From: The Department of Prosthetics, School of Dentistry, Karolinska Institutet, and the Division of Photogrammetry Royal Institute of Technology, Stockholm, Sweden.

MEASUREMENTS ON ROENTGENOGRAMS
A COMPARISON BETWEEN TWO METHODS

by

LENNART WICTORIN

INTRODUCTION

A roentgenogram depicts the relative penetration of the various dense parts of the object by the roentgenrays. How the position of the anatomical details in the object will be recorded will depend on the positional relationship between the focus, object and the film. A distinction is drawn between the outer orientation — that is, the position and direction of the ray bundle in relation to the radiographed object — and the inner orientation, that is the position of the centre of projection in relation to the image plane.

The roentgenogram has also long been used for measuring distances, angles, etc., of an object in the fields of the medicine and dentistry, and particularly in cephalometry, when the registration of the cranium is performed in a cephalostat. Longitudinal investigations are often performed, involving repeated registrations of the head in the cephalostat.

One of the measuring methods used then is tracing, in which the points and contours to be registered are transferred from the film to tracing paper, on which the measurements are then made. In a longitudinal study or investigation in which several roentgenograms are to be compared with each other the tracing is fitted to the next roentgenogram for the registration of new points and contours. It is possible to make a tracing for each roentgenogram, after which they are superimposed to provide a master tracing in which all the information is collected and registered.

Measurements directly on the roentgenogram can also be performed with dividers and ruler. A disadvantage of this method is that the roentgenogram is liable to damage and duplicate or simultaneous determinations cannot be performed.

A completely different approach is the photogrammetric method. Photogrammetry is the determination of the geometric properties such as size, shape and position of an object by measurements on photographs obtained with a central projection. Since two or more roentgenograms of the same object recorded consecutively or on different occasions are seldom identical, it is necessary if they are to provide reliable information to correct them with respect to a reference system or to oriente them with reference to each other. The correction may be performed if the object is plane and if four points on it and in the image are known. It can be done graphically and numerically or by a combined optical and mechanical method.

If the object is three dimensional the projecting bundles of rays are reconstructed; the inner orientation is assumed to be known. Five pairs of bundles of rays are then orientated in perspective positions in relation to one another (relative orientation). In this way a reconstruction of the object is obtained in the form of an "optical model", on which the measurements are then performed.

The photogrammetric method is, however, fairly time-consuming and expensive. It is questionable whether, in measurements on clinical roentgenograms, one has use of the high geometric quality provided by this technique. The cost usually increases with the quality, and as a rule the highest quality will usually be extremely expensive. Before the method is settled upon the requisite quality must therefore always be specified by the person using the results of the measurements.

In this study the tracing and photogrammetric methods were compared.

MATERIAL

This study was performed on 14 subjects who participated in a study entitled "Bone resorption in cases with complete upper denture" (*Wictorin*, 1964). These 14 patients were selected at random. Their profiles of the skull had been recorded on roentgenograms on three occasions at intervals of 3 and 9 months.

Method I

Tracings were performed on the first roentgenogram of each patient. The transfer medium was drawing film on an acetate base (10 A). The nasion with the caudal bony contours of the frontal and nasal bones were registered, as was the anterior nasal spine. The contour of the upper alveolar process was then drawn in. The tracing was orientated in relation to the next roentgenogram in the series. Discrepancies between the reference points, might then be found, possibly manifested in a variation in the distance between the nasion and the anterior nasal spine on the three roentgenograms of a particular patient. The orientation was then adjusted primarily with respect to the anterior nasal spine and the neighbouring points which were situated nearest the alveolar process. The resorption contour was then recorded on the tracing.

In measuring the resorption represented by the distance between the resorption contours, the tracing was inserted in a coordinate system; the axis of y was defined as the line from the nasion tangential to the resorption curve at its most anterior point on the first roentgenogram. The axis of x was defined as the line perpendicular to the y axis and tangential to the same resorption curve at its most caudal point (Fig. 1).

The resorption was measured as the perpendicular distance between the parallel tangents to the corresponding curves.

The measuring instruments consisted of an ordinary plastic ruler graduated in millimetres and a measuring magnifying glass with inlaid scale in tenths of a millimetre. From the expression $[\Sigma\, d^2/2n]^{\frac{1}{2}}$, where d is the difference between the two values, and n is the number of measurements — the average error of the measuring method was calculated as a standard deviation of 0.1 mm. This is an extremely close agreement and the precision may

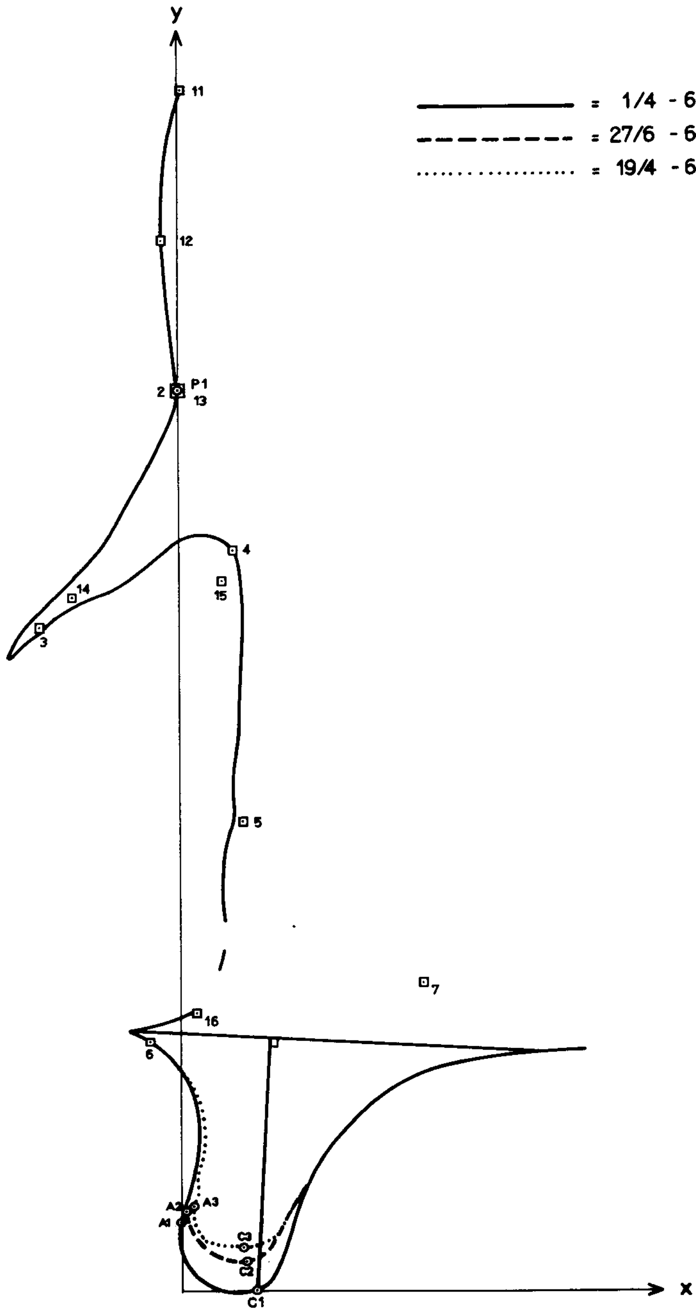

Fig. 1. The plotted profile.

be regarded as high. The individual differences were sometimes as high as 0.2 and 0.3 mm, as would be expected. A measuring glass is to be recommended for measurements on tracings.

The tracings were performed by two trained persons who had experience of the method. The results of the study are given in Table I.

Table I

Resorption values measured by the tracing method by two operators on two occasions. The values are in mm.

Case	Operator I								Operator II							
	Tracing I				Tracing II				Tracing I				Tracing II			
	A_{d1}	A_{d2}	C_{d1}	C_{d2}	A_{d1}	A_{d2}	C_{d1}	C_{d2}	A_{d1}	A_{d2}	C_{d1}	C_{d2}	A_{d1}	A_{d2}	C_{d1}	C_{d2}
C.K.	1.8	2.3	1.8	2.6	1.2	2.0	1.9	2.4	1.3	2.2	1.6	2.3	0.9	1.3	1.9	2.0
J.L.	0.9	1.2	1.3	1.4	0.9	1.6	1.0	1.3	1.2	2.2	0.9	1.4	0.9	1.3	1.0	1.2
M.H.	1.1	2.1	1.2	1.3	0.6	1.3	0.8	1.1	1.2	1.2	0.4	0.4	1.3	1.7	0.6	0.6
K.G.	0.5	1.3	1.6	2.2	1.3	2.4	1.9	2.3	0.7	0.6	1.6	1.4	0.4	1.3	1.3	2.2
P.F.	1.4	2.4	1.5	2.6	1.3	2.5	2.0	2.9	1.2	2.6	2.1	1.9	0.8	1.2	1.5	2.4
E.L.	2.2	2.9	2.2	3.1	1.4	2.1	2.6	3.0	1.1	1.8	2.3	3.2	1.3	1.6	2.2	3.0
A.B.	3.2	4.7	1.7	2.5	2.4	3.1	1.3	2.4	2.7	4.0	1.2	2.1	2.5	3.1	1.8	2.6
B.L.	1.8	2.7	2.2	3.2	2.0	2.3	1.3	3.5	2.0	2.6	2.6	4.8	0.8	1.7	2.4	3.3
G.W.	1.6	2.3	1.6	2.6	2.1	2.7	1.9	2.3	2.1	2.4	1.0	3.9	0.4	1.7	1.3	4.0
L.K.	2.5	4.0	3.2	4.8	2.7	3.9	3.1	4.3	3.1	4.1	3.3	5.0	2.3	4.1	3.9	5.0
A.Br.	2.7	3.6	3.5	3.6	1.4	1.7	3.2	3.5	1.1	1.1	3.2	3.5	0.7	0.8	3.4	3.5
K.F.	1.8	2.6	1.2	3.9	1.3	2.3	1.8	3.7	1.5	1.3	1.8	3.9	0.9	1.3	2.0	4.1
A.H.	0.8	2.5	2.5	2.5	1.6	2.3	2.3	2.7	1.4	2.4	2.6	3.1	1.0	1.6	2.3	2.7
E.Lo.	0.6	1.1	1.8	1.8	0.9	1.0	1.8	2.1	1.0	1.0	1.9	1.9	0.9	1.3	1.9	2.0
Means Group I	1.3	2.0	1.6	2.2	1.1	2.0	1.7	2.2	1.1	1.8	1.5	1.8	0.9	1.4	1.4	1.9
Means Group II	1.9	2.9	2.2	3.1	1.8	2.4	2.1	3.1	1.9	2.4	2.2	3.5	1.2	2.0	2.4	3.4

Method II

The photogrammetric method used in this study has been described elsewhere (*Wictorin,* 1964). It can be divided into the following stages.

(1) Reduction of the roentgenograms by a factor of five to obtain a size suitable for the photogrammetric instruments and to reduce the enlargement by the optical viewing system of the instrument to a value appropriate for clinical roentgenograms. It is also possible to increase the contrast by suitable choice of film, exposure constants and dark-room treatment. Dia-direct reversal film (Gaevert) was used.

(2) Photogrammetric analysis in the A 7 autograph. The reduced films were inserted in pairs in the two film holders, the film corresponding to the first roentgenogram being inserted in the left holder and the second or third film in the right. The two pairs of films so obtained were analysed in the same manner. In the relative orientation it was always the orientation values for the right film holder that were adjusted. This was performed as two translations (b_x and b_y) and a rotation ($\varkappa$) and a scale change (c, projector constant).

When the films had been oriented the resorption was registered in the anteroposterior (A_d) and cranio-caudal direction (C_d).

RESULTS AND DISCUSSION

The resorption values for the two methods and the two tracing operators are given in Tables I and II.

The resorption values differed for the photogrammetric method and the tracing method and for the tracing operators I and II (Tables I and II).

To examine the relationship between the two registration methods the correlation coefficient r was calculated from the expression:

$$r = \frac{\Sigma(x - \bar{x})\ (y - \bar{y})}{n \cdot S_x\, S_y}, \qquad (1)$$

Table II

Resorption values in mm. measured by the photogrammetric method, with means for the tracing method for comparison (calculated from Table I).

Case	Photogrammetric values				Tracing mean values			
	A_{d1}	A_{d2}	C_{d1}	C_{d2}	A_{d1}	A_{d2}	C_{d1}	C_{d2}
C.K.	0.4	0.9	2.1	2.1	1.2	1.9	1.6	2.4
J.L.	1.5	1.9	1.3	1.3	1.0	1.6	1.1	1.4
M.H.	0.5	1.1	0.4	0.4	1.1	1.6	0.8	0.9
K.G.	0.7	1.3	1.5	2.0	0.8	1.5	1.7	2.1
P.F.	0.5	1.5	1.9	2.4	1.2	2.2	1.8	2.5
E.L.	1.1	1.9	2.1	2.5	1.5	2.1	2.4	3.1
A.B.	2.9	3.4	0.8	1.5	2.7	3.8	1.5	2.5
B.L.	0.4	1.3	0.8	1.7	1.7	2.8	2.2	3.8
G.W.	0.4	1.2	0.9	2.0	1.6	2.3	1.5	3.3
L.K.	2.9	3.7	3.5	4.8	2.7	4.1	3.4	4.8
A.B.	2.1	2.4	2.7	2.9	1.5	1.9	3.4	3.6
K.F.	1.9	2.1	1.6	1.6	1.4	1.9	1.7	3.9
A.H.	1.2	2.0	2.7	2.7	1.2	2.2	2.5	2.8
E.Lo.	0.9	1.6	2.0	2.0	0.9	1.1	1.9	2.0

where x and y are the resorption values for the two methods, and S_x and S_y the corresponding standard deviations, calculated from

$$S = \left[\frac{\Sigma(x - \bar{x})^2}{n}\right]^{\frac{1}{2}}$$

While, as Table III shows there was a correlation between the measurement values, the design and performance of the experiment would lead one to expect a higher value for the correlation coefficient ($r > 0.95$). The coefficient found points to considerable discrepancies between the two methods of measurement. It must be borne in mind, however, that the coefficient indicates the strength of the correlation between the two variables but nothing of the cause and effect.

Table III

Correlation coefficients, r, for the photogrammetric and tracing methods. The tracing series consisted of means based on four observations (two operators on two occasions).

Resorption area	r
A_{d1}	0.72
A_{d2}	0.74
C_{d1}	0.82
C_{d2}	0.72

Analyses of variance and regression

To examine more closely the correlation between the two methods of measurement an analysis of variance was performed.

I. — To find whether the tracing method was used with satisfactory precision by the two operators the following calculations were performed.

From the two observations for each tracing operator a precision value s_i was calculated from the expression

$$s_i^2 = \frac{\Sigma\, d^2}{2n}, \qquad (2)$$

where d is the difference between the observations by one operator and n the number of observations. A high value of s_i indicates a low precision.

The following hypotheses were set up:

H_0: The precision was the same for the two operators.

H_1: The precision differed for the two operators.

F was calculated from the expression

$$F = \frac{s_I^2\ (\text{operator I})}{s_{II}^2\ (\text{operator II})}\ \text{Degrees of freedom (14,14)} \qquad (3)$$

The values of F, which are given in Table IV, are not significant except for the value of C_{d_2}, so that when judged on this basis the precision of the two operators did not differ appreciably.

It should also be noted that the precision values (s) were sometimes higher for operator I and sometimes for operator II.

II. — As the operators appeared to work with about the same precision an examination was made of whether the operators obtained statistically different resorption values — that is to say, whether their evaluations of the position of the resorption contours on the films were equivalent. For this purpose the mean of the two replicated resorption values for each operator was formed. The difference (D) between these means was calculated for each subject and for each resorption value. The deviation can be expressed by the formula

$$s_D^2 = \Sigma D^2/n \qquad (4)$$

where n is the number of differences. s_D^2 can be calculated from the primary observations in Table I.

The total tracing variance (precision) for the operators (s_T^2) was calculated from $s_T^2 = \frac{1}{2}(s_I^2 + s_{II}^2)$

The following hypotheses were set up:

H_0: The resorption values traced by the operators were the same.

Table IV

Values of F for the various resorption areas for the precision values of the two operators. For s_I^2 and s_{II}^2 see text.

Resorption area	s_I^2	s_{II}^2	F
A_{d_1}	0.205	0.253	0.81
A_{d_2}	0.335	0.294	1.13
C_{d_1}	0.083	0.066	1.26
C_{d_2}	0.029	0.136	0.21+*
Total	0.163	0.188	0.87

* See footnote on p. 529.

H_1: The resorption values traced by the operators were different.

F is calculated from

$$F = \frac{s_D^2}{s_T^2} \quad \text{Degrees of freedom (14,28)} \qquad (5)$$

As is seen from Table V, on the whole the operators traced the same resorption values. There were, however, differences in the value of C_{d2}, there being a significant difference between the operators. The variance coefficients s_D^2 for A_{d2} and for Total were higher than the value of C_{d2}. In spite of this F is not significantly dependent on s_T^2 being greater than A_{d2} and Total.

It should be pointed out that the discrepancies between the operators as regards the individual resorption values were large in certain cases.

Table V

Values of F for various resorption areas and the tracing values of the two operators. For s_D^2 and s_T^2 see text.

Resorption region	s_D^2	s_T^2	F
A_{d1}	0.257	0.229	1.12
A_{d2}	0.535	0.315	1.70
C_{d1}	0.139	0.075	1.85
C_{d2}	0.304	0.083	3.66++*
Total	0.309	0.175	1.77

It is also conceivable that the operators introduced a systematic error in the tracings of the resorption values. To examine these factors the analysis was taken a stage further.

III. — To find whether the photogrammetric and tracing methods resulted in different resorption values the following regression analysis was performed. The mean for the four tracing values was calculated and denoted by y. The photogrammetric values were denoted by x.

* See footnote on p. 529.

Suppose that the tracing values contain a constant error (m) and a scale error (c).

The following model for the regression analysis was set up:

$$y + v = m + c\,x; \tag{6}$$

where v is an improvement to y to obtain corresponding model values.

Normal equations were derived and solved

$$m = \frac{[y]\,[x^2] - [xy]\,[x]}{n\,[x^2] - [x]^2} \tag{7}$$

$$c = \frac{n\,[xy] - [x]\,[y]}{n\,[x^2] - [x]^2} \tag{8}$$

$$[v^2] = [y^2] - m\,[y] - c\,[xy] \tag{9}$$

By calculating s_0 the difference between the two methods was examined. s_0 was obtained from the expression

$$s_0^2 = \frac{[v^2]}{n - 2} \tag{10}$$

It was tested whether m and c differed from 0 and 1, respectively.

F is calculated according to (*Kendall—Stuart,* 1961):

$$F = \frac{n - 2}{2} \quad \frac{\Sigma\,(y - x)^2 - \Sigma\,v^2}{\Sigma\,v^2} \tag{11}$$

From (7) m was found to be 0.761 mm and from (8) c was 0.771 mm. s_0^2 was 0.409 mm (10). On inserting m and c in (11), F was found to be significant ($F = 9.12$); that is, H_0 is not accepted.

There was thus a constant error (m) and a scale error (c) between the two mensuration methods. The value of s_0, 0.64 mm, represents the discrepancy between the two methods, or — if it is assumed that the photogrammetric method gave true values — the accuracy of the tracing method.

As it was not established that the systematic difference between the two mensuration methods obtained in III was due to

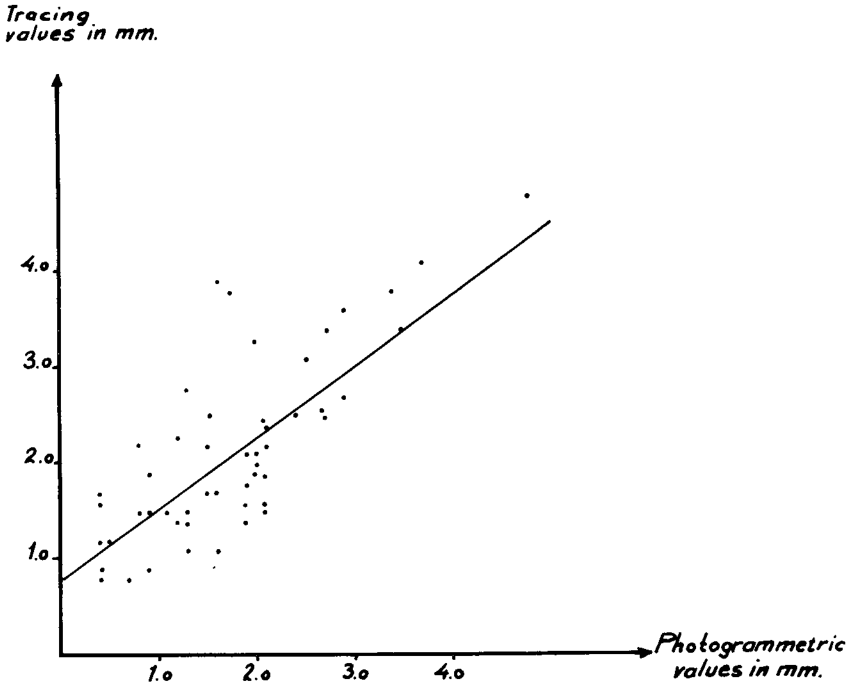

Fig. 2. Regression line for the two series. ($y = cx + m$; $c = 0.771$; $m = 0.761$).

only one of the operators, it was tested whether the mean of operator II's two tracing measurements was statistically different from the photogrammetric values. The procedure was as above (points 6—11).

The values of m and c were found to be 0.653 mm and 0.780 mm. The value of F in (11) was 5.82, which is significant. Thus, the tracing values for operator II were also statistically different from the photogrammetric values and there was a constant error (m) and a scale error (c).

Thus, the presence of a difference between the tracing values for the two operators did not influence the analysis between the two measuring methods.

IV. — If m differs from 0 and/or c differs from 1 it was examined whether the tracing precision s_T for both operators was statistically different from the precision of the photogrammetric method, s_c (*Wictorin,* 1964).

F was calculated from the expression:

$$F = \frac{s^2_T}{s^2_e} \qquad (12)$$

The following hypotheses were set up:

H_0: The precision was the same for the tracing and the photogrammetric methods.

H_1: The precision differed for the tracing and the photogrammetric methods.

F was tested.

The values of F calculated from (12) were as follows:

Resorption region	A_{d_2}	C_{d_2}	Total
Value of F	7.85^{++}	0.92	3.05^{++}

Except for C_{d_2} the values of F were significant.* There was thus for the total material a difference in precision for the two methods.

SUMMARY

A comparison between the tracing method and the photogrammetric method of measuring on roentgenograms has been performed. The comparison was based on the variation in the magnitude of measured resorption values, which was taken to represent the possibility of performing measurements on roentgenograms.

From the correlation coefficients (Table III) it was found that the connection between the methods was not so close as might be expected. This indicates that the methods can give different values and be statistically discrepant.

Since the correlation coefficient expresses only the strength of

* The term significant has been used with reservations. If the ratio between two variances is of such a magnitude that the probability P of obtaning a difference at least as great as the observed value is greater than 0.05 (where the null hypothesis is assumed to hold), then that observed difference is said to be non-significant.

$0.01 < P \leqq 0.05$ probably significant denoted by +

$0.001 < P \leqq 0.01$ significant denoted by ++

$0.001 \geqq P$ highly significant denoted by +++

the correlation and not the structure, a regression analysis was performed.

The precision for the tracing method was high enough for the two operators. There was no significant difference between them.

On the other hand, there was a constant error (m) and a scale error (c) between the resorption values obtained by the two methods, and there was a significant difference in the precisions.

Since the true value is not known it is impossible to draw reliable conclusions regarding the accuracy of the two methods. These factors should be examined.

RÉSUMÉ

MENSURATIONS SUR RADIOGRAPHIES
COMPARAISON ENTRE DEUX MÉTHODES

Une comparaison a été effectuée entre la méthode par tracé et la méthode photogrammétrique. La comparaison était basée sur la variation de la grandeur des valeurs mesurées pour une résorption, devant représenter la possibilité d'effectuer des mensurations sur radiographies.

Les coefficients de corrélation (tableau III) ont montré que la relation entre les méthodes n'était pas aussi proche qu'on l'avait espéré. Ceci indique que ces méthodes peuvent donner des valeurs différentes et ne pas concorder du point de vue statistique.

Etant donné que le coefficient de corrélation n'exprime que l'intensité de la corrélation et non sa structure, une analyse de régression a été effectuée.

La précision de la méthode par tracé était suffisamment élevée pour les deux opérateurs. Il n'y avait pas de différence significative entre eux.

D'autre part il y avait une erreur de constante (m) et une erreur d'échelle (c) entre les valeurs obtenues pour les resorptions par les deux méthodes, et il existait une différence significative entre les précisions.

Etant donné que la véritable valeur n'est pas connue, il est impossible de tirer des conclusions dignes de confiance en ce qui concerne l'exactitude des deux méthodes. L'étude de ces facteurs serait nécessaire.

ZUSAMMENFASSUNG

MESSUNGEN AUF RÖNTGENAUFNAHMEN

Ein Vergleich zwischen der "tracing"-Methode und der photogrammetrischen Methode über Messungen auf Röntgenaufnahmen ist ausgeführt worden. Der Vergleich war auf der Variation bei der Grösse von gemessenen Resorptionswerten basiert, die die Messungsmöglichkeiten bei Röntgenaufnahmen repräsentierte.

Von den Korrelationskoeffizienten (Tabelle III) wurde konstatiert, dass der Zusammenhang zwischen den Methoden nicht so nahe wie erwartet war.

Weil der Korrelationskoeffizient nur die Stärke und nicht die Veranlassung ausdrückt, wurde eine Regressionsanalyse ausgeführt.

Ein konstanter Fehler (m) und ein Skalafehler (c) zwischen den Resorptionswerten der zwei Methoden und eine signifikante Differenz in den Präzisionen wurden auch nachgewiesen.

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Address: *School of Dentistry,*
Karolinska Institutet,
Box 3207, Stockholm,
Sweden.