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GEOMETRIC ERRORS IN MEASUREMENTS ON X-RAY FILMS

A METHODOLOGIC STUDY ON LATERAL MODEL EXPOSURES

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INTRODUCTION

In order to estimate the radiographic pattern and morphology of the structures concerned, orthodontic x-ray cephalometrics will generally include accurate metric and angular measurements (*Humerfelt*, 1970). It has been shown that variability of x-ray cephalometric measurements may be influenced by the morphology of the landmarks (*Freunthaller*, 1964; *Richardson*, 1966) as well as by the tracing procedure (*Björk & Solow*, 1962; *Kvam & Krogstad*, 1969). These measurements will also be influenced by various geometric and technical factors however (*Nawrath*, 1959; *Carlsson*, 1967).

The purpose of the present study was to estimate linear measurement when the reference points on the films are accurately located. In addition, it was intended to study the difference in magnification between right and left side on profile roentgenograms, and also the difference in magnification due to individual variation in widths of the facial dimensions.

MATERIAL AND METHODS

The material consisted of 13 roentgenograms, which were obtained by repeated x-raying of an acrylic plate. The profile contours of the facial structures

Received for publication, September 28, 1970.

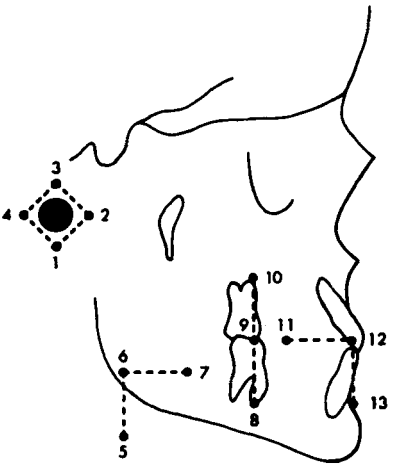

Fig. 1. Tracings of dento-facial structures on the model plate.

had been transferred to the plate from a lateral head plate. Before the x-raying thirteen steel bearings (0.8 mm) had been placed in the plate (Fig. 1). Four had been placed in the porion region (1, 2, 3, 4), three in the gonion region (5, 6, 7), three in the molar region (8, 9, 10) and finally three in the incisal region (11, 12, 13).

During the x-raying the acrylic plate was placed in an Evald-Harvold cephalostat,*) parallel to the film plane and with the central ray passing through the area corresponding to the earholes of the skull (Fig. 2). The plate could be moved to different controlled positions, thus the distance between the object and the film ranged from 13—37 cm with an increase of 2 cm from one exposure to the other.

The focus-film distance was 154 cm and the median sagittal plane (M.S.P.) 23 cm from the film. The film (Du Pont Cronex 4) was machinally developed and fixed (Agfa Gevaert G 150 and G 134) at 25°C. The x-ray characteristics were 90 kV and 15 mA, and the exposure time was 0.4 sec.

Two different series of measurements on the film were performed.

1. Eleven post-graduate students measured the distances 1—2, 2—3, 3—4, 4—1 on the film corresponding to the M.S.P. (Fig. 1). These measurements were done 5 times with one week between each registration using acetate paper to avoid scratching on the film (*Björk & Solow*, 1962).

2. One horizontal and one vertical distance in the porion, gonion, molar

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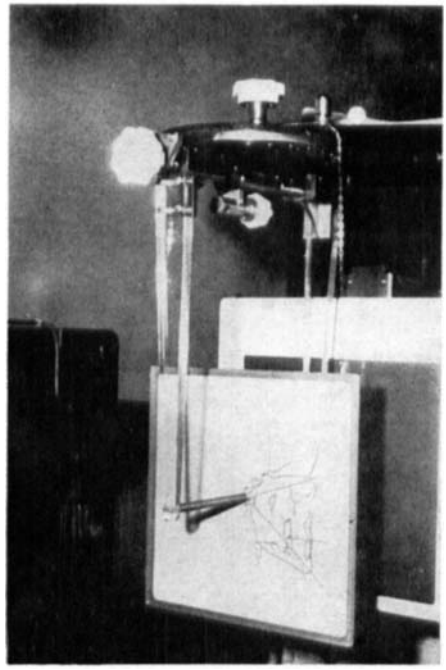

Fig. 2. The Evald-Harvold cephalostat with the model plate (30×30× 0.8 cm) in position.

and incisal regions were measured on all films. These measurements were performed only once.

The distance between the images of the pellets on the films were transfered to a sliding caliper by a pair of sharp-needled dividers, by scratching fine lines on the caliper after marking the vernier scale with a fatty pencil (Fig. 3). The vernier scale of the sliding caliper registered 1/10 mm.

RESULTS

The results from the first series of measurements appear in Table I. Table II gives the means ($\bar{x}$) and the standard deviations (S.D.) for the four distances. The object values and the calculated magnification of the object values on basis of the focus-film and the M.S.P.-film distances, (the calculated values) are also included in Table II. The means of the standard deviations for the five weeks which ranged between 0,15 and 0,24 mm, are visualized in Fig. 4.

Table III and Figs 5, 6, 7 and 8 show the results from the second series of measurements, and reveal that the increments in all the four regions were

Table 1.

Repeated measurements in

	I 1. week				II 2. week				III 3. week	
Post-Grad. No.	1—2	2—3	3—4	4—1	1—2	2—3	3—4	4—1	1—2	2—3
1	16.5	16.3	16.2	16.3	16.5	16.2	16.2	16.5	16.4	16.3
2	17.0	16.3	16.0	16.6	16.5	16.0	16.1	16.5	16.5	16.4
3	16.4	16.1	15.1	16.6	16.2	16.1	16.0	16.3	16.4	16.2
4	16.8	16.8	16.5	16.8	16.4	16.3	16.2	15.5	16.3	16.4
5	16.4	26.6	16.1	16.4	16.4	16.3	16.0	16.4	16.3	16.4
6	16.3	16.4	16.1	16.4	16.4	16.3	16.3	16.4	16.4	16.4
7	16.6	16.1	16.0	16.1	16.3	16.3	16.3	16.4	16.4	16.3
8	16.5	16.4	16.3	16.4	16.3	17.1	17.2	17.3	16.4	16.3
9	16.4	16.4	16.5	16.5	16.1	16.2	16.1	16.1	16.4	16.3
10	16.3	16.4	16.4	16.4	16.3	16.2	16.2	16.4	16.4	16.2
11	16.4	16.3	16.4	16.4	16.3	16.4	16.3	16.4	16.3	16.4
Σ	181.6	180.1	177.6	180.9	179.7	179.4	178.9	180.2	180.2	179.6
x	16.509	16.373	16.145	16.445	16.336	16.309	16.264	16.382	16.382	16.327
SD.	0.2115	0.2004	0.3933	0.1809	0.1206	0.2844	0.3295	0.4167	0.0602	0.079

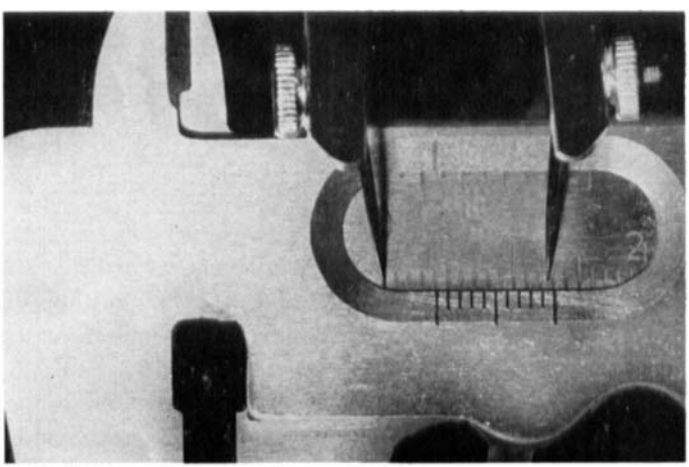

Fig. 3. A pair of sharp needled dividers transfering a measurement to the sliding caliper by scratching a fine line on the fat color.

the porion region

IV 4. week				V 5. week					
3—4	4—1	1—2	2—3	3—4	4—1	1—2	2—3	3—4	4—1
16.1	16.4	16.3	16.1	16.1	16.4	16.4	16.3	16.4	16.6
16.2	16.4	16.3	16.1	16.2	16.7	16.7	16.1	16.0	16.3
16.2	16.3	16.1	15.9	15.9	16.1	16.5	16.3	16.3	16.5
16.5	16.5	16.7	16.4	16.3	16.7	16.5	16.3	16.4	16.7
16.4	16.4	16.5	16.5	16.2	16.4	16.5	16.1	16.1	16.5
16.3	16.4	16.5	16.4	16.5	16.5	16.4	16.5	16.5	16.4
16.3	16.4	16.6	16.5	16.5	16.6	16.5	16.4	16.4	16.5
16.2	16.4	16.5	16.4	16.5	16.4	16.9	16.5	16.4	16.6
16.3	16.4	16.6	16.5	16.5	16.6	16.4	16.5	16.5	16.4
16.0	16.2	16.2	16.1	16.0	16.3	16.3	16.3	16.2	16.4
16.3	16.3	16.5	16.4	16.4	16.5	16.5	16.4	16.3	16.5
178.8	180.1	180.8	179.3	179.1	181.2	181.6	179.7	179.5	181.4
16.255	16.373	16.436	16.300	16.282	16.473	16.509	16.336	16.318	16.491
0.1368	0.0786	0.1858	0.2098	0.2128	0.1794	0.1640	0.1433	0.1601	0.1136

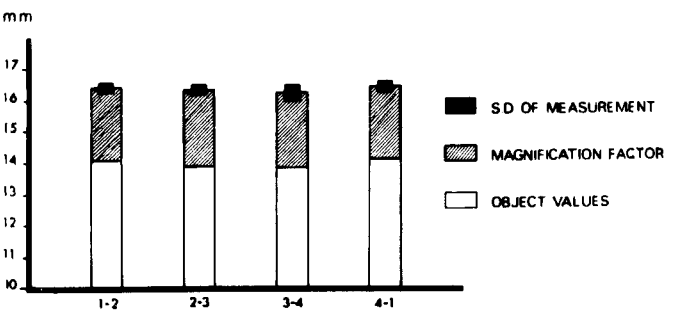

Fig. 4. Graphic illustration of the repeated series of measurements in the area of the external ear opening.

Table II.

The mean ($\bar{x}$), standard deviation (S.D.), object value and calculated value for the four measured distances of repeated measurements in the porion region

	1—2		2—3		3—4		4—1	
	x	S.D.	x	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1. week	16.51	0.22	16.37	0.20	16.15	0.39	16.45	0.18
2. week	16.34	0.12	16.31	0.28	16.26	0.32	16.38	0.41
3. week	16.38	0.06	16.33	0.07	16.26	0.13	16.37	0.07
4. week	16.44	0.18	16.30	0.20	16.28	0.21	16.47	0.17
5. week	16.51	0.16	16.34	0.14	16.32	0.16	16.49	0.11
x	16.43	0.15	16.33	0.18	16.25	0.24	16.43	0.19
Object values	14.10		13.90		13.85		14.10	
Calc. values	16.57		16.37		16.28		16.57	

Table III.

Measurements from various dento-facial regions at increasing object/film distances

Object/film distances, cm	Porion		Gonion		Molar		Incisal	
	1—3	2—4	5—6	6—7	8—9	9—10	11—12	12—13
11	21.1	21.5	21.5	21.0	21.8	21.5	21.3	21.1
13	21.6	21.5	21.6	21.5	22.0	22.0	21.5	21.4
15	21.8	22.0	21.9	21.9	22.3	22.3	21.9	21.6
17	22.0	22.1	22.2	21.9	22.6	22.6	22.0	22.0
19	22.6	22.6	22.5	22.4	22.8	22.8	22.5	22.2
21	22.8	22.8	22.9	22.7	23.0	23.0	22.8	22.5
23	23.0	23.1	23.3	23.0	23.3	23.3	23.2	23.0
25	23.2	23.3	23.6	23.4	23.7	23.7	23.6	23.4
27	23.9	23.9	24.1	23.9	24.2	24.3	23.9	23.9
29	24.0	24.0	24.3	24.2	24.2	24.6	24.1	24.1
31	24.6	24.6	24.7	24.6	25.0	25.0	24.5	24.4
33	25.0	25.0	25.0	24.9	25.1	25.1	24.9	24.8
35	25.4	25.4	25.4	25.2	25.8	25.7	25.4	25.2
$\bar{x}$	23.15	23.22	23.31	23.12	23.52	23.53	23.20	23.05
Total increm. in mm.	4.3	3.9	3.9	4.2	4.0	4.2	4.1	4.1

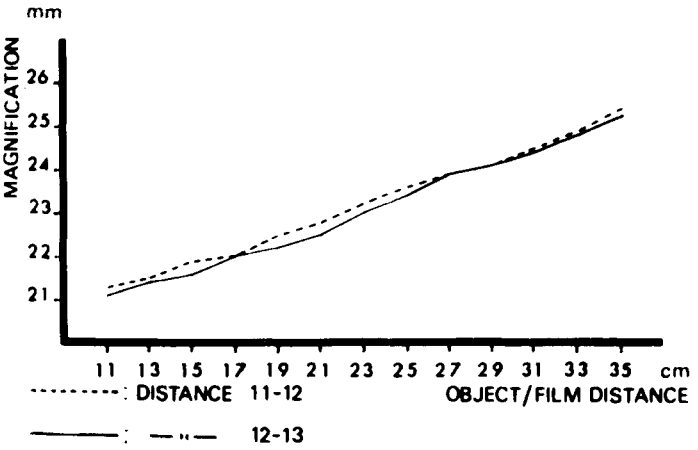

Fig. 5. Magnification in the porion region with increasing object-film distance.

about the same size averaging 4,1 mm, which rendered an average magnification factor of 0,085 mm per cm increased distance between object and film. In addition, table III and Figs. 5, 6, 7 and 8 show that the relationship between the degree of magnification and the object/film distance was linear.

On Figs. 6 and 7 the maximum and minimum values from the gonion and molar region as found by *Slagsvold* (1969) are included. Due to the

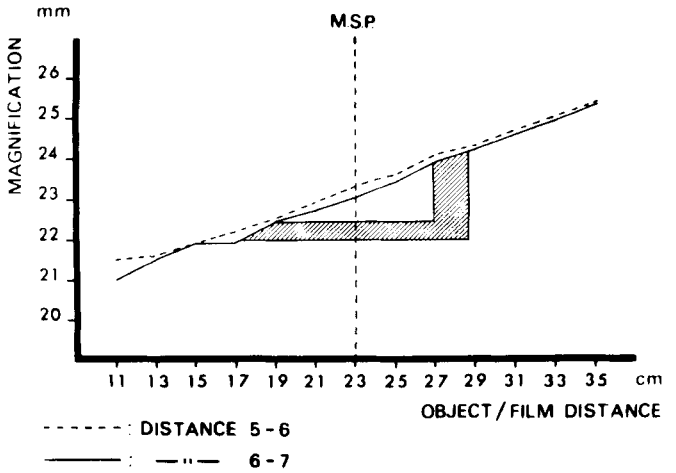

Fig. 6. Magnification in the gonion region with increasing object-film distances. Maximum and minimum widths are included.

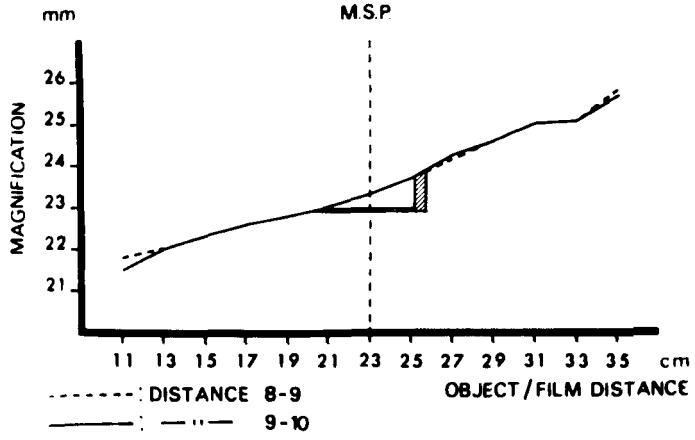

Fig. 7. Magnification in the molar region with increasing object-film distances. Maximum and minimum values are included.

fact that there is a linear relationship between the degree of magnification and the object/film distance, these values were used to estimate the difference in magnification between bilateral structures. From Fig. 6 was deduced that when the distance between film and focus was 154 cm and the distance between film and the median sagittal plane was 23 cm, the maximum and minimum differences in magnification between right and left side in the

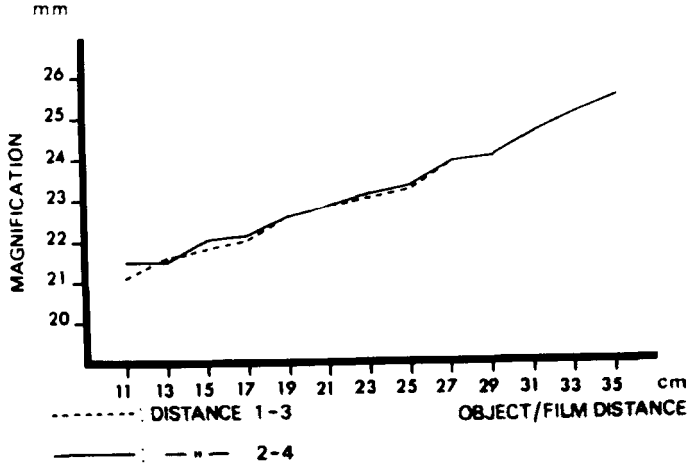

Fig. 8. Magnification in the incisal region with increasing object-film distance.

lower jaw angle area were 2,05 mm and 1,35 mm or 10,03% and 6,75 % respectively. The corresponding values in the molar area, Fig. 7, were 0,95 mm and 0,80 mm or 4,75 % and 4,00 %.

Figs. 6 and 7 were also used to visualize the difference in magnification between individual variation in widths on the same side. The difference between maximum and minimum gonial width on the side farthest away from the film was measured to 0,30 mm or 1,50 %, while the corresponding value in the molar area was 0,07 mm or 0,35 %.

DISCUSSION

As most linear dimensions of interest in X-ray cephalometry have a biologic variability which is considerably greater than the results from the first series of measurements, the present findings confirm that the error of measurements represents a small source of error, supporting the observations of *Richardson* (1966) and *Savara et al.* (1966).

It may also be pointed out that the error of measurements must be expected to be independent of the size of the dimensions, whereas the variability is correlated with it (*Pearson*, 1896). This implies that if the points of the measurements are well defined, and the measurement procedure is carried out with sufficient precision, the influence of the error of measurement upon the variability will be negligible except for small dimensions.

The postgraduate students were not specially trained in measuring technique when the measurements started. It is evident from Table I and II that the standard deviation decreased during the five weeks. Consequently a training period is of advantage also with the present technique. This is in accordance with earlier findings (*Kvam & Krogstad*, 1969), although it does not seem to apply to trained participants (*Kuzma & Zwemer*, 1968).

The magnification due to increased distance between the film and object is of definite importance. The magnification factor was 0,085 mm per cm increased object/film distance. Out of geometrical considerations it is obvious that the magnification factor will increase when the object is approaching the focus, and decrease when it is approaching the film. It is also well known that the magnification factor decreases when the distance between focus and film increases.

Another factor involved in the question of film to target distance, however, is the penumbra effect which is a function of the size of the focal spot and

the tube/object distance (*Horowitz & Hixon*, 1966). It has been stated that the penumbra phenomenon with increasing object/film distance will make the landmarks more difficult to localize. For this reason the distance should be kept as small as possible. When using steel pellets as landmarks, comparison between exposures with increasing distances (Figs. 5, 6, 7 and 8) revealed that the penumbra effect did not influence the measurements significantly, in spite of the great object/film distance applied.

The difference in magnification between linear dimensions on the right and the left side is of general interest. The values deduced from the second series of measurements (Figs. 6 and 7) show that this source of error has to be considered. The error can, however, be reduced by using those structures which are located nearest to the film, or by bisecting the bilateral images.

Individual variations in width will also influence headplate measurements taken from structures on the same side. The values found on Figs. 6 and 7 are quite small. Because these values are based on maximum and minimum values, they will ordinarily be even smaller, and can be considered negligible for most purposes.

It should be emphasized, however, that the present findings are based on dimensions parallel to the film plane. Distortion due to varying axes and planes of the composed facial structures on the two sides and due to asymmetrical morphological characteristics, complicates comparison (*Solow*, 1966). The methods applied in the present investigation excludes the possibility of evaluating these factors, however.

SUMMARY

A plastic model head plate with steel bearings in four different regions was used to obtain thirteen lateral x-ray exposures with varying object-film distances. Utilizing a described measuring technique five weekly repeated measurements from the porion region were done, as well as measurements from four regions on all thirteen films.

The error of measurements was small, a finding ascribed to the accurate localization of landmarks. The measurements following increased object/film distance were shown to be linear and did not involve greater error of measurements. The difference in magnification of bilateral structures has to be considered, whereas errors due to varying, individual widths can be neglected for general cephalometric purposes.

RÉSUMÉ

ERREURS GÉOMÉTRIQUES DANS LES MENSURATIONS SUR FILMS RADIOGRAPHIQUES. ÉTUDE MÉTHODOLOGIQUE SUR DES CLICHÉS DE PROFIL D'UN MODÈLE

Une plaque modèle plastique de la tête, avec des repères d'acier situés dans 4 régions différentes, a été utilisée pour la prise de 13 radiographies de profil, avec différentes distances film-objet.

En utilisant une méthode de mensuration dont la description a été donnée, 5 mesures de la région du porion répétées chaque semaine ont été effectuées, ainsi que des mesures de 4 régions sur chacun des 13 films.

L'erreur inhérente aux mesures était peu élevée, ce qui a été attribué à la précision de la localisation des repères.

Les mesures faites après augmentation de la distance film-objet se sont révélées être linéaires et ne comportaient pas d'élévation de l'erreur inhérente aux mesures. Il faut tenir compte de la différence de l'agrandissement des structures bilatérales, tandis que les erreurs dues à la variation individuelle des largeurs peuvent être négligées dans l'utilisation céphalométrique en général.

ZUSAMMENFASSUNG

GEOMETRISCHE FEHLER BEIM VERMESSEN VON SEITLICHEN FERNRÖNTGENAUFNAHMEN

Ein Plastikmodell einer seitlichen Fernröntgenaufnahme wurde in vier verschiedenen Bereichen mit Metallindikatoren versehen und unter wechselndem Objekt-Film Abstand dreizehn Mal geröntgt. Bei Verwendung einer beschriebenen Vermessungstechnik wurden mit Zeitabstand von einer Woche die Abstände in Porion gemessen. Zusätzlich wurden die Abstände der Metallindikatoren innerhalb der vier verschiedenen Bereiche an allen dreizehn Rötgenaufnahmen festgelegt.

Der Messfehler war gering. Dieser Befund wurde der genauen Lokalisation der Messpunkte zugeschrieben. Eine Vergrösserung des Film-Objekt Abstandes führte bei gleichbleibendem Messfehler zu einer linearen Zunahme der Masse. Die unterschiedliche Vergrösserung von bilateralen Massen muss beobachtet werden, während Fehler, die durch individuelle Variation in Breite verursacht waren, wurden gemessen und für allgemeine Zwecke als belanglos gehalten.

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