On-Line Computer System for the Analysis of Cephalometric Radiographs

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Computerized cephalometrics has come to be regarded by some orthodontists and researchers as an all-embracing final answer to our orthodontic diagnostic and growth prediction problems, and by others as the death knell of the "cephalometric numbers game." Both these extreme stands are counterproductive and, when modified, would seem to suggest that the rapidity of data handling and the inherent strict and uniform logic involved in data preparation for the computer would be a most useful additional aspect to the technique of radiographic cephalometrics.

The limitations of computerized cephalometrics would seem to be largely the limitations inherent in the radiographic technique itself. The use of two-dimensional records only, i.e., lateral and frontal cephalometric radiographs, poses the major biological limitation and is present due to our difficulty in visualizing suitable common landmarks in these views. Growth and treatment changes are three-dimensional phenomena and can only be approximated in somewhat general terms from a two-dimensional record. An additional, if more subtle problem, is that we also assume that growth and treatment changes are linear in nature, whereas these changes usually are curvilinear, again on a three-dimensional basis. The lack of accuracy in pinpointing radiographic landmarks and the often dubious biological significance of these landmarks remain a limitation irrespective of whether the data are computerized or not.

A computer system for instant retrieval and analysis of cephalometric records at various stages of the treatment of a patient would be of value in diagnosis, as well as for clinical decision-making during the treatment process. Cleall and Chebib[2] suggested a computerized method for the analyses of orthodontic data digitizable into coordinates in two dimensions. The computer programs developed at that time required the digitization of the records onto punch cards and later batch processing of these punched cards (a time-consuming method where one submits the cards at the local computer center and waits at least several hours for the cards to be processed). The present study describes a dynamic interactive system whereby the records are digitized directly into the computer (and most errors noticed and corrected immediately) and then, from a remote terminal in one's office, various analyses and facial plots can be retrieved in an immediate conversational manner and at any desired moment.

An on-line computer system "Cephalometric Records Analysis Program" (C.R.A.P.) was developed with the primary objective of immediate clinical analysis of cephalometric radiographs for diagnosis and case progress assessments. It is not suggested that the computer alone, regardless of how sophisticated its programming, can give an over-all assessment of an orthodontic case and, as such, this system is not comparable with Rickett's conception of computerized diagnosis.[6] The system

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Fig. 1 Teletype and digitizing equipment installed at the University of Manitoba. Radiographs are digitized and transmitted into the main computer via city telephone lines.

in its present form allows for 1,024 current patient records having a total of 2,048 cephalometric records. It was originally built into the University of Manitoba IBM 370 computer system using three disc files and 120K core space. The system has also been installed with updates into the University of Illinois Chicago Circle Campus' IBM 370. The program is called via the TSO (Time Sharing Option), an IBM conversational system installed at both of these universities.

The program allows for entering new patients, entering coordinates of cephalometric records, retrieving old patients, and analyzing their cephalometric records by several standard analyses, such as Downs,[4] Tweed,[7]

Fig. 2 Administrative records of patients are updated through a television-type terminal (Vucom) located at the reception area.

Fig. 3 Portable computer terminal may be used in the clinic or office to obtain reports on the patient.

Wylie,[9] and others, as well as any special analysis that the clinician may wish to perform.

Any one of several types of remote terminals may be used to access the system from various locations connected to the IBM computer by existing city telephone lines. At the University of Manitoba a teletype (Fig. 1) connected to a Ruscom Digitizer is used to enter the coordinates of the cephalometric records, as well as obtaining hard copies of standard analyses. A television-type terminal (Fig. 2) is located at the clinic reception area to enter new patients and obtain information regarding current patients. A portable terminal (Fig. 3) is used in the clinic proper or at various locations for diagnostic purposes. An IBM 2741 terminal (Fig. 4) is used mainly for program testing and on-line plotting of the cephalometric records. With the exception of the plotter connected to the IBM 2741 and the digitizer connected to the teletype, these four types of terminals are used for these various func-

Fig. 4 An IBM 2741 terminal is used for programming and on-line plotting.

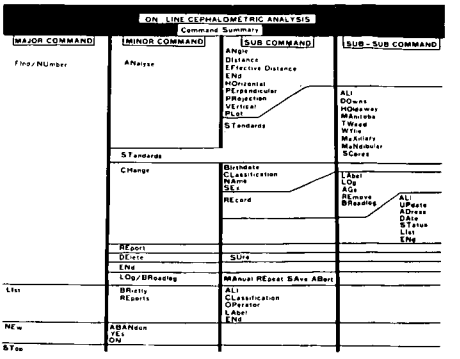

Fig. 6 The command summary for the on-line cephalometrics analysis system.

tions interchangeably. Alternative hardware, including a graphpen digitizer and Hazeltine terminals with rapid printing giving faster transmission rates, is being installed at the University of Illinois (Fig. 5).

The capabilities of the system may be enumerated through an examination of Figure 6 which shows a summary of the commands available. The capitalized letters, the first two of each command, suffice as an abbreviation of each command.

The major commands (seen in left-hand column) provide the possibility to add new patients to the records, search for and retrieve old ones, or obtain lists of selected patients. A new patient is entered by name, and the computer then assigns a number (between 1 and 1,024). The appropriate general information about the patient is recorded, including sex, birthdate, and classification. All patient records are kept on a direct access disc file. As

Fig. 5 Digitizing equipment used at the University of Illinois. A graph-pen digitizer and a television-type terminal (Hazeltine) connected to a fast thermoprinter may be seen.

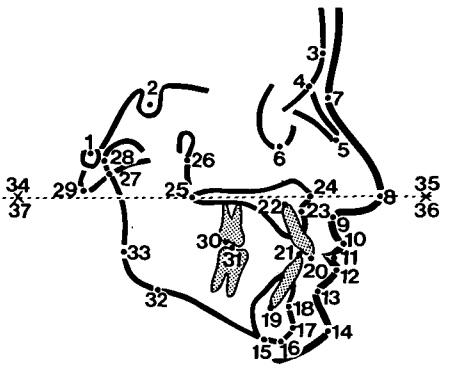

Fig. 7 Thirty-three landmarks are used for the regular cephalometric analysis. Maxillary and mandibular analyses require two axes defined by points 34 through 37.

a new patient is entered into the system, it is subjected to a checking procedure where the computer will warn the user of all other patients with similar last names that have already been entered into the system, lest a patient be entered twice.

This patient record, thereon, is retrievable either by the patient's name (major command FIND), or by his number (major command NUMBER). During the searching procedure, if the entered name of the patient does not completely match any of those in the system, the computer yields a printout of all patients whose first four letters of the last name match the required patient.

A list of several patient reports may also be requested using major command LIST. This is most useful in a university clinic where an immediate rapid patient list can be retrieved under such headings as: type of case, who is treating the patient, or the stage of treatment.

Once a patient is retrieved by FIND or NUMBER, minor commands, ANALYSE, STANDARDS, CHANGE REPORT, DELETE, LOG, and BROADLOG are available. These commands are described in the following sections:

Minor commands LOG and BROADLOG: These two minor commands allow for the digitization of preselected thirty-seven landmarks (Fig. 7). Rather than digitize the vast number of coordinates suitable for morphological growth research[8], it was decided to digitize only those radiographic landmarks used in conventional radiographic cephalometrics. This reduced the time for routine clinical evaluations required to digitize each radiograph and permits the addition of other coordinates, for example, multiple soft tissue landmarks for the analysis of cinefluorographic research.[1] The thirty-seven points that are digitized have been selected to provide for most of the conventional cephalometric analyses, as well as for localized analyses such as tooth movement. These latter are based on the "best fit" system using palatal outlines and mandibular landmarks similar to our conventional treatment assessment techniques. The coordinates of each landmark are recorded by the digitizer and transferred through the terminal to the computer's memory directly without the use of a tracing or punch card. Two correction factors are built into the system for a radiographic magnification of 9% (minor command LOG) or 7% (minor command BROADLOG) depending upon the cephalometer used. While all measurements are corrected for magnification, this procedure is reversed in specific cases, such as the linear data of the Wylie analysis, so that the printout gives measurements comparable with the standards, or when plotting back the templates, so that the plot will be of equal size as the original radiograph.

At the completion of "logging" a cephalometric radiograph, it is dated by age of the patient when the radiograph was taken, as well as by a label showing the stage of treatment. The

labels selected are "A" for pretreatment, "P" for progress records, "B" for the record taken at the end of the active treatment, "C" for the radiograph taken at the end of retention, and "D" for two or more years postretention.

Upon digitization the record is automatically corrected for magnification and standardized by rotation along the SN line, and stored on a computer disc file.[2]

The minor command CHANGE allows for changing information already entered about the patient, such as birthdate, classification, name, sex, changing the cephalometric record or information pertaining to a cephalometric record. General information in the patient's file such as the address or phone number, etc., are also updated. Altering incorrect coordinates of one or more landmarks if these are found to be incorrectly digitized from superimposition of the radiographs on the plotted template or removal of a cephalometric record are also possible in the various sections of subcommand RECORD of this minor command (Fig. 6).

Minor command DELETE allows for the permanent deletion of a patient (and his cephalometric records) from the computer. This procedure is protected by a secret password against accidental deletion of patients and the records.

Minor command REPORT allows for the production of a complete report concerning the administrative information relative to the patient. This area of the program is most useful in a teaching clinic where it forms the basis for the patient control system, irrespective of whether any radiographs are to be analyzed or not.

Minor command STANDARDS allows for complete analysis of all the patient's cephalometric records by one or more of the standard orthodontic analyses which have been built into the system. They are shown in the sub-subcommand section: Downs, Holdaway, Tweed, Wylie, Illinois Maxillary, Mandibular, Manitoba analysis and Factor Scores analysis as well as ALL standard analyses. Downs,[4] Holdaway,[5] Tweed,[7] Wylie[9] analyses are well-known to orthodontists. The Maxillary and Mandibular analyses are designed to assess tooth movement during treatment. A simple tracing of the maxillary and mandibular outlines, excluding the dental areas, the pterygomaxillary fissure, and any cancellous spaces in the palatal area, but including the inferior dental canal and symphyseal details is made. An approximate palatal plane is located and two pin holes are made through the tracing and the original radiograph. Using a "best fit" system on the maxillary and mandibular outlines, these pin holes are transferred to the subsequent radiographs and become landmarks 34, 35, 36, and 37 (Fig. 7). The computer superimposes on these points of registration and permits changes in the relationship of the dental units to be assessed.

The Manitoba and Illinois analyses include a series of angles and distances selected to describe the facial structures and, along with the standard values, are used for teaching. The factor scores analysis is based on a principal component analysis of 600 patients whereby each patient is described by six factor scores.[3] All coefficients and methods for the calculation of all components of these standard analyses are programmed into the system; it is possible to obtain instant analysis on any standard system as required (Fig. 8).

Minor command ANALYSE allows for additional analyses that the researcher or clinician may wish to examine. Such analyses may be requested by entering the subcommands: ANGLE,

DISTANCE, EFFECTIVE DISTANCE, HORIZONTAL, PERPENDICULAR, PROJECTION, or VERTICAL, followed by the identification of the landmarks involved. An ANGLE may be requested by the three points which define it, where the center point establishes the angle to be read, or as the angle between two lines, each line defined by two landmarks. The DISTANCE is simply the linear measurement between two landmark areas. The EFFECTIVE DISTANCE is the distance between a landmark and the point of intersection of two lines one of which includes the landmark. The HORIZONTAL distance is the linear measurement between two landmarks as projected on the SN line or any line parallel to SN. The PERPENDICULAR distance is that distance measured perpendicularly from a point to a line defined by two other landmarks. PROJECTION is the distance between two landmarks as projected on any other line defined by two other landmarks. PROJECTION is more general than HORIZONTAL in that any line, not just SN, may be used. Hence, HORIZONTAL is a special case of PROJECTION. The VERTICAL distance between two landmarks is the length of the line connecting two landmarks projected onto a line perpendicular to SN. Hence, VERTICAL is also a special case of PROJECTION.

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DOWNS ANALYSIS

MEASURE	MEAN	S.D.	A 1134	P 1203	B 1213	C 1313	D 1507
FACIAL ANGLE	87.80	3.51	82.61	82.13	83.95	83.78	81.32
CONVEX ANGLE	3.0	4.49	8.66	6.43	4.22	4.64	4.79
A-B PLANE	-4.80	2.33	-7.93	-6.52	-4.76	-5.09	-4.71
MAND. PLANE	21.93	4.80	34.93	30.64	31.13	32.45	31.62
Y-AXIS ANGLE	59.40	3.33	63.21	63.41	62.54	65.60	65.36
OCCL. PLANE	9.50	3.50	12.95	13.76	11.58	9.46	11.18
UI - LI	135.40	9.15	123.41	111.37	113.32	119.17	125.37
LI - OCL. PL	144.50		115.96	121.26	119.94	122.79	114.93
LI - MP	91.40	7.89	98.32	134.38	130.39	99.80	94.47
UI - AP	2.70	1.79	4.57	8.22	7.33	5.82	5.66

HOLDAWAY ANALYSIS

MEASURE	MEAN	S.D.	A 1134	P 1203	B 1213	C 1310	D 1507
SNA	80.80	3.43	79.39	78.18	77.40	77.53	77.86
SNB	78.00	3.41	74.63	74.16	74.65	74.57	74.96
ANB	2.80	1.64	4.79	4.32	2.75	2.95	2.91
LI - NB	4.35	2.81	5.75	6.87	7.28	6.27	5.54
P - NB	1.81	1.32	1.45	1.66	1.43	1.40	1.24

MANITOBA ANALYSIS

MEASURE	MEAN	S.D.	A 1134	P 1203	B 1213	C 1310	D 1507
FACIAL ANGLE	85.97	3.51	82.61	82.13	83.95	83.78	81.32
CONVEX ANGLE	4.99	4.49	8.66	6.43	4.22	4.64	4.79
SNA	81.95	3.43	79.39	78.18	77.40	77.53	77.86
SNB	78.99	3.41	74.66	74.16	74.65	74.57	74.96
ANB	2.96	1.64	4.79	4.32	2.75	2.95	2.91
MAND. PLANE	25.59	4.80	33.93	30.64	31.13	32.45	31.62
SN - PG	79.55	3.57	75.43	75.45	75.43	75.33	75.61
SN - MP	32.33	5.46	38.47	37.72	39.64	37.91	37.32
P - NB	1.81	1.32	1.45	1.66	1.43	1.40	1.24
UI - LI	127.14	9.15	123.41	111.37	113.32	119.17	125.37
UI - SN	103.53	5.51	103.49	126.83	126.95	103.13	102.84
UI - AP	5.92	1.79	4.57	8.22	7.33	5.82	5.66
LI - MP	97.31	7.39	98.32	134.38	100.39	99.80	94.47
LI - AP	2.71	1.74	2.37	4.47	5.84	3.95	3.29
LI - NB	4.85	2.21	5.75	6.87	7.28	6.27	5.54

TWEED ANALYSIS

MEASURE	MEAN	S.D.	A 1134	P 1203	B 1213	C 1313	D 1507
LI - MP	90.00		98.32	134.38	130.39	99.80	94.47
LI - FH	65.00		51.68	44.98	48.48	47.75	53.91
MAND. PLANE	25.00		30.93	30.64	31.13	32.45	31.62

WYLIE ANALYSIS

MEASURE	BOY	GIRL	A 1134	P 1203	B 1213	C 1313	D 1507
GL - SELLA	18.00	17.0	17.81	19.78	19.48	18.87	19.73
SELLA - PTM	18.00	17.0	21.66	21.25	20.93	19.91	19.84
MAX. LENGTH	52.00	52.0	49.73	53.84	55.06	54.39	55.21
PTM - U6	15.00	16.0	13.38	9.87	14.13	14.40	13.55
MAND. LENGTH	103.00	101.	101.68	106.97	108.92	106.89	109.57
WYLIE SCORE	2.0	3.0	0.10	3.33	0.73	3.32	2.26
TOT.FACE HT.	115.00	113.	117.34	123.49	123.13	123.69	125.61
UPP.FACE HT.	50.10	48.8	50.33	51.18	52.42	53.18	53.21
LOW.FACE HT.	64.60	64.1	67.01	69.32	70.71	70.50	72.59
UFH/TFH	43.60	43.2	42.89	42.47	42.57	43.00	42.33

MAXILLA ANALYSIS

MEASURE			P-A	B-A	C-A	D-C	D-A
UI(VERTICAL)	22.00	EXTD	-1.68	-2.99	-2.86	2.28	-3.58
UI (HORIZON.	25.00	PROT	5.16	4.59	1.38	1.22	2.59
UI-PAL. PL.	125.00	PRCL	7.94	10.22	6.37	-2.78	3.59
UI - O.P.	47.00	PRCL	1.07	0.43	-5.04	0.58	-4.46
O.P-PAL PL	15.00	DPUA	6.87	9.78	11.41	-3.36	8.35
UM(VERTICAL)	28.00	EXTD	1.22	2.12	3.48	0.19	3.67
UM(HORIZON.)	65.00	MESL	-1.97	0.23	0.53	-0.40	0.13
ARCH LENGTH	36.00	INCR	6.43	3.42	-2.17	1.79	1.62

MANDIBLE ANALYSIS

MEASURE			P-A	B-A	C-A	D-C	D-A
LI(VERTICAL)	22.00	EXTD	0.32	1.39	2.95	3.53	3.48
LI(HORIZON.)	26.00	PROT	1.81	2.84	1.68	-0.76	0.92
LI - M.P.	61.00	PRCL	5.31	3.20	1.57	-5.23	-3.66
LI - O.P.	62.00	PRCL	5.30	3.98	6.82	-7.89	-1.06
O.P-M.P.	15.00	DPUA	-0.21	0.78	5.25	-2.66	2.59
LM(VERTICAL)	19.00	EXTD	0.41	1.18	0.26	1.82	2.08
LM(HORIZON.)	72.00	MESL	-1.41	0.16	-3.05	1.51	1.45
ARCH LENGTH	36.00	INCR	3.24	1.80	1.53	-2.20	-0.67

F.SCORES ANALYSIS

FACTOR	A 1134	P 1203	B 1213	C 1313	D 1507
FACTOR 1	-8.98	4.91	5.30	5.17	6.21
FACTOR 2	-5.34	-6.93	-5.36	-6.21	-3.72
FACTOR 3	-1.51	-2.91	-1.84	-2.32	-3.41
FACTOR 4	-1.31	-0.46	-1.49	-2.56	-3.03
FACTOR 5	1.18	-3.24	-3.24	3.37	1.63
FACTOR 6	1.38	-1.66	-3.16	-1.49	-2.45

Fig. 8 A sample output of the standard analyses for a patient.

The final subcommand of ANALYSE is PLOT which allows the production of a template of the cephalometric record required on paper via the on-line plotter (Fig. 4). This is useful in some research projects, or routinely for checking against the original radiograph for errors in digitizing the data, and for quickly viewing a patient's progress.

The major command LIST, as mentioned earlier, allows one to obtain selected listings of patients (either BRIEF listings or DETAILED reports of patients) selected according to classification, operator, or stage of treatment.

A prompting message listing the options available to the user at the time may be obtained at any time during the

use of the system by simply entering a blank (null) line.

Installing such a system requires a medium to large size computer, the availability of direct access disc storage, and an interactive system such as the time sharing TSO, CP/CMS, etc.

Although this system may be used for certain research projects, it has been designed as a patient-oriented diagnostic and patient-control system. It is not designed, therefore, to be used for mass analyses of large numbers of subject or subpopulation studies. The data stored in coordinate form may, however, be available for such studies by specially designed programs to obtain specific analyses. In this regard computer-punched cards containing the digitized data may be obtained and used for analyses not built into this system, e.g., batch studies on samples of the data. In addition, a CALCOMP plotter located at the computer center may be used to produce accurate templates of the cephalometric records of specified patients.

This system, although designed for analysis of cephalometric data, may be used with little or no modification for the analysis of any type of research data capable of being introduced to the computer in a digital, x, y coordinate form (e.g., histology, photographs, orthodontic models, etc.).

In summary, a simplified on-line computer-aided cephalometric analysis system has been presented. This will permit standard cephalometric analyses to be made and can be modified for individual operator's analysis. The system would be useful in large practices or in institutions where the hardware cost of approximately $10,000 could be justified.

The system speeds and standardizes a somewhat tedious orthodontic operation, but still demands that the orthodontist make the important diagnostic decisions. The system is most useful for universities but must, in the authors' minds, never replace the learning experience of training and analyzing cephalometric radiographs manually, as it must always be remembered that radiographic cephalometrics itself is only an aid to diagnosis and provides us with some clinically useful, albeit incomplete, information relating to craniofacial morphology.

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