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GEOMETRICAL ERRORS IN LATERAL SKULL X-RAY PROJECTIONS

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Lateral skull x-ray projections can be used to diagnose large deformations of the skeleton of the head. In orthodontia however more detailed studies are made of the skeletal dimensions. These studies are made by drawing lines on the x-ray image from one anatomical landmark to the other and collect exact measurements of the distances and angles formed by this construction in the facial bone pattern.

From a theoretical viewpoint it would be most convenient to use a true lateral orthogonal projection. This means a projection in which all projecting rays are parallel and at right angles to the median plane and film. If the skull, which is a three dimensional object, is projected with parallel rays we can read two of the three coordinates of each landmark from the roentgenogram.

Due to practical limitations all the requirements for a true lateral projection cannot be met.

It is stated that the rays should be directed perpendicular to the median plane. Since different investigators use different planes, it will be necessary to define the median plane. If it is constructed using landmarks on the soft tissue the difficulty is encountered that not all investigators will locate these points at the same place, and that the location may also vary when the experiment is repeated by the same investigator. In addition to this lack of reproducibility there is the drawback that immobilisation of the patients head is difficult to obtain.

We therefore should be aware of the possibility that the patient moves out of the desired position immediately before or at the moment the exposure is made.

A good fixation is obtained however when a fixation pin in the left and right external auditory meatus is used. The simplest method makes use of a median plane perpendicular to the line connecting the two ear fixation pins and at equal distances from these pins. This median plane may not be the plane which all orthodontists will accept, but it has the advantage that it gives a better reproducibility.

For diagnostic purposes the reproducibility may be of less importance

and we may be inclined to use in this case a plane that better fits our ideas of where the median plane should be constructed.

However if the reproducibility is of less importance it will be of no significance whether the pictures are obtained by using one or the other median plane. The choice of the median plane being free we prefer for diagnostic purposes also the ear fixation pins, because they permit a good fixation of the patients head.

If we choose this method of fixation and the median plane belonging to it, the distance of the focal spot to the median plane should be considered.

With the focal spot at an infinite distance the rays will be parallel. In our practical work however there is always a divergence of the rays, the degree of divergence depending on the distance of the focal spot to the median plane. These divergent rays will enlarge the dimensions and produce an enlarged picture.

The amount of magnification depends of the distance focal spot – median plane and the distance median plane – film.

The focal spot distances used in practical work, vary between 1.5 and 6 meters. One of the purposes of this work was to investigate the influence of different focal spot distances. Besides this magnification there are a number of other factors producing geometrical errors, which also should be considered. Under geometrical error is ment the error produced purely in projecting the skull. Apart from the geometrical factors there are a number of non-geometrical factors of importance as for instance: the unsharpness produced by the intensifying screen or the errors made in measuring distances.

The final error in our work is build up from the total geometrical and the total non-geometrical errors.

In our case where only the effects of the geometrical factors are studied the question has to be put how large this error may be. In general it can be said that if one of the many types of errors is very large in comparison to the others, this large one determines mainly the final error that is produced. It is obvious that if we only reduce the smallest error the result will only be slightly influenced. If we want to reduce the final error our first effort should therefore be directed against this largest error.

From the foregoing we can conclude that if we want to keep the final error small, the geometrical error should not exceed the non-geometrical errors.

We will now review briefly the main non-geometrical factors. There is first the unsharpness due to the intensifying screens in the cassette. The error produced by reading the unsharp image depends on the amount of

unsharpness the screen produces. Faster screens produce more unsharpness than slow screens. The unsharpness can vary between 0.08 and 0.4 mm.[1]

Another form of unsharpness is caused by the size of the focal spot. If the focal spot is large the image will have a large unsharpness. This unsharpness is also influenced by the distances from the focal spot to the patient and from the patient to the film. Table 1 shows the relation between the focal spot distance and the unsharpness for a given set of conditions.

TABLE 1

Unsharpness produced by the focal spot

Focal spot	2 mm.
Median plane – film	11 cm.
Object – film	16 cm.

Focal spot – Median plane in meters	Unsharpness in mm.
6	0.05
4	0.08
2	0.16

An other form of error is produced when the tracing is made from the roentgenogram and when the distances are measured.

This type of error has a value between 0.2 and 0.5 mm.[3]

Table 2 shows the figures so far mentioned and we can conclude that these unsharpnesses and errors are in the range of 0.1-0.5 mm.

TABLE 2

Unsharpness from intensifying screen	0.08-0.4 mm.
Unsharpness from focal spot	0.05-0.2 mm.
Error made with tracing and measuring	0.2 -0.5 mm.

The geometrical error should therefore not exceed 0.5 mm and if possible be even smaller.

In the following discussion we will use as a limit for the geometrical

error 0.5 mm. It should be emphasized however that this is an arbitrary choice.

In our discussion of geometrical errors we will first limit our field to landmarks located in the median plane.

We want to study the error produced when a landmark is located at a distance of 100 mm from the central axis through the ear fixation pins. The distance is indicated by „x" and the projection of this distance on the film is indicated by y_0. Fig. 1.

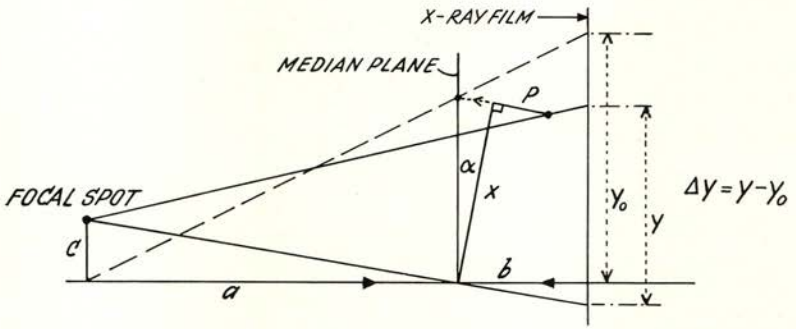

Fig. 1. Schematic drawing illustrating the geometric factors producing errors as explained in the text.

When these points are projected on the films there are 3 errors which can be made.

First the x-ray tube may be off the central axis through the ear fixation pins.

This error is indicated with „c" in fig. 1.

An other error is produced when the patients head is rotated over a small angle α.

Thirdly the landmark may be located at a distance „p" from the median plane. An example of this error is found in patients with a chin deviation.

In fig. 1 the distance which should be found is indicated by y_0 and the distance found by y. The difference between these two is the error $\triangle$ y.*) To simplify the problem we will first neglect factor „c". (The incorrect position of the x-ray tube). The influence of α and „p" remain.

*) $\triangle$ y was calculated using the following equation:

$$\triangle y = \frac{a + b}{a}\left(\frac{c\,T + a\,V}{a + T} - x\right)$$

where $T = x \sin \alpha + p \cos \alpha$
and $V = x \cos \alpha - p \sin \alpha$.

In fig. 2 is shown the relation between α, p, and △ y for four focal spot distances whereas „x" is supposed to be 100 mm and „b" 70 mm (the distance from the median plane to the film).
On the horizontal axis we can read α, the angle of rotation of the head of the patient. On the vertical axis the error △ y is plotted. Each curve represents

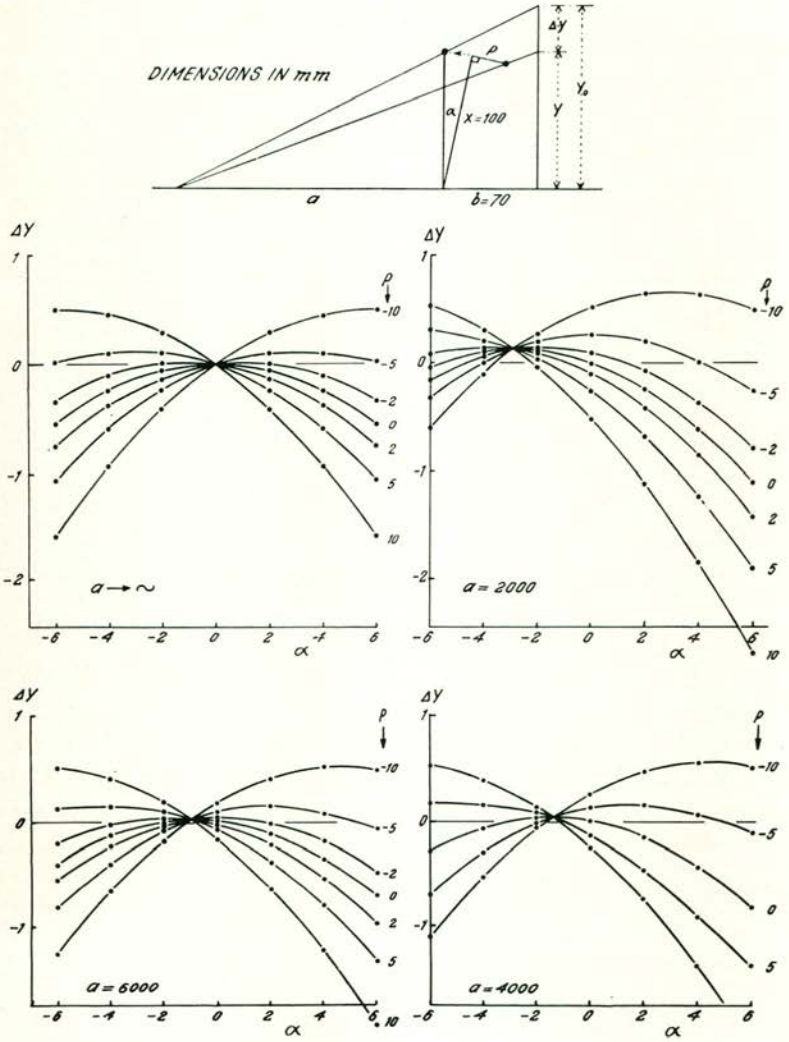

Fig. 2. Relation between α, p and △ y for four focal spot distances. X-ray tube on the central axis.

the relation between α and $\triangle$ y for a certain value of „p". We can read from the curves for a focal spot distance of 2 meters that for a chin point deviation of 5 mm and no angle of rotation the error is 0.25 mm. An error of 0.5 mm is produced with a rotation of 1.3°.

For a larger focal spot distance for instance 4 m the angle of rotation for an error of 0.5 mm is 2.1°.

If the chin deviation is larger, for example 10 mm, the focal spot at 2 m and if there is no rotation of the head, an error of more than 0.5 mm is produced.

Are the roentgenograms taken from 4 meters we can expect an error of 0.25 mm without rotation. An error of 0.5 mm is produced when the angle of rotation is 1.1°.

At 6 meters distance the tolerances for the angle of rotation become larger.

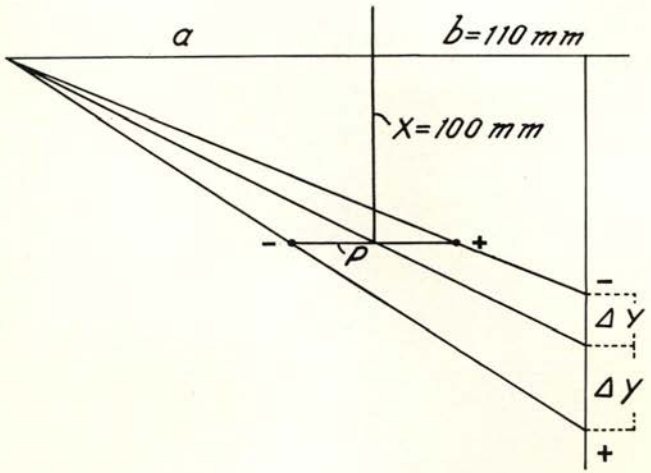

Fig. 3. Errors ($\triangle$ y) produced by chin point deviations (p).

Distance a in m.	$\triangle$ y in mm.			
	p = +10	p = —10	p = +5	p = —5
~	0.00	0.00	0.00	0.00
6 m.	—0.17	0.17	—0.08	0.08
5 m.	—0.20	0.20	—0.10	0.10
4 m.	—0.26	0.26	—0.13	0.13
3 m.	—0.34	0.35	—0.17	0.17
2 m.	—0.52	0.53	—0.26	0.26
1 m.	—1.10	1.12	—0.55	0.56

Fig 3. shows a summary of the effect of the focal spot distance on the error produced with 5 or 10 mm chin point deviation, when α is zero, that means no rotation of the head.

The same curves, but with „c "incorporated as an error are shown in fig. 4. „c" is assumed to be + or — 20 mm. By comparing the curves obtained with c = 0 and c = 20 (fig. 2 and fig 4.) we see that there is only a slight difference.

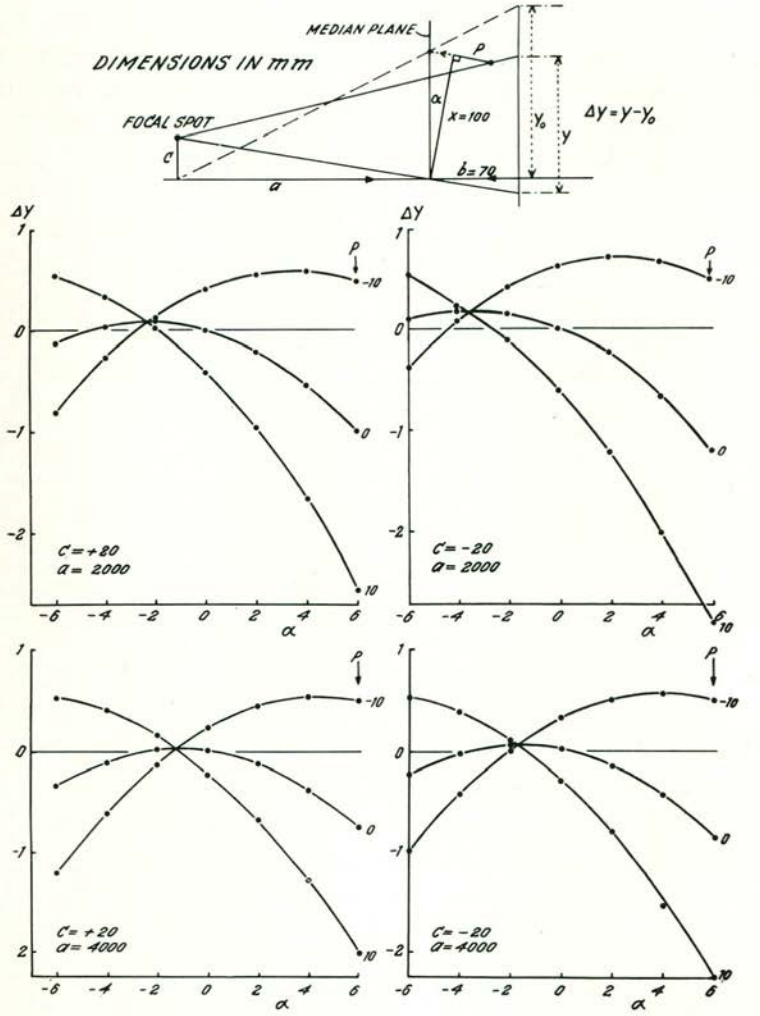

Fig. 4. Relation between α, p and $\triangle$ y for four focal spot distances. X-ray tube off the central axis.

From these graphs we can conclude that the angle α should be kept as small as possible. This calls for a good fixation of the patients head. The distance „a" should be large, how large can be read from the graphs.

The distance „b" affects only the magnification. If „b" is increased the magnification is also increased. The amount of enlargement affects the distance $\triangle$ y. The errors are therefore larger with larger values for „b".

The variations in the magnification are however only a few percent, and an increase of the errors with a few percent can be neglected. The distances actually measured on the roentgenogram are much larger than the errors produced by α and „p". The effect of the length „b" on the distances measured can therefore not be neglected.

Fig. 5 shows the enlargement for „b" is 8 and 10.5 cm in combination with 4 focal spot distances. The figure represents a technique in which one ear fixation pin is kept at a fixed distance from the film.

When a distance of 100 mm in the median plane is projected in position A or in position B we will find a difference in length on the film as

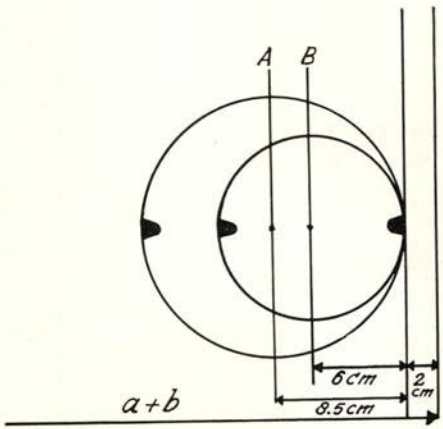

Fig. 5. Errors produced when one ear fixation pin is kept at a fixed distance (2 cm) from the film.

a + b in m.	Enlargement		Difference in mm. on a distance of 100 mm.
	B	A	
~	1.000	1.000	0
6	1.014	1.018	0.4
4	1.020	1.027	0.7
2	1.042	1.055	1.3

indicated in the last column of fig. 5. This error can be reduced when the median plane is kept at the same distance from the film.

We will now study the errors produced when landmarks not lying in the median plane are projected.

We will first assume that the skull of the patient is symmetrical and not rotated. Since there is a landmark on the right and on the left side we will find a pair of landmarks.

As an example we will use the projections of the angles of the mandible. In a true lateral projection there would be a superimposition of both angles of the mandible, and they are projected as if they were located in the median plane half way the line connecting the two angles of the mandible.

With the x-ray tube not at an infinite distance we will find two images,

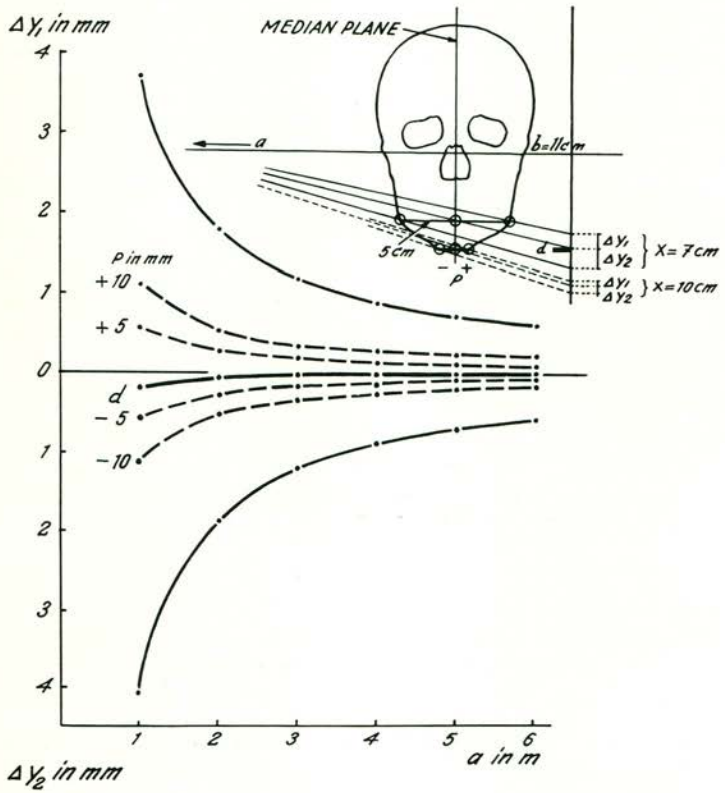

Fig. 6. Errors produced when projecting the angles of the mandible of a non rotated symmetrical skull.

one from the left side and one from the right side of the patients (fig. 6). The distance of the projections of the two angles from the projection of the point half way the two angles is indicated by $\triangle y_1$, and $\triangle y_2$. These distances are the errors produced due to the distance „a" not being infinite. In the curve these two distances are plotted as a function of „a". „a" is on the horizontal axis $\triangle y_1$ and $\triangle y_2$ on the vertical axis. The upper and the lower curves show this relation.

The errors are very large and exceed 1 mm unless we use a distance of more than 4 meters. If we draw on the roentgenogram a line from the left side projection to the right side projection and use the mid-point of this line, the error is extremely reduced and at a focal spot distance of 1 meter not even exceeds a few tenth of a millimeter.

In the fig. 6 this error is indicated with the letter „d" and can also be found in the graph.

To permit comparisons the errors produced with chin deviations of 5 and 10 mm are also incorporated.

We can conclude that in symmetrical skulls the errors are small when the left and right side projections are averaged.

Our next problem deals with non rotated asymmetrical skulls. If there is an asymmetry we have to study the error produced by each half of the head.

To symplify the problem and to obtain curves which can be used universally the distance „b" will be neglected in our first approach. In addition to this we use a value of 1 for „x". The only factors which remain are „a" (the focal spot distance) and „p", (the distance of the landmark from the median plane). These two factors produce an error $\triangle y'$ in the median plane. Fig. 7. This error $\triangle y'$ is plotted in the graph. We have on the horizontal axis the values for „p" and on the vertical axis the error $\triangle y'$ as well as y'.

The error $\triangle y'$ is proportional to „x". If we multiply the vertical axis with „x" we can read the errors produced when „x" is not equal 1.

An example will be given how to read from the graphs how large an error is produced in projecting one angle of the mandible. For this landmark we assume that „p" will be 5 cm and „x" 70 mm. Since $x = 70$ mm the vertical scale has to be multiplied with 70 to show errors in mm in the median plane.

For a focal spot distance of 2 m we read an error of 0.025×70 mm $=$ 1.8 mm. With a focal spot distance of 6 meter this error can be reduced to 0.010×70 mm $= 0.7$ mm.

It was calculated that an error of 0.5 mm is produced when the focal spot distance is 7.20 m.

The above figures represent the error in the median plane. The errors actually occuring on the film are found when the values are multiplied with the enlargement factor $\frac{a+b}{a}$ as shown in the lower left corner of the figure.

This increase of the error can in most cases be neglected for the same reason as already explained when the errors of landmarks in the median plane were discussed.

Our last problem deals with the errors produced by projecting landmarks not lying in the median plane in a rotated skull. This problem is identical to the projection of landmarks in the median plane having a small deviation from this plane. See fig. 1 (chin point deviations).

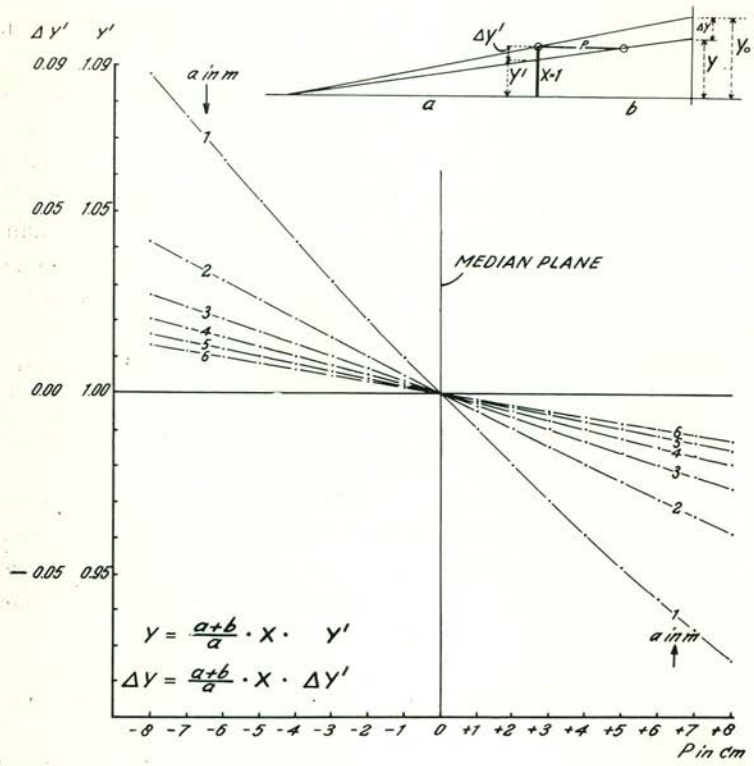

Fig. 7. Relation between △ y' and „a" in asymmetrical non rotated skulls (see text).

Only different values have to be substituted for „x" and „p". In table 3 the values for $\triangle$ y are given for the angles of the mandible x = 7 cm and p = $\pm$ 5 cm.

TABLE 3

Errors (in mm.) in projecting the angles of the mandible in a rotated skull. (x = 7 cm. b = 11 cm. see fig. 1).

a in m.	p in cm.	α						
		—6°	—4°	—2°	0	2°	4°	6°
~	+5	4.8	3.3	1.7	0	—1.8	—3.7	—5.6
	—5	—5.6	—3.7	—1.8	0	1.7	3.3	4.8
6	+5	4.4	2.8	1.2	—0.6	—2.4	—4.3	—6.3
	—5	—5.1	—3.1	—1.2	0.6	2.3	4.0	5.5
4	+5	4.2	2.6	0.9	—0.9	—2.7	—4.7	—6.7
	—5	—4.8	—2.8	—0.9	0.9	2.6	4.3	5.8
2	+5	3.5	1.8	0.0	—1.8	—3.7	—5.7	—7.8
	—5	—3.9	—1.9	0.1	1.9	3.6	5.3	6.8

One can see that the errors are extremely large unless „a" is more than 6 meters and „α" is very small. Even if the rays are parallel (a = ~) α should not exceed 0.5°.

If the skull is symmetrical and the left and right side projections are averaged the errors are small as is shown in table 4.

TABLE 4

Errors (in mm.) in locating the angle of the mandible in a symmetrical rotated skull when left and right side projection are averaged. (x = 7 cm, b = 11 cm and p = $\pm$ 5 cm. See fig. 1.)

a in m.	α						
	—6°	—4°	—2°	0°	2°	4°	6°
~	—0.4	—0.2	—0.0	0	—0.0	—0.2	—0.4
6	—0.3	—0.1	—0.0	+0.0	—0.1	—0.2	—0.4
4	—0.3	—0.1	—0.0	+0.0	—0.1	—0.2	—0.4
2	—0.2	—0.1	+0.0	+0.0	—0.0	—0.2	—0.5

Discussion:

From the foregoing it will be clear that the choice for the focal spot distance, and the apparatus to be used for the fixation of the patients head depends on the size of the error that is acceptable.

The errors occuring under specific conditions can be read from the presented graphs.

For landmarks located in the median plane and landmarks in symmetrical skulls it can be said that the geometrical errors can be kept within reasonable limits in comparison to the other sources of errors if: 1th the left and right side projection are averaged, 2nd the angle of rotation of the head is kept very small, 3rd the focal spot distance is at least several meters.

For asymmetrical skulls the errors of landmarks not lying in the median plane are much larger and can only be kept within reasonable limits if the focal spot distance is at least 6 meters and if α is kept extremely small.

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