Coordinate Analysis Applied to Orthodontic Studies

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Many experiments designed to investigate problems or to produce basic information useful in orthodontics involve handling masses of detailed quantitative data. Analysis of cephalometric radiographs on a cross-sectional basis[1] or longitudinally for growth studies[2] or to assess treatment changes requires the accurate determination and measurement of the positions of specific radiographic landmarks. This type of data would fall into the above category. Similarly, but with increased data handling problems, would be the sequential frame analysis or other radiographic data obtained from cinefluorographic films involving functional studies of swallowing,[3] speech,[4] head posture and mastication. Any attempt to study the growth of bone quantitatively in experimental animals, e.g., with vital stains[5] or radiographically, etc., may also result in large amounts of detailed measurements requiring statistical processing.

Taking the problem one step further in which many parameters are to be studied coincidentally in a single study, for example, cinefluorographic sequences of jaw closure and swallowing, cephalometric radiography, physiographic cinematography and study model analysis, the vast amount of subjective and quantitative data requiring analysis engenders not only much tedious tracing and recording, but also a tendency to introduce large errors.

The various types of data described, while in themselves giving very different information and involving different subjective values when it comes to interpretation, have one thing in common, namely, that selected points are plotted and their interrelationships are measured either in a linear or angular manner. Group means and measures of variability are required and the interrelationships of several variables must be able to be computed. The purpose of this paper is, therefore, to suggest a system of standardized data processing applicable to these various types of experimental material.

Materials and Methods

All records must be in a form suitable for the localization of specific points, for example, the position of radiographic landmarks on a cephalometric radiograph or tracing, or cinefluorographic film frame, the anatomical details of a histological slide, or landmarks on a dental study model. The "x" and "y" coordinates are then recorded for each of these points in a set sequence. It is unimportant as to what method is used to record the coordinates; readings may be taken directly from the dial gauges of a cinefluorographic motion analyzer, a calibrated microscope stage, radiographs of oriented dental models or a strip of chart digitizer (Fig. 1). The x-y coordinates are then recorded on tape or cards using a key punch in a set sequential manner with provision for "missing data."

The data are now in the form of coordinate values which relate each point to each other for an individual's record. However, before grouped data can be compared, these individuals' data must be processed to give means and a measure of the variability. As the tracings or histological slides, etc., will be randomly oriented, a technique must

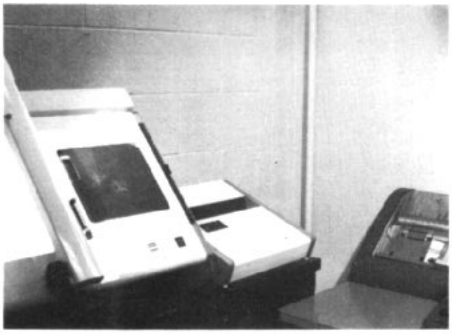

Fig. 1 Showing a strip chart digitizer and IBM key punch.

be devised to permit valid "pooling" of the coordinates.

A computer program was developed to calculate the necessary parameters from sets of coordinates obtained from individual's records of varying orientation and elevation. The program mathematically superimposes the sets of coordinates on a given point, performs simultaneous rotations around that point in a given direction, and calculates standardized coordinates for the points of each sample. It also calculates means and standard deviations of the standardized coordinates of each point, the distances between points and of the values for selected angles, and performs plots of individual templates and a template plot of the means.

Mathematical Basis

The coordinates of the landmarks of each individual's record are transformed to standardized coordinates based on a common set of axes. These axes are predefined by a point of origin and a directional point common to all records and chosen by the user. The axes for each record are shifted to the point of origin and rotated around it so the positive direction of the x axis passes through the directional point (Fig. 2). The standardized coordinates for any point may, therefore, be calculated as:

$$X_S = (X - X_O) \text{ Cos } a + (Y - Y_O) \text{ Sin } a$$

$$Y_S = -(X - X_O) \text{ Sin } a + (Y - Y_O) \text{ Cos } a$$

where:

X_S, Y_S are the coordinates of the point on the new axes,

X, Y are the coordinates of the point on the original axes,

X_O, Y_O are the coordinates of the point of origin on the original axes,

and a is the angle of rotation defined by $\tan a = (Y_D - Y_O) / (X_D - X_O)$

where X_D and Y_D are the original coordinates of the point of direction.

These relationships may be inferred from Figure 2.

Since some of the standardized coordinates will have negative values, a constant, XS, may be added to all standardized X coordinates and another, YS, to all standardized Y coordinates. The standardized coordinates of the new point of origin will, therefore, be XS and YS.

In this manner coordinates taken from different individual's records will be comparable and amenable to analysis by various statistical methods.

The calculations of distances and angles from coordinates are based on

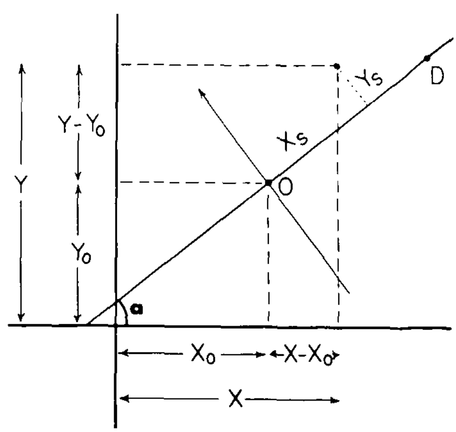

Fig. 2 Showing the trigometric basis for standardizing the sets of coordinates obtained from any group of individuals' records.

standard trigonometrical formulae and are independent of the references axes.*

The Computer Program

The computer program was written in Fortran IV and is used in the University of Manitoba IBM 360-65 computer system. It can with little effort be modified to suit other computer systems. Listing of the source statements and the users instructions are available by request from the authors.

The program requires a core storage of approximately 130,000 bytes and can handle a maximum of 50 landmarks per sample. The number of samples per data sets and the number of data sets which may be processed at any one time are not limited. The main features of the program are as follows:

Coordinates

Standardization of coordinates of each landmark to a common set of axes.

Calculation of mean and standard deviation of the standardized coordinates for each landmark.

Checking on the coordinates causing a listing of landmarks whose coordinates do not conform with the coordinates of the other samples.

Distances

Two types of distances may be calculated: 1) a distance defined by two landmarks and 2) a distance of a landmark to a straight line connecting two other landmarks.

For each type of distance the mean and standard deviation of the selected distances are calculated. In addition, similar distances are calculated from the mean coordinates.

Angles

Two types of angles may be calculated: 1) an angle defined by three landmarks and 2) an angle formed at the intersection of two straight lines defined by four landmarks. For each type of angle the mean and the standard deviation of the selected angles are calculated in addition to similar angles calculated from the mean coordinates involved.

Plotting

Plots of the landmarks (template) after standardization of the coordinates may be produced for each sample. A template drawn from the mean coordinates (Fig. 3) may also be produced.

Other Features

The program can handle missing observations, thus the number of samples used in the calculation of the means and standard deviations of coordinates, distances and angles is also produced.

A conversion factor (inches to centimeters) is also built in the program and may be used when needed. Similarly, a correction factor to allow for magnification errors (e.g., in cinefluorographic work) is needed.

A simple example of the use of the program is given in the concluding section.

Cephalometric Study of Normal Occlusion

Sample 1 (Early Mixed Dentition)

The first sample consisted of twenty-one Caucasian Winnipeg boys and girls (ten males and eleven females) whose ages ranged from 6 to 8 years. These patients had just erupted both upper central incisors and had normally developing Class I occlusions (as far as it was possible to assess at this age). Cephalometric radiographs were taken in occlusion.

Sample 2 (Permanent Dentition)

The second sample consisted of twenty-five Caucasian Winnipeg boys and girls (eleven males and fourteen females) whose ages ranged from 11.5

* The main computational formulae used may be obtained from the authors upon request.

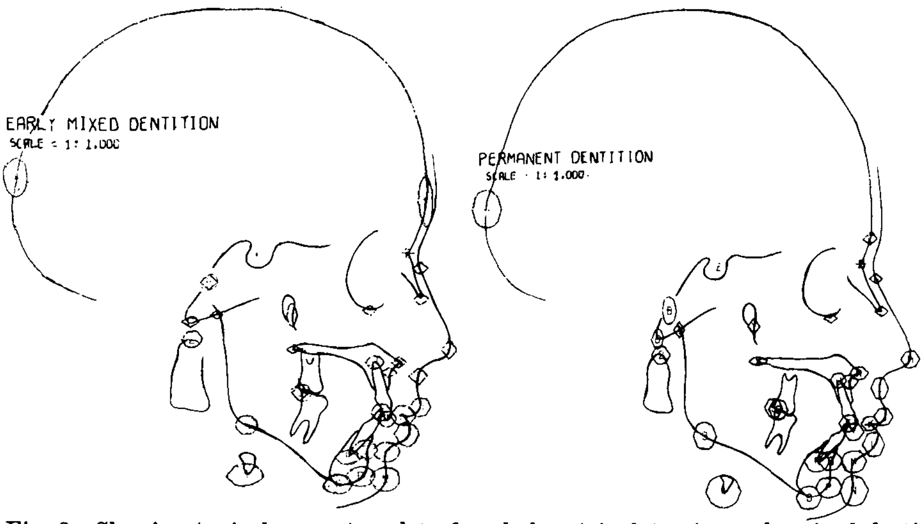

Fig. 3 Showing typical computer plot of cephalometric data. An early mixed dentition group (left) and an early permanent dentition group (right) are shown. The irregular outlines around each landmark represent the standard deviations of each coordinate measurement. The appropriate anatomical details have been drawn in free-hand.

to 12.5 years. All patients had second molars erupted and presented with excellent Class I occlusions. Cephalometric radiographs were taken in occlusion.

The radiographs for both samples were analyzed on a strip chart digitizer (Fig. 1). The coordinates of thirty-three radiographic landmarks were recorded (Fig. 3). Each radiograph took approximately 3 to 4 minutes to be read and punched by a trained technician; a total of approximately 3 hours was required to record the data. C.P.U. time was 0.4 minutes, and the time to transfer the data from the computer print-out sheets to mean tables required 45 minutes. The total time after processing the cephalometric radiographs was 3 hours 45.4 minutes. This represents a great saving in time for the analysis of this type of group data.

TABLE I

Normal Manitoba Cephalometric Data

	Early Mixed Dentition		Permanent Dentition	
Measurement	Means	S.D.	Means	S.D.
Facial Angle	87.2	3.1	84.0	3.9
Angle of Convexity	6.6	4.8	5.9	4.6
SNA	80.3	3.3	83.0	3.2
SNB	76.8	3.4	79.7	3.2
ANB	3.4	1.8	3.4	2.0
Mand. Plane Angle	23.3	5.8	27.6	6.1
U.1 to L.1	130.6	9.9	122.6	9.5
U.1 to SN	101.7	6.6	105.9	4.5
U.1 to AP (mm)	4.6	1.6	6.9	1.9
L.1 to Mand. Plane	4.2	8.1	10.1	8.7
L.1 to AP (mm)	1.4	1.4	3.6	1.8
L.1 to NB (mm)	3.5	1.7	6.1	2.2
P to NB (mm)	0.4	1.2	1.1	1.0

The normative data produced are shown in Table I.

SUMMARY

A computerized system for obtaining standardized data from various types of records often obtained in orthodontic practice or research was developed. The processed data so obtained can be used to compare one designated group with another or to compare the records of a given individual with normative data.

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