of the image which renders measurements invalid. Then, again, the metal wires inserted in the root canals for the purpose of indicating the root direction are effective for only the marginal part. The curves of the root and the distorted relation of it between the image and the actual sizes of the tooth could not be estimated with certainty.

Finally, it may be mentioned that one cannot expect the same angular measurement on living subjects as on skulls where the

Table IV.
The angle between the root and the radiographic film — direct measurement using metal reference points and protractor (e in the formula).

Tooth	Males		Females		Sex unknown			Total	
	No.	$M \pm E (M)$	σ	No.	$M \pm E (M)$	σ	No.	$M \pm E (M)$	σ
+1+	85	38.91 ± 1.00	9.22	13	36.00 ± 2.73	9.84	43	41.33 ± 1.53	10.02
+2+	91	36.62 ± 0.92	8.78	13	30.08 ± 2.85	10.27	46	33.50 ± 1.39	9.42
+3+	103	39.28 ± 0.77	7.82	16	34.44 ± 2.17	8.66	44	38.70 ± 1.30	8.59
+5+ one root	35	29.7 ± 1.5	9.1	5	30.6	—	27	29.2 ± 2.1	10.9
5+ b two	60	29.57 ± 1.05	8.12	13	30.92 ± 2.74	9.87	21	29.81 ± 1.78	8.16
roots p	61	29.87 ± 1.39	10.86	13	32.69 ± 2.33	8.39	21	29.81 ± 2.57	11.77
+6+ db	83	41.22 ± 0.94	8.52	15	46.07 ± 2.85	11.04	44	43.27 ± 1.47	9.47
+6+ p	81	6.22 ± 0.79	7.14	15	8.93 ± 2.20	8.51	42	7.74 ± 1.44	9.36
								29.6 ± 1.2	9.6
								29.81 ± 0.86	8.30
								30.34 ± 1.10	10.71
								42.37 ± 0.78	9.27
								6.98 ± 0.68	8.01

soft tissues are absent. This is illustrated by a comparison with the investigation of 1940 in which jaw casts from living subjects with canines *in situ* were available. In 44 cases the mean was 32.1 ± 86 with a standard deviation of 5.7, while the value for the same tooth in the cranium investigation comprising 163 cases was 38.65 ± 0.64 , with a standard deviation of 8.2. Of course the application of the film on the hard cast is not the same as on living tissue but the smaller angle and the standard deviation in the cranium material might in any case have been expected. It might be possible to establish more realistic conditions if a large number of dentists could be brought to apply the method systematically to living subjects, giving attention to teeth of all types that are to be extracted. The period of activity of a single practitioner is too short, of course, for obtaining a large enough clinical case series that might provide a reliable comparison between the real and image dimensions of the teeth.

Tables V and VI. An examination of the inclination of the roots in the jaw was pursued by making craniofor measurements, using metal reference pins placed in the root canal to give the inclination of the roots in relation to the plane of the skull.

Table V thus shows that inclination of the long axis to the frontal plane. It is of advantage here to find the position of the palatinal root of the second incisor in relation to the two adjacent teeth. The difference in inclination was almost 3° ; this can be compared with the figures in Table IV which gives the root—film angle; for the lateral incisor this is 35.1, for the medial incisor 39.4, and for the canine 38.7 — a reasonably close agreement.

The table might furthermore be of interest in cases where details are required of the positions of the various teeth in relation to one another and to the plane of the skull. In a similar way it might be possible to employ Table VI where the inclinations of the roots are obtained in relation to the sagittal plane. There was, unfortunately, no possibility of performing craniofor measurements of the film position that might serve to check the direct reading of the angle.

As has been mentioned earlier the ordinary anthropological measurements were made on the skull material to provide a measure of their representativeness for this part of the world. The mean length, width and height of 201 skulls were found to be 184.4, 141.1 and 128.4 cm, respectively.

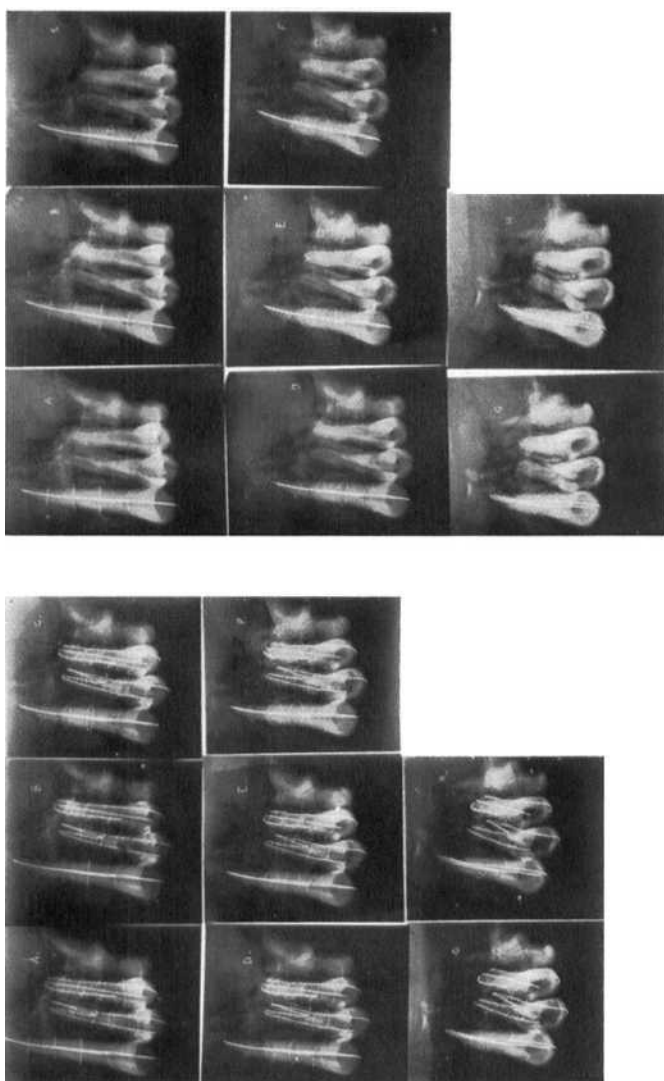


Fig. 2. Radiographs taken with the described projection arrangement. They illustrate two upper premolars with identical images before and after preparation of the teeth. A comparison between the prepared and unprepared teeth perhaps gives an indication of the magnitudes of the positional changes of the anatomical details, even with but a moderate displacement of the beam; the difficulty of establishing such a comparison in clinical radiography when the metallic reference points are not used is immediately apparent.

HERULE: An 'Anatomic' Projection Method for Dental Radiography.

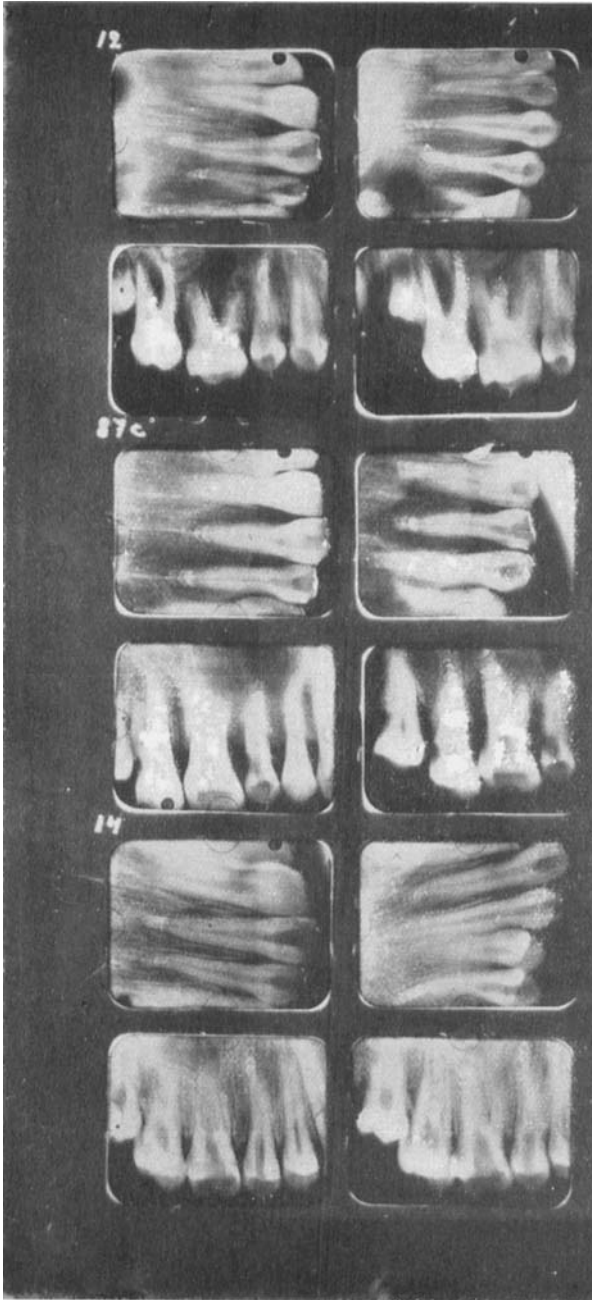


Fig. 8. A specimen radiograph series (crania material). The roots were created with a contrast medium. The exposures for the three orbital planes were made on the same film (see Table III).

PLATE III.

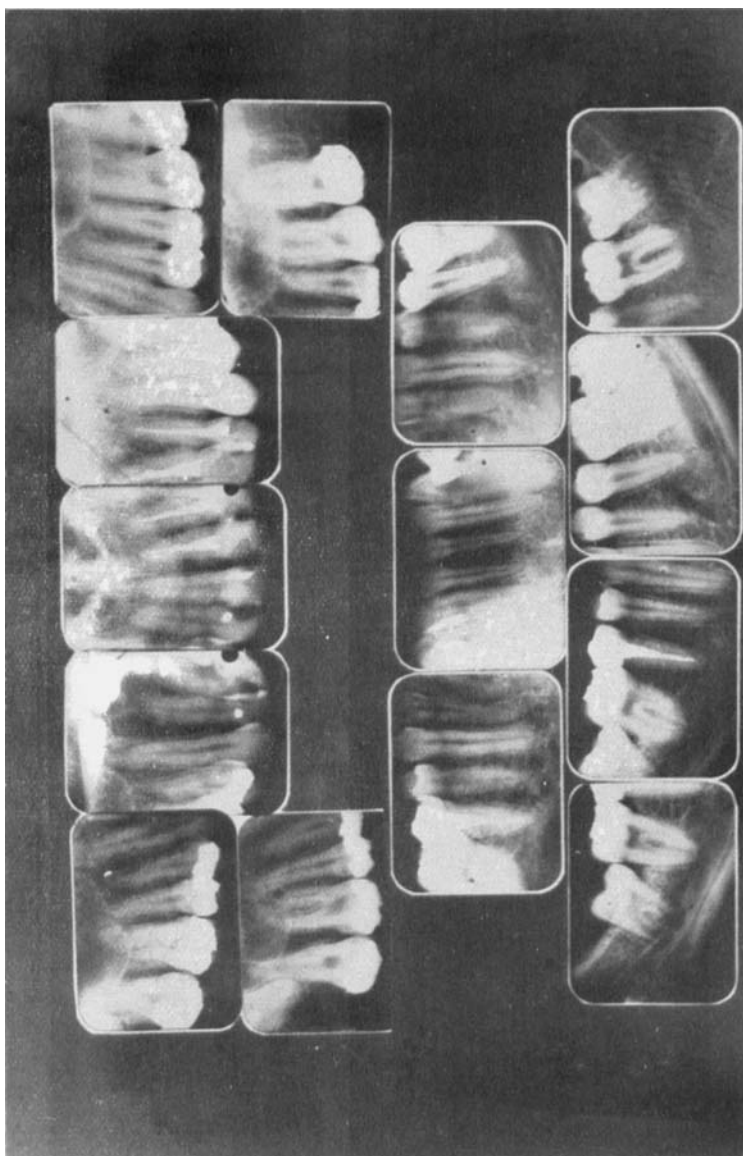


Fig. 9. The first series *in vivo*.

The height and breadth of the face were 115.7 and 130.3 cm in 201 and 195 cases, respectively.

The figures seem to agree well with those Martin gives for the Germanic types.

Measurements were also made of the palatal height and the width of the dental arch. The former was measured from the plane through the molar cusps, the mean of the values obtained being 17.6 mm. This remarkably low figure can be explained by referring to Table VIII which shows the height of the dental crowns of various teeth reckoned from the cemento-enamel junction on the buccal side to the buccal cusp or edge. The averages of all these values show that a large part of the material is characterized by very heavy abrasion.

The widths of the dental arches were measured with Lundström's instrument by two methods: between the central fossae of the molars and between the palatal contours of the same teeth. The means of 177 crania were respectively 55.6 and 42.8 mm.

Summary.

1. The technical difficulties inherent in the various methods for directing the ray bundle in dental radiography are pointed out.

The free-hand method was examined on a previous occasion when attention was devoted to the influence of the free method on the structure of the image when the method was mechanically reproduced, and to the distortion of the image and the facility with which various operators mastered the technique.

The anatomic methods offer the unquestionable advantage that the direction of the ray has more regard to the individual anatomic conditions than a third setting method that is based wholly on mechanical measurements. Other workers have published anatomic methods for dental radiography but their application by the present writer has proved them frequently deficient, in that the detailed and often vague instructions for the direction of the central beam are by no means easy for beginners to follow.

The author proceeds from the supposition that it might be possible to devise an anatomic method on the basis of simplified

orientations. This suggestion was bound up with theoretical considerations.

2. The X-ray bundle diverges from a point focus. If the object is projected on a film surface parallel to the planes of the object, a simple relation is obtained between the measurements of the object and the image. If on the other hand the object and the film are mutually inclined the relationship will become very complicated.

A special case in the latter group is the bisector or isometric X-ray projection which at a very early stage was set up as the ideal standard for tooth projection. A correct application of this rule gives an image with accurate linear dimensions, and nearly all published methods have this as their aim, by either direct or indirect means. During the last decade other, and in some respects more important, demands have been made on the properties of the tooth image that cannot be realized by the bisector rule. Yet it can hardly be disputed that for the great majority of routine investigations the bisector rule can still be accepted as the basic standard.

The bisector setting is obtained in the freehand method by direct sighting of the central ray on the apex and perpendicular to the bisector. In the mechanized and anatomic methods the same object is realized indirectly — provided skill and luck permit.

It is obvious that in practical work the image cannot be obtained unless the focus is on the theoretical central ray that passes through the apex and is perpendicular to the bisector of the angle between the tooth and the plate. The target distance is of no consequence to the dimensions of the image as a whole. (It has been shown in a previous paper, however, that this does influence the inner dimensional characteristics of the image.) If one amuses oneself by sketching the various projection conditions obtained by moving the focus along a theoretical central ray, it is easy to see that the different positions of the focus can be defined by two co-ordinates for the horizontal and vertical positions. On which point in the facial profile the horizontal is incident is dependent, of course, on the length of the vertical co-ordinate.

As an example, consider the level of the supra-orbital ridge, this being a well-defined an anatomic point: at what distance should the focus be from the head in order that it should lie on the theoretical ray path that gives the bisector image? It is clear that since the ray bundle is emitted radially from the focus, the

Table VII.
Actual lengths of the various teeth measured from the cusp or crown edge to the apex (l in the formula).

Tooth	Males			Females			Sex unknown			Total		
	No.	$M \pm E (M)$	σ	No.	$M \pm E (M)$	σ	No.	$M \pm E (M)$	σ	No.	$M \pm E (M)$	σ
	+1+	84	21.72 ± 0.28	2.59	13	21.18 ± 0.62	2.25	43	21.39 ± 0.43	2.85	140	21.57 ± 0.22
+2+	88	20.61 ± 0.27	2.51	14	19.96 ± 0.50	1.86	45	20.71 ± 0.39	2.61	147	20.60 ± 0.20	2.48
+3+	100	25.74 ± 0.23	2.33	16	24.29 ± 0.73	2.91	45	25.43 ± 0.45	3.04	161	25.51 ± 0.21	2.62
+5+ b	33	20.45 ± 0.39	2.26	5	19.92	—	27	20.42 ± 0.40	2.08	65	20.40 ± 0.26	2.11
two roots	60	21.58 ± 0.27	2.09	13	20.14 ± 0.64	2.31	20	21.31 ± 0.50	2.23	93	21.32 ± 0.23	2.18
+6 db	84	19.10 ± 0.21	1.97	15	18.15 ± 0.42	1.62	44	18.99 ± 0.26	1.71	143	18.97 ± 0.16	1.87
+7 mb	89	20.07 ± 0.23	2.15	15	19.75 ± 0.52	2.02	46	19.59 ± 0.29	1.98	150	19.89 ± 0.17	2.08

central ray mechanically marked on the apparatus can very well be directed on the upper border of the orbit at the same time as another ray in the cone projects the tooth according to the bisector theory provided, of course, the focus is displaced so far from the head that it is on the theoretical ray path.

3. From the schematic diagram it is clear that it is quite possible to reckon how far the focus shall be from the longitudinal axis of the tooth in order to give a bisector image. For this calculation certain factors must be known: the actual length of the tooth (l), the distance from the cusp to the upper edge of the orbit (a), and the angle between the tooth and the plane of the film (v). The required horizontal distance, x , is given by the expression

$$x = \frac{a - l}{\tan \frac{v}{2}}$$

4. A practical method evolved from the theory must furthermore, be based on reliable average values of the actual lengths and angles involved. The author has tried to obtain a statistical grounding for the estimate of mean values of these quantities by performing measurements on about 200 crania.

5. Preliminary surveys were performed which might indicate whether such a method might be of general use and have advantages over other methods in respect of the teaching of dental radiography and the accessibility of the radiographs.

An experimental series was carried out with canines of human subjects, which teeth were due for extraction. Plastic impressions of the jaw were taken previous to the extractions. Quite untrained students were then required to take radiographs of the teeth using the method in question. The teeth were then extracted and set in the plastic impressions after which a positive cast of the jaw was prepared in the usual manner. The possibility was thus provided of measuring the actual length and the angle between the plane of the film when a metal reference pin was placed in the root canal. These operations could be executed with about 44 persons. The teeth were X-rayed in systematic series by 141 students and comparisons drawn between the actual measurements; the distances determined from the radiographs might be

Table VIII.
The actual height of the crown measured from the cusp or the edge to the cementoamel junction (crania material).

Tooth	Males			Females			Sex unknown			Total		
	No.	$M \pm E (M)$	σ	No.	$M \pm E (M)$	σ	No.	$M \pm E (M)$	σ	No.	$M \pm E (M)$	σ
	+1+	78	8.41 ± 0.25	2.21	13	9.13 ± 0.40	1.45	41	8.50 ± 0.37	2.35	132	8.51 ± 0.19
+2+	83	7.68 ± 0.20	1.86	14	8.49 ± 0.40	1.49	44	7.99 ± 0.33	2.19	141	7.86 ± 0.16	1.94
+3+	96	8.56 ± 0.17	1.64	16	8.53 ± 0.49	1.94	45	8.73 ± 0.29	1.96	157	8.60 ± 0.14	1.76
5+ { one root two roots	28	6.05 ± 0.26	1.35	5	6.50	—	26	6.18 ± 0.25	1.25	59	6.14 ± 0.16	1.23
+6+	56	6.48 ± 0.15	1.09	13	6.40 ± 0.39	1.40	19	6.69 ± 0.33	1.46	88	6.51 ± 0.13	1.21
+7+	78	5.92 ± 0.11	0.98	15	5.78 ± 0.28	1.08	43	5.98 ± 0.16	1.05	136	5.921 ± 0.086	1.006
	86	6.52 ± 0.10	0.96	15	6.48 ± 0.25	0.95	43	6.45 ± 0.20	1.31	144	6.492 ± 0.089	1.067

considered to have proved unexpectedly favourable since the deviation in the mean was little more than 1 mm or 4 % of the actual distances.

The mean of the tooth—film angles was $32.09^\circ \pm 0.86$ with a standard deviation of 5.71° .

The distance from the incisal edge of the canine to the supra-orbital ridge was measured on 190 men and 375 women. In the first case the mean was 8.69 cm and in the latter 8.15 cm, with a significant difference. The results of these preliminary surveys were encouraging.

6. The normal anthropological skull measurements of the specimens are in conformity with those characteristic of the Germanic race (Martin).

Some of the individual measurements were taken with a cubic cranifor and the projection by the hair cross tube against the base plate, while others were taken with the assistance of a special cranifor constructed by the author.

The material was divided into three groups — females, males and sex undetermined. When the classification was uncertain on account of incomplete journal data the weight was put on the collected material.

7. The method has been tested experimentally using crania where the horizontal target distance with respect to the structure of the apparatus and the thickness of the soft parts was found to be about 25 cm. For each examined tooth three radiographs were taken on one film, with the horizontal beam incident on each of the three orbital lines. The root apices were covered with a contrast medium to mark their positions more clearly in the radiographs. It was then possible to compare the actual tooth dimensions with those of the image referring to higher or lower points of incidence in the orbit region, and this without incurring errors due to changing the film. As expected, it proved in this series that the length of the image was shorter the higher the level of the incidence point but at the highest — in the supra-orbital ridge — the images were still longer by some millimetres than the actual dimensions.

The analysis of the 200 skulls completed, a calculation of the theoretical target distance from the formula that would give the actual tooth length from the image shows that the target distance

should have been increased or decreased some centimetres, depending on which teeth were being projected.

8. If the mean value of the angles and the distances in the cranium obtained in the investigation of the larger material are inserted in the formula, a more reliable basis for the conditions in respect of the target distance in clinical work should be obtained. The author would caution, however, against the conclusion that a method of this type, that is essentially theoretical yet based on average material, should be capable of yielding consistently very accurate results in the individual case.

On the other hand the method would seem to have two important advantages: namely, that the operator need not be trained in order to be able to apply it correctly, and that it is considerably more accurate than other methods would appear to be.

9. From the theoretical presentation it is seen that the central beam is used as a means of procuring the horizontal direction. If the exposure is made with the direction cone in this position the rays might miss the tooth on account of the small aperture of the diaphragm. The method thus requires that the apparatus shall be of such a type that the focus lies on the axis of rotation of the tube. In this case the theoretical projection conditions are not affected by the rotation.

The very large and valuable collection of skulls belonging to the Institute of Anatomy of the University of Uppsala, were placed at my disposal through the extreme kindness of Professor HOLMDAHL, the present Head of the Institute, who was also generous enough to make available suitable working premises for the investigation.

Professor INGELMARK, prosector at the same Institute, has been of great assistance on anatomic and associated problems.

Dr. MÄRT RAUD and Dr. BERTIL FORS have helped with the measurement work.

Professor GUNNAR DAHLBERG, of the Institute of Race Biology, Uppsala, kindly assisted with the planning of the work from the point of view of the statistical analysis, at the same time placing personnel at my disposal for the statistical working up of the material.

My assistant instructors have been ready and willing at all times to assist in many connections.

A word of thanks is due to Professor LUNDSTRÖM for his kindness in placing at my disposal his instrument for measurement of the palatal height and width of the dental arch.

The craniofor designed by myself was constructed by ÅKE TYLLSTRÖM, a mechanic at the Royal Institute of Technology, Stockholm.

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