Cephalometric Methods in Research and Private Practice[1]

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It is now about twenty years since Dr. B. Holly Broadbent first introduced cephalometric radiographs to the orthodontic profession. During these twenty years cephalometrics has grown from an isolated laboratory experiment to a valuable clinical and research tool in daily use by many practicing orthodontists.

This expansion from research into private practice has raised many problems for those working with cephalometrics.

These problems cover the entire cephalometric technic from the installation of equipment to the tracing and interpretation of films, but they all revolve around the few basic factors which set cephalometrics apart from other radiographic technics. The objective here will be to evaluate critically these basic factors so that some of our problems may be more readily understood.

WHAT IS CEPHALOMETRICS?

Cephalometrics, freely translated, means "head measuring", and this is exactly what it is. We can see the same things on films taken by conventional technics, but only a cephalometric film can be used for accurately measuring them.

With a cephalometric film we can make absolute measurements, both linear and angular. We can take these measurements from one film and with confidence compare them to those from another. Or we can take a tracing of one film and with confidence superimpose it on the tracing of another.

These measurements and comparisons are possible because a cephalometric film is made with the patient, film, and x-ray tube all in known positions. Some of these positions are not only known but standardized. This control which cephalometrics gives us over these three important factors is the important difference from conventional technics. Actually we can boil the distinguishing features of cephalometrics down to just two points;

1. It places the patient in a definite, reproduceable pose.
2. It controls the enlargement and distortion which are present in *every* radiograph by making them accurately measurable.

WHAT ARE OUR PROBLEMS?

Positioning the patient with sufficient accuracy is a difficult problem only when we use parts of the machine itself as reference points for measuring. This problem is most acute in the accurate location of porion. Although this has become an important point in cephalometric work, it will not be taken up here.

Enlargement and *distortion* are our two greatest overall problems, hanging over our heads like a rather hazy but real sword of Damocles. We know that they are there, but are not sure when they might descend on us and cause trouble.

These two factors, enlargement and distortion, are the major considerations in cephalometric work; the big reasons for all the careful technics of measurement and standardization.

Before actually tackling enlargement

[1]Read before the Edward H. Angle Society of Orthodontia, French Lick, Indiana, November 1, 1949.

and distortion themselves, there is another problem common to all radiographs which we should evaluate first. This is blurring of the image, which places a definite limitation on the accuracy with which we can locate and measure a point on the film.

If we become familiar with the limitation imposed by blurring first, we can save ourselves the trouble of worrying about errors too small to measure later.

Blurring of The Image

Blurring can be caused by:

1. Motion of subject or machine.
2. Optical blurring, which is dependent on the size of the x-ray anode focal spot.
3. Grain, caused by intensifying screens and film. (intensifying screens are the only important source of grain in our work).

Motion:

A snapshot is ordinarily made with an exposure time of 1/25 second or faster. In cephalometric work we measure our exposure time in seconds. This gives ample time for movement to blur the film.

It is usually possible to install the equipment so that *it* will cause no movement. But the patient! Of course we have him almost hanging by his ears, so he can't go far; but the earposts are in a mobile, cartilagenous canal. The nasion rest, and any other supports which we might add, also rest on freely movable tissue. As a result there is always enough freedom of movement to blur a film.

Even if our patient doesn't move his entire head, he can still breathe, talk, swallow, cry, moisten his lips, or otherwise move the mandibular structures.

This blurring due to motion can vary from nothing to enough to make a film worthless. Because of this variability, actual dimensional values will not be assigned to blurring due to motion, but it should be kept in mind and minimized by such measures as the following;

1. Make the patient comfortable. Be sure that his is sitting square and erect, not bent down or stretched up too far.
2. Adjust earposts carefully. Too loose gives inadequate support and poor position; too tight may make him squirm all through the exposure.
3. Have him arrest his breathing during the exposure.
4. Reduce exposure time with intensifying screens and the highest milliamperage available. Doubling milliamps cuts time and movement in half.

Optical Blurring:

This effect is quite constant for a particular installation and can be accurately determined.

Shadows produce the x-ray picture. Since the source of the rays which cast the shadow is a rectangular area and not a point, the shadow is fuzzy around the edges. Fig. 1 diagrams this familiar effect, showing the shadow cast by a flashlight for purposes of illustration.

The width of the fuzzy part of the shadow (the penumbra) is *directly proportional* to the size of the anode target in the x-ray tube *and* to the distance of the subject from the film. Blurring is increased whenever these are increased. The width is *inversely proportional* to the distance of the x-ray target from the subject.

To reduce optical blurring then, all that we have to do is to get the patient as close as possible to the film, as far as possible from the x-ray, and to use the smallest possible target.

In the cephalometric technic the patient is near enough to the film to keep the effect of this distance at a practical minimum. He is fixed at a

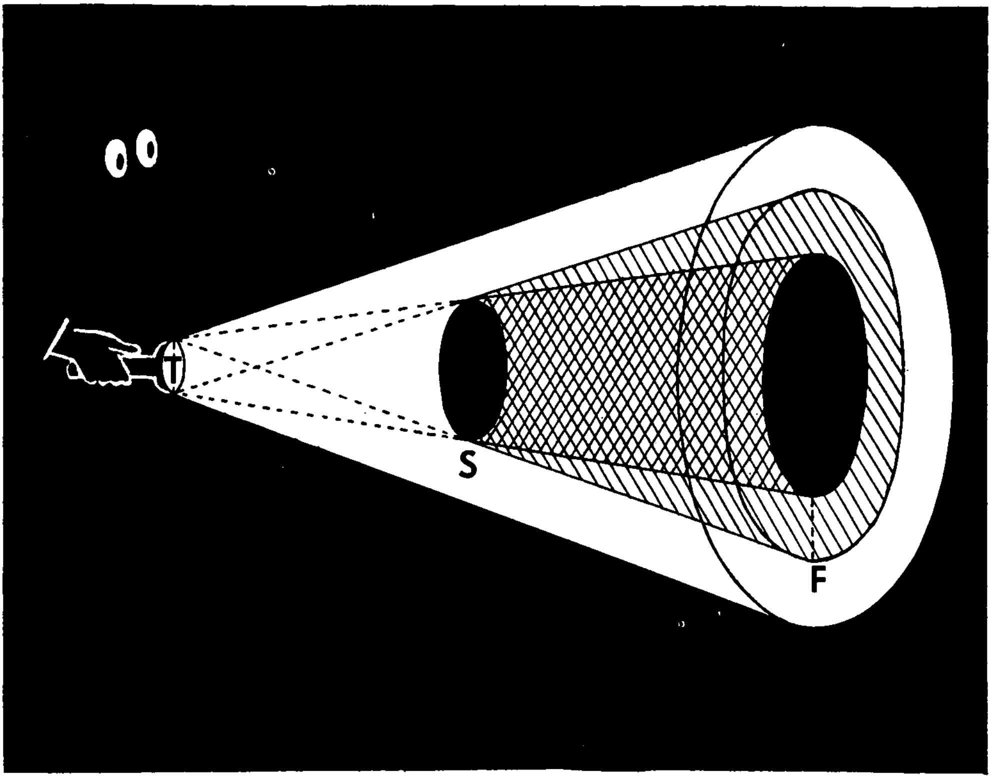

Fig. 1. The shadow cast by a flashlight beam, illustrating the effect of target size on sharpness. T represents the x-ray target (source of the rays), S the subject, and F the film. The shaded ring around the shadow on the film is the blurred penumbra area.

distance of five feet from the x-ray target, which is a good compromise of all the factors dependent on this distance. This leaves target size as the only one of the three which we might do much about.

Target size is a fixed characteristic of each x-ray tube, and may vary from one to several millimeters square. Since optical blurring is directly proportional to this dimension, it is obvious that it can be very important.

For a target with an effective size only 1.5 mm. square, the width of the penumbra will be as much as 0.14 mm.[1] This means that there is a blurred area this wide along the edge of every image on the film. While this width is small,

[1]This is determined from the triangles in Fig. 1 by the formula $\frac{T}{TS} = \frac{F}{SF}$

Where: T=Effective target width (the diagonal of longest dimension of a 1.5 mm. square target is 2.12 mm.).
TS=Target-subject distance (five feet or 152.4 cm.).
F=Penumbra width on film.
SF=Subject-film distance (assumed to be 10 cm.).

Substituting in the formula, we have:

$$\frac{0.212 \text{ cm.}}{152.4 \text{ cm.}} = \frac{F}{10 \text{ cm.}}$$

Solving for F,

$$F = 0.014 \text{ cm.} = 0.14 \text{ mm.}$$

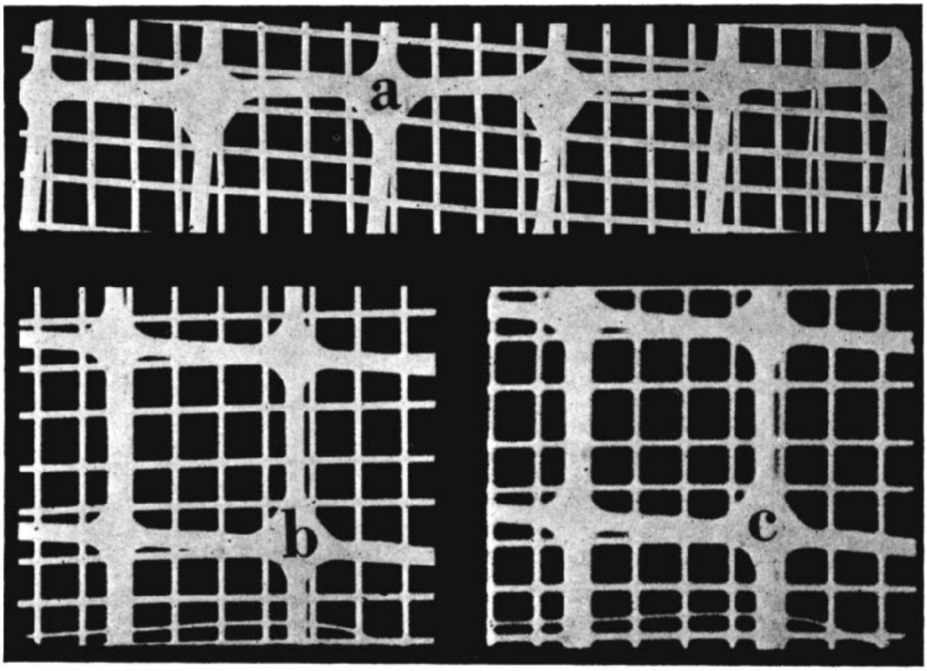

Fig. 2. The effect of X-ray target size. The subject is wire mesh; large squares are 1/4'' mesh, small squares 1/16 '' mesh. Target 1.5 mm. Target-subject distance 5 feet.
A. Subject against cassette (effect of target size practically eliminated).
B. Subject 10 cm. from film (approximate position of cephalometric film).
C. Subject 20 cm. from film (same effect as 3.0 mm. target with subject 10 cm. from film).

remember that it is only the beginning, and its effect enters into each measurement twice (at each end of the line being measured). Even if nothing else affected our accuracy, it would be impossible to measure closer than 0.14 mm. at each end of a line; a total possible error of 0.28 mm.! Fig. 2 illustrates this effect on actual x-ray films.

Initial choice of an x-ray tube is the only important control which we have over this optical blurring, and here we meet two opposing problems. A small target cannot handle as much current (milliamperage) as a larger one, so when we gain in a small target size we lose in potential exposure speed and motion.

Our problem is to get size and current into a favorable balance and then use them to best advantage. Our selection of milliamperage is usually limited, somewhere between 10 and 30 milliamperes. Once the tube is selected, it *must* be operated at the highest possible milliamperage to get the best balance between optical blurring and motion. Using an oversize target or less than the maximum milliamperage with the idea of prolonging tube life is an unnecessary sacrifice of quality. Cephalometric work is very light duty service, and tube ratings already include a very adequate safety factor.

INTENSIFYING SCREENS:

Here we really have troubles. Of all the necessary evils with which we must contend, intensifying screens stand squarely at the top of the list.

Fig. 3 shows how these screens can blur a film, and this blurring is just as obvious on a skull picture. But don't

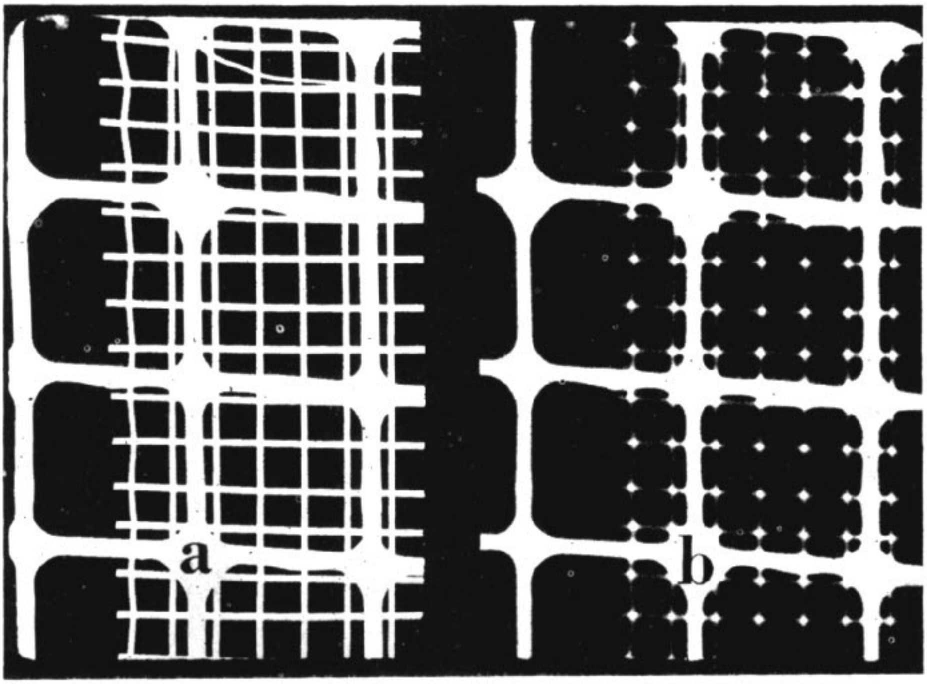

Fig. 3. Effect of intensifying screens. Subject same as fig. 2. In each case the subject is against the cassette to eliminate the effect of target size.
A. No-screen film without screens.
B. Blue brand film with high definition screens.

throw your screens away yet! If we don't use them, even the most patient patient will have difficulty sitting still long enough to have his picture taken; and in addition he will be exposed to much more dangerous radiation.

These screens depend for their intensifying action on the fact that they contain many particles of a mineral which glows when it is exposed to x-rays. Light radiates in all directions from each of these glowing particles, so that each glowing particle produces a small blurred spot on the film. The picture which we see is nothing more than a composite of all these glowing particles. This image on the film compares with the original x-ray pattern in much the same way that a newspaper reproduction compares with the original photograph.

Since this blurring is caused by the scattering of light, the extent of the blurred area depends to some extent on the amount of light being scattered. The edges of a very dark area on the film (produced by very brightly glowing particles) will be blurred noticeably more than the edges of a lighter area. This can be easily seen on a film where a metallic part of the machine casts a shadow over part of the skull and the surrounding black area. The regular outline of the metal will change markedly where it passes from the skull to the surrounding black area.

We cannot calculate exact dimensions for this blurring as we did for optical blurring, but a comparison of Fig. 2 and Fig. 3 shows the much greater effect of the screens. Fig. 4 shows the combined effects of target size and screens on one film in a cephalometric setup.

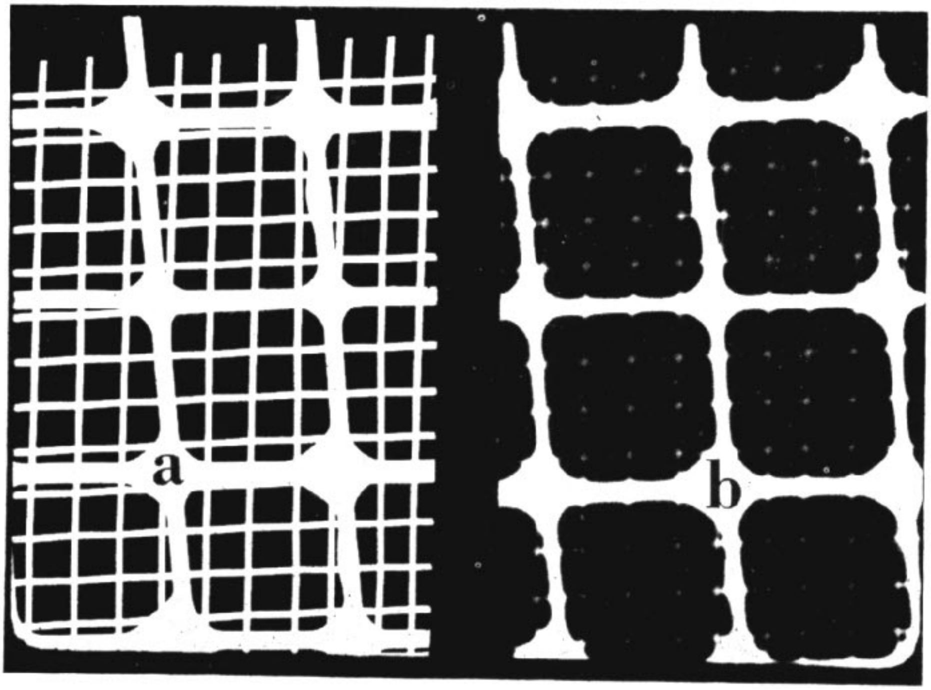

Fig. 4. Combined effect of target size and screens. Subject same as Fig. 2.
A. No-screen film, without screens, subject against cassette.
B. Blue brand film, high definition screens, subject 10 cm. from film.
Exposure adjusted to give comparable density on film.

How much over-all blurring do we get?

We calculated an approximate effect of 1/4 mm. due to target size, and we can readily see that the unmeasured error of the screens is much greater. If we assume that there is no motion whatsoever, just these two factors alone would make it difficult to stand behind a dimension expressed in units smaller than 1/2 mm.

There is one point which should be mentioned in connection with blurring. Much blurring is camouflaged on the film by the fact that one edge of a blurred area may show up as a rather sharp line while the other edge is hidden by the adjacent image. Thus we may get rather consistent measurements, giving the impression that there is no error. In reality the error is merely a constant one, which may be either cancelled out or compounded in the course of measurement and calculation.

Enlargement

Distances are the key to enlargement, much the same as with optical blurring. In this case we will modify Fig. 1 by ignoring optical blurring and making our flashlight a point source of x-rays. This gives us Fig. 5.

All of the discussion to follow on enlargement and distortion applies to both the lateral and the postero-anterior views. For simplicity however, discussion will be confined to the lateral view. To apply these discussions to the P-A view all that is necessary is to substitute the trans-porionic plane for the sagittal plane.

In the cephalometric technic the film and the sagittal plane of the patient are parallel. This means that all of the angles in triangle Tdg (Fig. 5) are equal to the corresponding angles in triangle TDG. In mathematical terms, these two triangles are similar and cor-

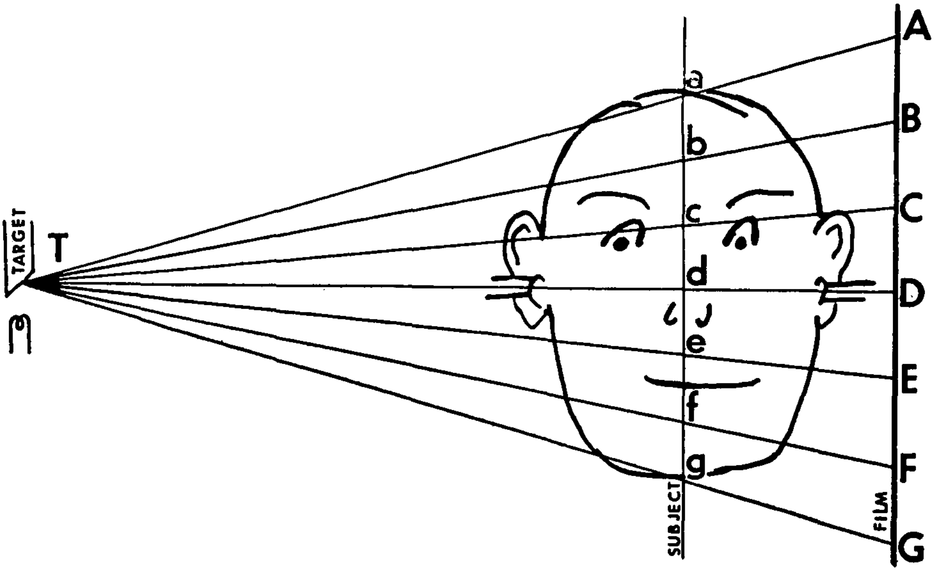

Fig. 5. Diagram showing enlargement of the subject on the film. T is the target, ag the sagittal plane of the subject, and AG the film. TD is the "central ray", perpendicular to the film.

responding sides are proportional.

This means that we have an easy way to determine enlargement with a simple proportion.[2] The table in Fig. 6 shows the enlargement of objects 10 cm. and 15 cm. long on a cephalometric film, using different film positions. From this table we see that the enlargement on a cephalometric film is between 5% and 8%. Since this much error can be very important, the next step is to decide what to do about it.

Controlling Errors Due to Enlargement:

Fortunately, enlargement can be readily controlled, thanks to the data which we always have for cephalometric films. How we control it depends partly on personal preference and partly on our objectives.

The simplest solution is to make enlargement constant and then ignore it. With enlargement constant, it can be safely ignored for angular measurements, superimposing serial tracings, and for ratios of linear measurments. Correction of measurements is necessary only for obtaining absolute linear values.

Correction with constant enlargement is simple, since the same correc-

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[2]Here is the calculation of enlargement for a typical case:

$$\frac{Td}{TD} = \frac{dg}{DG}$$

Td is standardized at 5 feet or 152.4 cm.

dD may vary, but we will assume that it is 10 cm., making TD = 162.4 cm.

dg will be assumed to be 10 cm.

Substituting these figures in the equation, we have;

$$\frac{152.4}{162.4} = \frac{10}{DG}$$

Solving for DG, we find;

DG = 10.656

This is an enlargement of 6.56%.

Fig. 6. Enlargement at five foot distance, target to subject.

Distance from subject to film	Length of the image of a 10 cm. subject on the film	Length of the image of a 15 cm. subject on the film	Enlargement
8 cm.	10.525 cm.	15.787 cm.	5.25%
9 cm.	10.590 cm.	15.885 cm.	5.90%
10 cm.	10.656 cm.	15.984 cm.	6.56%
11 cm.	10.722 cm.	16.083 cm.	7.22%
12 cm.	10.787 cm.	16.180 cm.	7.87%

tion factor or scale can always be used. Obtaining constant enlargement merely requires using the same subject-film distance for all pictures.

With variable enlargement (variable film position), correction for enlargement is still not necessary for comparison of angles or for linear ratios where the figures in each ratio come from the same film. *Correction is necessary* for superimposing serial tracings when linear distances are being compared, for linear ratios where the figures in the ratio are from different films, and for absolute linear measurements.

Correction for enlargement can be done in many ways. It can be done with scales projected on the film, as originally described by Dr. Broadbent. It can be done by determining the actual ratio, as described in footnote 2. It can be done with a slide rule, by-passing the actual ratio itself and reading the correct dimension directly (Fig. 7).

Any method of correction requires two dimensions in addition to the one being corrected. These are the distance from x-ray target to subject (measured to sagittal plane, the midpoint between the earposts), and the subject-film distance (measured from sagittal plane to film). For parts not in the sagittal plane, these figures must be corrected for the actual location of the part.

How accurately should these distances be measured? If we look at Fig. 6 we can see that moving the film 1 cm. changes the length of a 15 cm. line about 1 mm. Since we are not likely to encounter a line longer than 15 cm. in cephalometric work, this figure can be used as a safe guide.

We can then say for a rule of thumb that *the change in dimension due to change in enlargement will not be more than* 1/10 *the change in subject-film distance.* In other words, if we plan to measure the film to the nearest millimeter, it would give adequate accuracy to measure film position to the nearest centimeter.

Since blurring limits our accuracy to several tenths of a millimeter, measuring film position within several millimeters should give adequate accuracy. In actual practice, then, we can measure this distance in millimeters and so reduce the possible error from this source of insignificance. This distance *must* be recorded for every film.

Target-subject distance requires the same proportional accuracy. Since it is a much larger dimension, careful measurement with ordinary methods should give adequate accuracy here. This dimension is, of course, always fixed.

Distortion

Distortion is considerably more serious than simple enlargement, since it can play havoc with just about everything which we might try to do with a cephalometric film. Angles, lines, and proportion are *all* altered by distortion.

Distortion is the result of the fact that our patient is three dimensional, and those parts which lie outside the

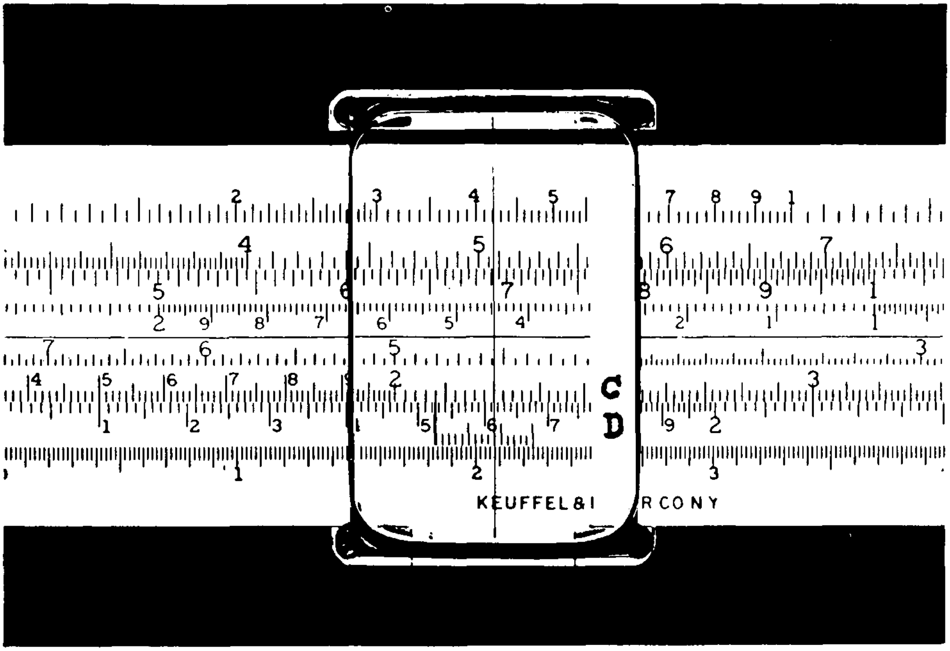


Fig. 7. Slide rule modified to calculate enlargement. The short scale is added under the D scale. This short scale represents the scale of subject-film distances, and begins with its zero point at 152.4 (the 5 foot target distance in centimeters). The movable hairline is used to indicate film position on the short scale. The C scale (on the slide) is used to read dimensions for the subject and its image on the film.

To make the calculation illustrated here, the film position is indicated with the hairline on the short scale (9 cm.). The dimension measured on the film (22 mm.) is placed under the hairline on the C scale of the slide. The true sagittal dimension (20.8 mm.) is then read on the C scale opposite the zero point of the short scale.

If the actual part of the subject being measured is not in the sagittal plane (as was assumed above), the correct dimension is read. opposite the point on the short scale which indicates its actual distance from the sagittal plane. For parts lying in front of the sagittal plane (right side of the face), the short scale would have to be extended to the left.

Correction is even easier when a constant film position is used and all points are in the sagittal plane. Then 152.4 is placed opposite the point on the short scale which represents the film position. Correct dimensions are then read on the C scale directly opposite the measured dimensions on the D scale.

sagittal plane are enlarged varying amounts. We use many such points, including orbitale, first molars, mandibular border, and pterygo-maxillary fissure. In all of these cases, the point on the side farthest from the film is affected more by enlargement than its mate, giving us a distorted view.

This distortion is dependent *only* on the perpendicular distance of the points involved from the film. *Position on the film or position in relation to the "central ray" has no bearing on enlargement or distortion.* As a result, there can be no distortion *within* a single plane parallel to the film; distortion exists only *between* such planes.[3]

Conventional cephalometric practice

[3]This is readily illustrated by Fig. 5. It is a geometric fact that corresponding sides of similar triangles are proportional to one another. In this case, this means that $\frac{ab}{AB} = \frac{bc}{BC} = \frac{cd}{CD} =$ etc. Since these lines all bear the same ratio to one another, it is obvious that enlargement is the same for each one.

with bilateral points has been to use only the left side points for measurement, a carry-over from anthropometric practice for the measurement of dried skulls. For dried skulls, this is a very convenient solution to the problem of what to do with two measurements when you only want one. In cephalometrics it is not only less convenient, but it can introduce considerable error. In fact, it can introduce three errors.

Only one of these three errors is due directly to the distortion which we are discussing. This error is very noticeable in the changes brought about in the mandibular border angle when we measure only one side (Fig. 8).

The same problem appears to a varying degree with other measurements using points not in the same plane. The error in each case depends on the positions of the points being measured and on the nature of the measurement itself.

Correction of this error is simple. All that has to be done is to use the midpoint between bilateral points instead of the left or right point alone. This has the effect of projecting the points to the sagittal plane and making all measurements from this common base where enlargement is the same

There is a slight error in this method due to the fact that one side is closer to the x-ray tube than the other. This makes enlargement not exactly proportional to the distance of the points from the sagittal plane, as we assume when we use the midpoint. Fortunately, this error can be shown to be insignificant for our purposes.[4]

This midpoint method also helps us by reducing the other two errors referred to in connection with taking measurements only on the left side.

One of these is the question which sometimes arises as to just which *is* the left side on the film. In most cases this is easy to decide, but in an asymmetry, or if the patient was not well positioned, it may be impossible to decide with certainty. Of course if we use the midpoint it makes no difference which side is which.

The other possible error is caused by poor patient position. We know that this should never happen, but let's face it; sometimes it does happen. As mentioned earlier, the patient cannot be made completely immobile, and unfortunately our patients are not always selected for their cooperative attitude. This problem increases to the point of impossibility with very young children.

Suppose that our patient *has* shifted, although we still have the earposts engaged in some fashion. What will it do to our measurements? Of course porion as we usually determine it will be of little value in such a case, but the other points can still be useful.

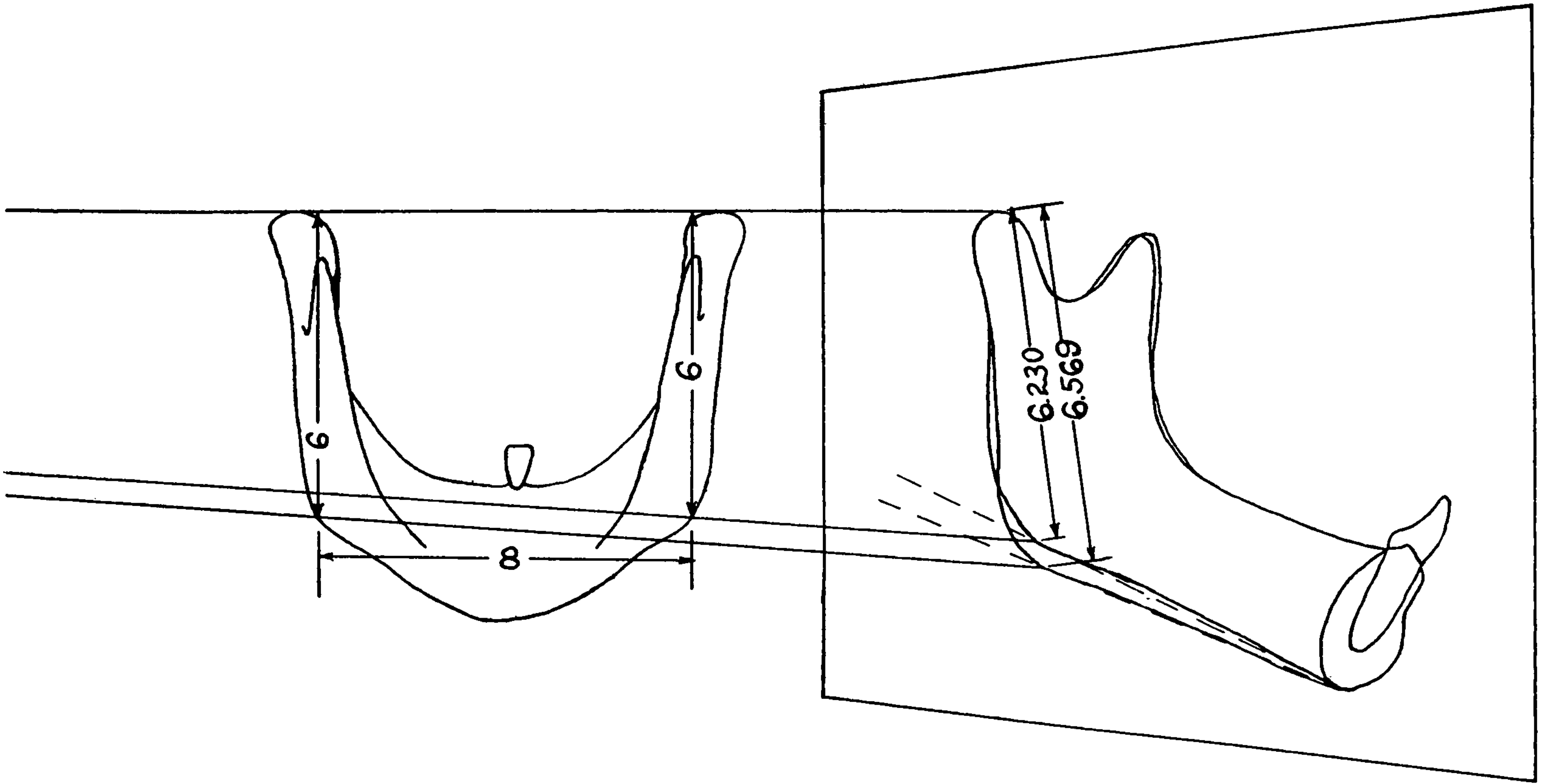
If the movement has not changed the sagittal plane (trans-porionic axes of patient and machine still parallel), nothing but porion will be affected. If he tilts his head, or turns it to right or left (any rotation not around the trans-porionic axis), other things will happen. Any such rotation will move corresponding right and left points in opposite directions in relation to their sagittal projections.

So? Presto! We take the midpoint between the two points on the film and our error is gone.

This correction applies only to slight

[4]Using the illustration in Fig. 8 again, the midpoint between 6.230 cm. and 6.569 cm. is *6.399 cm.* This is the midpoint on the film which we would use for our measurements. Using the actual midpoint on the patient, 6 cm. from the midpoint between right and left porion, we find that enlargement would place it *6.393 cm.* from the porion image. In other words, the point which we would use by taking the midpoint on the film would be 0.006 cm. in error.

Using the impossibly extreme case of two points 16 cm. apart laterally and 10 cm. from porion, we still find a difference of only 0.029 cm. between the true sagittal projection and that obtained by using the midpoint on the film.



Distortion of mandibular border angle. The side farthest from the film is projected lower than the side nearest the film, due to differences in enlargement. Englargement of the sagittal plane, including the symphysis, is midway between the two. The true angle can be found by taking the midpoint between the right and left images, which has the effect of projecting the points to the sagittal plane. The sagittal plane then becomes a common base for all measurements, equalizing the effects of variations in enlargement. Distance of film from sagittal plane is 10 cm.

rotations of the head. A large movement would change the distance between various parts and the film enough to make an appreciable change in enlargement. It could also change the view enough to make us pick up false points for measurement. In other words, we have here a helpful compensation for unavoidable errors, not an excuse for careless technic.

Summary and Discussion

Many factors affect the accuracy of cephalometric radiographs, and if we are to get the most out of this work we should know what these limitations are.

Blurring, under favorable conditions, limits the possible accuracy of measurement to about 1/2 mm.

Enlargement is usually somewhere between 5% and 8% for sagittal points. It does not affect angles, or some proportions. It does affect linear measurements and some proportions involving linear measurements. Enlargement must be considered in superimposing serial tracings.

Correction of errors due to enlargement is easily accomplished when required, with a choice of several different methods available.

Distortion is the result of differences in the amount of enlargement of different parts in the same picture. It affects *any* measurement or comparison (including angles) of parts not lying entirely in one plane parallel to the film. It is readily corrected by projecting bilateral points to the sagittal plane, which means using the midpoint between right and left points on the film.

All of these errors exist in EVERY radiograph. What cephalometrics has to offer is control over them, so that they may be measured, evaluated, or cancelled out as indicated.

The latter procedure, "cancelling out", can be applied to both enlargement and distortion. All that is required for enlargement is the addition of further standardization to our present technics. If we can measure and calculate enlargement, why not make it constant by using a constant film position? This actually simplifies our technic at the same time that it removes a source of error. In the special cases where enlargement must still be considered, the necessary correction is simplified by the fact that we need to use only one correction scale or conversion factor.

There is even more reason for cancelling out distortion, because this is the only practical means we have of eliminating the error. This error has been present in much of our work, and while often harmless, it should be eliminated when elimination is such a simple matter.

How Important Are These Corrections? This depends on what we are trying to do with cephalometrics.

Diagnosis has probably received the greatest impetus in private practice. We have been provided with excellent methods of cephalometric appraisal, and the thought of being able to plug in our x-ray and grind out perfect diagnoses is positively enchanting. But it doesn't work that way.

Cephalometric films, taken at just one point in a child's life, tell us just one thing; what he looks like at that particular time. From this one picture, with the help of the plans of analysis which we have been given, we can make a reasonably intelligent *guess* at what *might* happen in the future.

To go this far with cephalometrics—to make our guess—we don't need to worry about enlargement and distortion. We don't even need a cephalometric instrument. Any radiograph will do. It may not do much, but it will do all that a cephalometric film can do at this point. To worry about a few millimeters or degrees in this diagnostic phase is just deluding ourselves. These things are not so subject to objectification, at this time at least, that our plans should hinge on such small differences.

But stopping with the cephalometric diagnosis is much like buying a new automobile, parking it in front of the house, and curling up with a stack of maps and travel folders. It may impress the neighbors, but it won't get us very far. Our diagnostic analyses have provided us with excellent maps and travel folders, but they are no substitute for taking the trip ourselves. The survey work has been done, the roads are marked; all that we have to do is get started.

Where do we go? Cephalometrics was developed for just one thing: accurate measurements. And these accurate measurements are of value only if we make comparisons between them. So let's compare; let's check up on our diagnostic guesswork and see what *really* happens. Some of the answers can be downright startling. Let's start getting pictures *before* we plan to start treatment; then our later diagnosis will involve a little less guesswork.

These are the applications where we have to worry about errors; serial work on the same patient. Here we become concerned with the smallest possible changes, and any measureable error becomes significant. If we know what the possible errors are, and either correct for them or at least think of them before jumping at our conclusions, we will be reasonably safe.

This applies to research and private practice alike. There can be no dual system of standards, separating research and practice. Either it is cephalometrics or it is not. Either we can measure heads or we cannot. The distinction between research and practice is in the ultimate use to which the information is put, not in the information itself.

The cephalometric requirements in either case are simple:

1. Orient and adjust the equipment carefully.
2. Position the patient carefully.
3. Record the subject-film distance (in millimeters) if a constant film position is not used.
4. Record the patient's name, age, and the date.

This is all that is necessary at the time that the film is made. When the film or tracing is being studied, make the necessary corrections for enlargement and distortion *only as required.* If the four requirements above have been met, this can be easily done at *any time.* If the requirements have not been met, we have just another radiograph, useless from the cephalometric standpoint for either practice *or* research.

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