Computerized Cephalometrics

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A method to analyse cephalometric radiographs with the help of a computer has been described. With the system a cephalometric radiograph can be analysed and the results compared to corresponding analyses of individuals with ideal occlusion. The results can also be visualized as schematic figures of the patients. The computer calculates means and standard deviations of groups of individuals and can visualize the results as mean figures. A program to train operators in pinpointing radiographic reference points has also been developed. A methodological study has shown that the errors of the computerized method are of little importance compared to the errors made in pinpointing radiographic reference points. A clinical test of the system has shown that inexperienced operators are able to use the system after about one hour's training. The method is about twenty minutes faster compared to an ordinary manual radiographic analysis. Some future aspects are also discussed.

Key-words: Roentgenocephalometry; graphics; statistics; education

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The aim of the present work was to develop an on-line computer system for analyses of cephalometric radiographs and to test the described system. The system was not suggested to give an over-all assessment of an orthodontic case with growth prediction like the RMDS system (10) proposed by Ricketts (9). The system was merely supposed to facilitate routine cephalometric analyses and biometric studies in connection with orthodontic education and clinical work.

Digitizers and graphical screen terminals are commercially available and can easily be connected with a main computer by ordinary telephone lines. Therefore such outfits can be used as peripherial units at acceptable costs and the system is thereby available for several users. Furthermore such units are becoming more and more common in different disciplines and the combined use for several applications has reduced the costs considerably. A similar IBM-system has been described (5), but apart from the costs the IBM system is difficult to modify for our local specifications and statistical analyses. The system proposed by Walker (11) is too comprehensive to be routinely used in an orthodontic clinic.

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DESCRIPTION OF THE COMPUTER SYSTEM

The reference points used on the radiographs are given in Fig. 1 and Table 1. The goals for the system were:

1. To analyse single cephalometric radiographs and compare the results with corresponding analyses of individuals with ideal occlusion.
2. To standardize and visualize the results on-line in order to give the possibility for immediate correction thereby reducing the errors in data entry.
3. To visualize the results of the analyses by drawing schematic figures which also, as it should be on-line, gives a possibility to immediate correction reducing the errors in data entry.
4. To be able to calculate means and standard deviations of groups of individuals and subsequently visualize the results as mean figures.
5. To create the possibility of superimposing schematic figures and thereby visualizing the differences.
6. To create a program in order to train members of the staff and students in pinpointing radiographic landmarks.

The user directs the system by giving the computer commands from the keyboard of the terminal. The analyses start with marking the reference points on a tracingfilm. This tracingfilm will be put on a graphic tablet. Thereafter the points will be marked with the marking pen belonging to the digitizer unit and are then entered into the system as coordinates. The results of the analyses, angular and linear measurements, are immediately available on the screen. They can also be transferred either to a plotting device or to a line-printer.

The computer used is a NORD 10 with a word length of 16-bits (= binary digits). Floating point numbers are represented by three full words (i.e. 48 bits). The program is written in standard FORTRAN and uses a memory of about 45 k words.

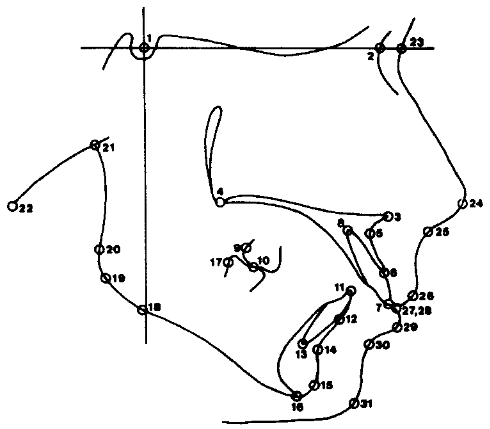

Fig. 1. Reference points on the radiographs (of Table 1).

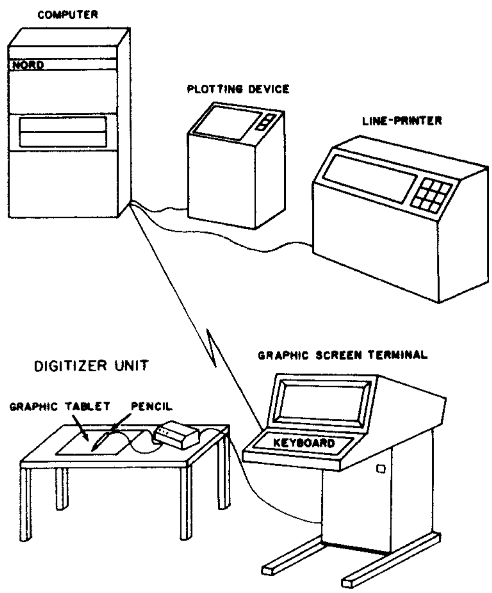

Fig. 2. Hardware units used in the computer system.

Apart from the standard peripheral units – like line-printers and disc-storage – the system uses a Tektronix 4012 graphic screen terminal, a Tektronix 4953 digitizer unit (Tektronix AB, Fack, S-171 04 Solna) and as a hardcopy unit and paper plotting device a Versatec 1200A printer/plotter using an electrostatic method (Saven AB, Box 49, S-185 00 Vaxholm). In the present study all the equipment was located on the premises

Table 1. *Code number, abbreviation, definition of the reference points and reference lines used in the present system of analysis (of Fig. 1)*

Point	
1 S	The center of sella turcica
2 N	Nasion
3 Sp	Spina, the apex of the anterior nasal spina
4 Pm	Pterygomaxillare
5 A (ss)	Subspinale
6 Pr	Prosthion
7 Is	Incision superius
8 –	Apex of the most prominent upper incisor
9 –	The most posterior point on the distal surface of the crown on the maxillary first molar
10 –	The most inferior point of the disto-buccal cusp of the maxillary first molar
11 Ii	Incision inferious
12 Id	Infradentale
13 –	Apex of the most prominent lower incisor
14 B (sm)	Supramentale
15 P	Pogonion
16 Gn	Gnathion
17 –	The most posterior point on the distal surface of the crown of the lower first molar
18 –	The point where the mandibular line touches the distal part of the lower border of the mandible
19 Go	Gonion
20 –	The inferior tangent point of the tangent to the posterior contour of the mandible
21 Ar	Articulare
22 Ba	Basion
23 –	The point where the SN-line crosses the soft tissue line
24 A	Apex nasalis
25 Ss	Sulcus superior
26 Ls	Labrale superior
27, 28	The contact point between the upper and the lower lip. When the lips are kept together this point is marked twice, otherwise the inferior and the superior points of the lipcontours are marked
29 Li	Labrale inferior
30 Si	Sulcus inferior
31 M	Menton
Reference lines	
ML	Mandibular line
OL	Occlusal line. A line from point 10 through a point in the middle of the distance $I_s - I_i$
S–N	Sella – nasion line
SNP	Sella – nasion perpendicular. The perpendicular to S-N through sella.
SpPm	Nasal line

of the computer department at the Karolinska Institute. In the future, though, the digitizer unit and the graphic screen terminal will be located in the orthodontic department of the Eastman Institute connected via ordinary telephone lines to the central computer.

The digitizer unit consists of a "pencil" and a graphic tablet. It can not be used with back illumination. Such units exists but are usually more expensive. One is thus restricted either to use tracings or to use projectors for ordinary X-ray films (both methods are used at the Karolinska Institute). The units used in the investigation are represented schematically in Fig. 2.

The program

When the operator runs the program the first line that will be displayed on the terminal screen is: "Put in your command "1" for help". Entering the digit 1 results in a list of available commands with the numbers 1 to 11 which could be used to select subprograms (Table 2).

Command 2 ("registration"). The registration procedure starts with the inputting of points according to Fig. 1. It is however necessary to answer a question first regarding the actual scale factor of the picture and a second question whether the soft tissue should be registered or not. Thereafter the marking procedure begins with the point 1 (S), and the point 2 (N), which establishes the orthogonal coordinate system with the origo in S and the X-axis towards N.

After defining the coordinate-system the marking re-starts from point 1 and continues with the other reference points in numerical order. If the soft tissue measurements are to be calculated there are 31 points to be marked, else 22. During the marking procedure the operator can give some commands to correct mistakes, for instance by restarting from a given point or by controlling movement of the tracing during a session. When the marking procedure is completed a schematic cephalometric drawing will appear on the terminal screen. Angular and linear measurements will be printed in digital form on the display. If the result of the registration is considered to be acceptable, the coordinates will be stored on a direct access file. The registration of one picture takes about one minute.

Command 3 ("read earlier patients") is used to recover coordinates of earlier registered and stored pictures.

Command 4 ("values") gives the values of the measurements for patients which have been read under the command 3 (Table 3).

Command 5 ("plot on screen") visualizes the results by drawing schematic figures of pictures which have been read under command 3 or constructed under command 9 ("mean patients").

Table 2. *Commands available in the system*

1 . . .	Help
2 . . .	Registrate a patient
3 . . .	Read earlier patients
4 . . .	Values
5 . . .	Plot on screen
6 . . .	Plot on versatec
7 . . .	Which are read?
8 . . .	Training
9 . . .	Mean patient
10 . .	Arbitrary values
11 . .	Finish

Command 6 ("plot on Versatec") plots a similar geometrical figure to command 5 with the advantage of having the same size as the original radiograph. It can therefore be superimposed on the radiograph to test the precision of the registration procedure. This plot can also be used to visualize mean figures or differences between pictures superimposed on the S-N line (Fig. 3).

Command 7 ("which are read") gives information on which patient numbers have been read under command 3.

Command 8 ("training") is used to train members of the staff and students in pinpointing radiographic landmarks. Some given radiographs can be marked according to the principles given under command 2. These radiographs, which have been carefully registered in advance, and the actual registrations are compared with one another. The program thereby tells if the markings are acceptable or not.

Command 9 ("mean patient") calculates mean values and standard deviations for a specific group of radiographs. It is possible to calculate these values on two groups at the same time and to visualize the differences between the groups by using command 6. All statistical calculation are performed according to conventional formulae.

Command 10 ("arbitrary values") gives the user the possibility of measuring arbitrary angles and linear measures with any re-

Table 3. *The print of an analysis of a single subject. X is the actual value, $\bar{x}$ and s are the mean and the standard deviation of the reference group. For explanation of the abbreviated reference points, see Table 1. Observe though, that the numbers used are symbols of the teeth, not of reference points. All linear measurements are computed in the orthogonal coordinate system with the origo in S and the X-axis towards N. The Y-axis is called SNP*

Angular measures	X_i	$\frac{X_i - \bar{X}}{S}$
SNA	80.2	- 0.5
SNB	76.3	- 1.1
ANB	3.9	0.8
11, 21/SN	106,5	0.5
41,31/ML	102.0	0.7
SN/SPPm	5.2	- 0.6
SN/OL	14.9	- 0.8
SN/ML	31.0	- 0.2
Gonionangle	123.3	0.5
Linear measures		
Horizontal		
16,26 – SNP	23.7	0.9
Is – SNP	65.1	1.6
I_i – SNP	60.9	1.2
Is – I_i	4.2	2.2
46,36 – SNP	24.5	1.2
A – SNP	62.7	1.6
B – SNP	50.1	0.4
Vertical		
S – GN	111.2	3.1
SP – GN	60.3	2.2
S – 16,26	62.4	3.1
S – 46.36	71.0	4.4
Is – Ii	5.4	1.9
Soft tissue measures		
Horizontal		
Ss – SNP	77.0	1.8
Ls – SNP	76.6	1.3
Li – SNP	71.7	1.5
Si – SNP	63.2	1.4
Vertical		
Ss – Si	34.1	0.6
Ss – Ls	11.7	0.3
Li – Si	10.3	1.9

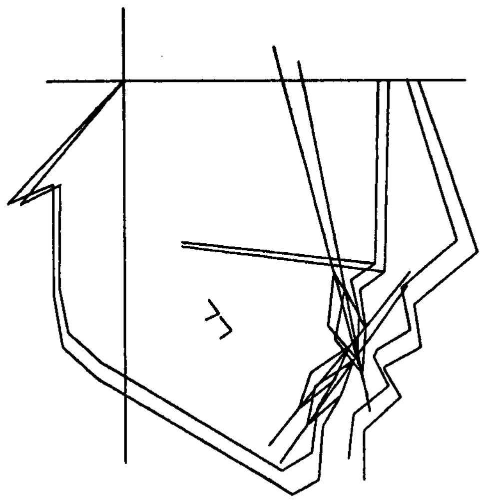

Fig. 3. Computer drawing based on the mean values from two age groups of the reference material. The drawings of each age group are superimposed on the S-N line.

gistered points on requested patients. Mean values and standard deviations are calculated.

Command 11 ("finish") is used to stop the program.

METHODOLOGICAL STUDY

The limitations of cephalometrics are mainly concerned with the lack of accuracy in pinpointing radiographic landmarks and the often dubious biological significance of these landmarks (1, 2, 3, 4, 7, 8). Marking the points inducing the coordinate system (S, N) is of particular interest because errors thereby effect all measurements. The way the operator holds the marking pencil and puts this pencil on the plotting board also involves a risk of making errors. However, the system has the advantage of using inbuilt controlling possibilities. The operator can control his markings continuously during the registration on the graphical screen. After the registration he can plot a schematic drawing of the result and superimpose it on the original radiograph.

The purpose of the methodological study was to analyse the error of the computerized method of measuring on radiographs compared to earlier strictly manual methods.

MATERIALS AND METHODS

The measuring errors were calculated in three trials. The first trial concerned the accuracy of transferring points from the tracing film via the digitizer to the computer and included the rounding errors of the computer. Four dentists made ten repeated registrations each on the same tracing with the use of the marking pencil at the digitizing board. The variances of all angular and linear measurements for the different dentists were calculated according to conventional formulae.

The second trial concerned the accuracy of pinpointing the reference points on the radiographs. The material consisted of five cephalometric radiographs randomly selected from the files of our clinic.

The errors of the method, which included the errors described in the first trial, were estimated by double registrations of the reference points of the five radiographs by five different dentists. All the reference points were transferred to the computer by one of the dentists. The accidental error of specific value, V, on double determinations was calculated according to the formula:

$V_k = \Sigma d_i^2/2n$, where d_i is the difference

between two measurements, n is the number of double determinations and the index k is one of the measurements from Table 3. In spite of the fact that standard deviations are mainly used in the medical and in the odontological literature as dipersive measures, variances are presented in this paper. This is due to two causes: a) variances can simply be added to get a total error and b) variances are the most common measure in technological literature.

The third trial was to calculate the errors in angular and linear measurements that would appear if point 2 (N) (this point defines the coordinate system) were misplaced within a circle with the radius of 1 mm.

RESULTS

The variances of all measurements, according to Table 3, calculated for each dentist are summarized in classes with the interval 0.25 (with mm and degrees squared for the linear and the angular measures respectively). The frequency of variances in the different classes for the first and second trial are illustrated in Figs 4 and 5 respectively. The second trial is furthermore illustrated with separate histograms for angular, linear and soft tissue measurements (Fig. 6), all measurements according to Table 3. It can be seen from the histograms that most of the variances of the angular and linear measurements, due to errors when transferring reference points to the computer and to rounding errors in the computer, are mainly in the class 0–0.25. The errors made when pinpointing the reference points are much greater – up to a maximum of 3.25. Thus the errors made when pinpointing the references points strongly dominate the errors of the method.

The result of the third trial showed that the angles were not influenced by the misplaced point 2 (N) and the linear measures differed with a maximum of 1.5 % from the accurate values.

A CLINICAL TEST OF THE SYSTEM

A clinical test of the computerized system was performed by six dentists who were undertaking orthodontic training. None of them had any earlier experience with com

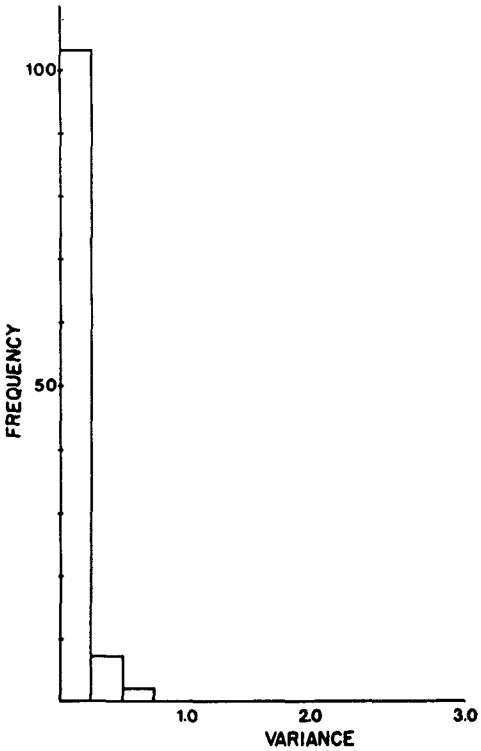

Fig. 4. Histogram showing the variance found in the first trial concerning the accuracy of transferring points from the tracing film via the computer unit. Absolute frequency is represented on the y-axis.

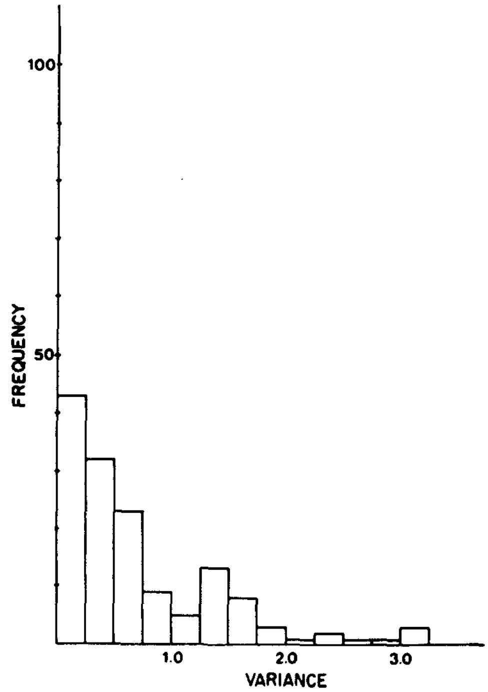

Fig. 5. Histogram showing the variance found in the second trial concerning the total error of the method. Absolute frequency is represented on the y-axis.

puters. They were introduced to the method by studying a manual (6) and by the help of an instructor. This introduction took about one hour. After this short training they were all able to use the system and perform all the described commands. They were then told to give their opinion of the method in a questionnaire. The results of the evaluation have been published (6), but some aspects are reviewed here.

All dentists were satisfied with the system and the user interface. They estimated the time saving component to be about 20 minutes when compared with an ordinary manual radiographic analysis. They thought that the plotting could be done by a dental nurse or other assistent personell after some training. Finally they considered the method, at the present time, suitable for research projects and follow up studies of treated patients, although no reference materials had been included in the system at that time.

DISCUSSION

There are many advantages of the computerized method of cephalometric analyses in connection with orthodontic education and biometric studies. First of all, it speeds up and standardizes the collection of measurements from radiographs. Second, it simplifies the analyses of the collected data and makes it easier to store these data. Third, the presented method visualizes the results of the analyses as schematic figures thereby facilitating the description of results. Mean values and standard deviations

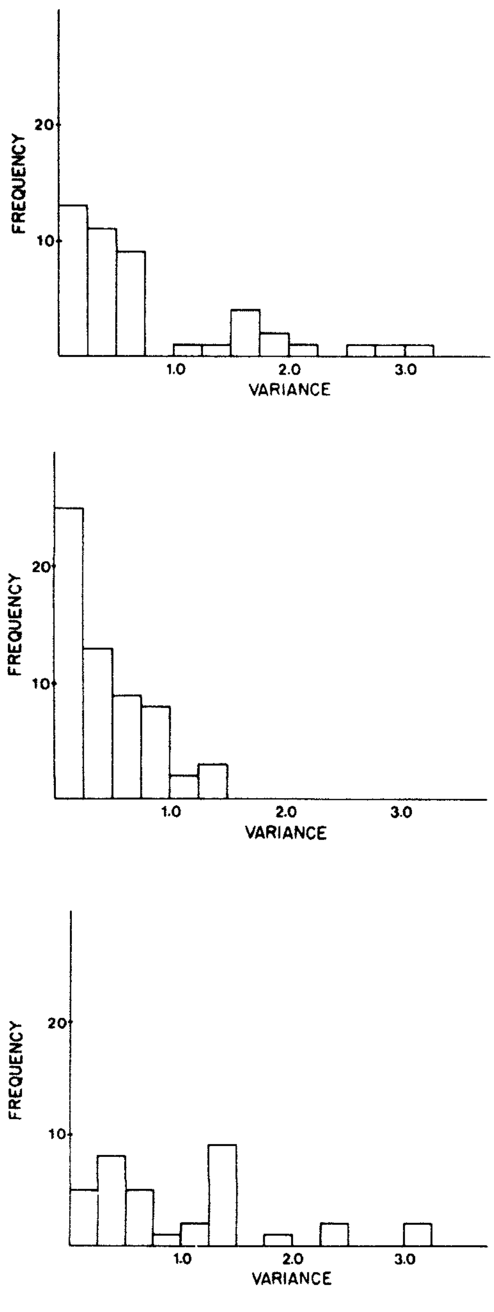

Fig. 6. Histograms showing the variances for the angular measurements (a), linear measurements (b) and soft tissue measurements (c) in the second trial. Absolute frequency is represented on the y-axis.

for groups of patients are easily calculated and visualized.

The restrictions of computerized cephalometrics are only the limitations inherent in the radiographic technique itself. The lack of accuracy in pinpointing the radiographic landmarks has been pointed out by many authors. The errors found in the methodological study were of the same magnitude as those found by other authors (1, 4, 7, 8). The methodological study has also shown that the accuracy of transferring the reference points from the tracing film with the digitizer to the computer is good and the small errors that are produced are of little importance. The use of mean values from four repeated registrations of one radiograph in order to minimize the effect of the errors in pinpointing reference points has been proposed (2). We are also going to use the technique with repeated pinpointing of landmarks in further studies. First, one operator marks the twenty-two or thirty-one reference points on the tracing film. With the use of this tracing film two other operators independently check the first markings. All three operators then make the final decision of the placement of the markings which thereafter are transferred to the computer.

If some of the analysing time saved by the use of the computer is spent on repeated registrations of landmarks, the analysing results can be more accurate than with ordinary manual analysing methods. The training program included in the system will contribute to more standardized and accurate analyses.

It is evident that the inherent possibilities of modern interactive computer systems with graphics and the involvement of system programmers in the projects will open advantages, all of which cannot be foreseen. Some aspects should, however, be mentioned:

– the presented system makes more accurate determinations of linear and angular measures possible at a much reduced cost.

- the immediate and extensive comparison with earlier measurements does not only contribute to more accurate values but also to earlier and better clinical decicions.
- the growing and easily accessible data base of cephalometric measurements makes a continuous follow-up possible. Predictions for different therapeutic methods can then be adopted more quickly in clinical practice.
- training in and standardization of cephalometry are made possible to an extent which in earlier completely manual evaluations, from practical and economical points of view, could not be realized.
- "spin-off" effects in adjacent areas are likely to occur when the basic methods on a "general" computer system have been developed.

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