COMPUTERIZED CEPHALOMETRICS

by

JOHN MAMUTIL

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My parents,
to whom I attribute my humble achievements,
through their countless sacrifices.

CHAPTER ONE

INTRODUCTION

"Anything that can be measured can be computerized, and anything that can be weighted or scaled can be put back into a feedback system of logic. Scientific analysis, and overwhelming data are available to support the current programs. Greater understanding is available not only with regard to the central tendencies, but with the exceptions that are recognized. As soon as exceptions became identifiable, individual propensities were determined and programmed."

Robert Ricketts (1978)

The assessment of craniofacial dimensions is not a new skill in orthodontics. The earliest methods assessed facial proportions from an artistic point of view with beauty and harmony as the guiding principles. However, the judgement of beauty changes both with time and different cultures, and these principles change likewise.

Work on cephalometrics has its associations with anthropology which in turn dates back to classic times. However, its association with computerization spans just over a generation. It is interesting to note that computerized cephalometrics had its origins at around about the same time as the birth of computing, whilst the application of computers to many other disciplines had a more gradual exposure. One may surmise from this observation that cephalometrics in the 1950's was already regarded as a science which required automation in its quantification, storage and analysis.

The earliest work on computerized cephalometrics is claimed by Walker (1972) who together with Krogman between 1963 and 1967 used computers to digitize cephalograms. Their work was inspired by developments in New Zealand in the late 1950's whereby "shapes" were quantified and reduced onto punch cards. Ricketts (1981) likewise started his series of computer investigations in 1965. He felt that the complexities involved in three dimensional analysis, and studies into growth, lent themselves to the application of computer technology.

Ricketts (1972b) in an overview of computerized cephalometrics suggested six questions as a form of justifying his part in the development of the Rocky Mountain Data Systems (RMDS). His thoughts of that time are still relevant today and in fact may be answered in the light of today's technology with its greater ease and greater accessibility.

His queries were:

1. Why is cephalometrics important to contemporary orthodontics?
2. Why is the computer needed to supplement the clinical application of cephalometrics?
3. Why is an organization almost mandatory for the ultimate application of computerized cephalometrics?
4. What are the features of a computerized program?
5. How is the orthodontist to use or apply this tool for the benefit of himself and his patients?
6. Is there a scientific basis for a computer program and what changes are necessary for computer application?

The above issues justified the establishment and maintenance of the RMDS which apart from providing a service to orthodontists in the form of analyses of study models and cephalograms, also formed the basis of a vast database of individual craniofacial dimensions. The database then formed the basis for studies into growth prediction and the establishment of normative analyses.

As computerization became more accessible, other research groups developed computer systems for their own purposes using a range of hardware and software.

This treatise attempts to collate some of the material used in computerized cephalometrics and investigate the problems involved both historically and those which we face with current technology. Some of the current, popular cephalometric software packages will be reviewed and compared and suggestions made as to possible improvements in their design. Finally, the Appendix includes the source code to the author's own digitization routines and a suggested format for archiving cephalometric data. In doing so it is expected that the questions posed by Ricketts (1972b) will be addressed to rationalize the use of computer technology as applied to cephalometrics.

CHAPTER TWO

CEPHALOMETRIC RADIOGRAPHY

A careful study of a subject involves various degrees of analysis depending on the depth of the study. The Macquarie dictionary (1985) defines "analysis" as the process of separating or resolving a thing into its constituent parts or elements. Looking back into the Renaissance, Durer analysed the human face by dividing the face into quadrants and determining its ideal proportions. Many centuries later, his method was applied to the analysis of cephalometric radiographs by de Coster and Moorrees (Rakosi, 1982). Cephalometry - the scientific measurement of the dimensions of the head - was the first method to prove of value in orthodontics. It was introduced under the name of "gnathostatics" in 1922 and was used to assess craniofacial growth and determine treatment responses. From this developed cephalometric radiography.

The first x-ray pictures of the skull in the standard lateral view were taken by Pacini and Carrera in 1922. Since then a number of others produced this type of radiograph but it was not until 1931 when Hofrath and Broadbent simultaneously and independently developed standardised methods for the production of cephalometric radiographs. This they did using special holders known as cephalostats which permitted a standardised assessment of growth and of treatment response, as well as having diagnostic potential. Broadbent's pioneering work was followed by a number of people who developed a wide range of analyses to be applied to these x-ray images.

2.1 The Basis of Radiographic Cephalometrics - Landmarks

In order to perform measurements of the cephalograms - it was necessary to identify, locate and create landmarks or reference points on the x-ray images of the head. Initially, this was accomplished by borrowing identified anthropological points and planes such as the Frankfort Horizontal. As more and more analyses were developed, new points or landmarks were developed to establish measuring points. A prime example of this is the work by Walker (1972) who plotted 177 points on a lateral cephalograph in order to digitize it.

Cephalometric landmarks are not defined anatomical landmarks, but for simplicity's sake may be defined as conveniently located points on an x-ray, which may be either anatomical or constructed. Reproducibility is another important criterion for a cephalometric landmark.

2.2 Classification of Analyses

The basic elements of analysis are angles and distances. Measurements (in degrees or millimetres) may be treated as absolute or relative, or they may be related to each other to express proportional correlations. According to Rakosi (1982), the various analyses that have been proposed over the years may be grouped into the following:

a. Angular - dealing with angles,

b. Linear - dealing with distances and lengths,

c. Coordinate - involving the Cartesian (X,Y) or even 3-D planes,

d. Arcial - involving the construction of arcs to perform relational analyses.

These in turn may be grouped according to the following concepts on which normal values have been based.

a. Mononormative analyses - averages serve as the norms for these and may be arithmetical (average figures) or geometrical (average tracings on a transparent sheet). The Bolton Standards (Broadbent et al, 1975) are an example of the latter.

b. Multinormative - for these, a whole series of norms are used, with age and sex taken into account, eg. Bolton Standards.

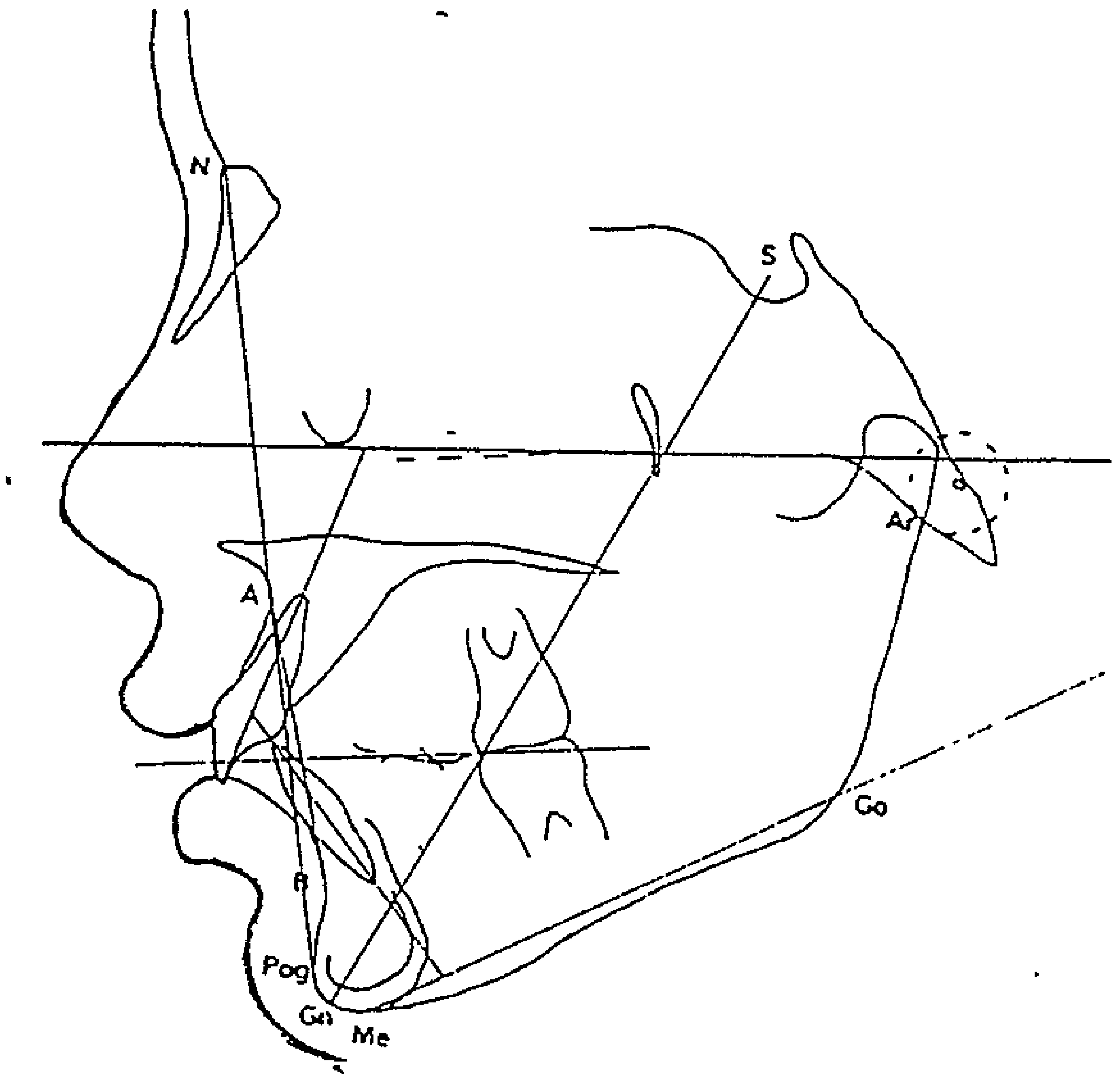
c. Correlative - used to assess individual variations of facial structure to establish their mutual relationships, eg., Sassouni's arcial analysis.

2.2.1 Angular Analyses

Downs (1948) presented one of the earliest of the comprehensive analyses in which various angles are considered in isolation and compared with "norms" or average figures.

The Downs' analysis was based on a study of 20 individuals (age range 12 to 17 years) with excellent occlusions. He used 10 figures and angles to determine the deviant aspects of a person's occlusion and skeletal pattern. Downs also pointed out that these measurements should be analysed as a whole rather than individually and should take into account type, function and esthetics. The Y axis was used to determine direction of facial growth.

Vorrhies and Adams (1951) made a graphic representation of Downs' data by plotting the ranges for each measurement on a "Wigglegram" (fig. 2.1). Downs was able to use this "Wigglegram" in a study on dentofacial profiles as a graphic method of comparing individuals to the norms.



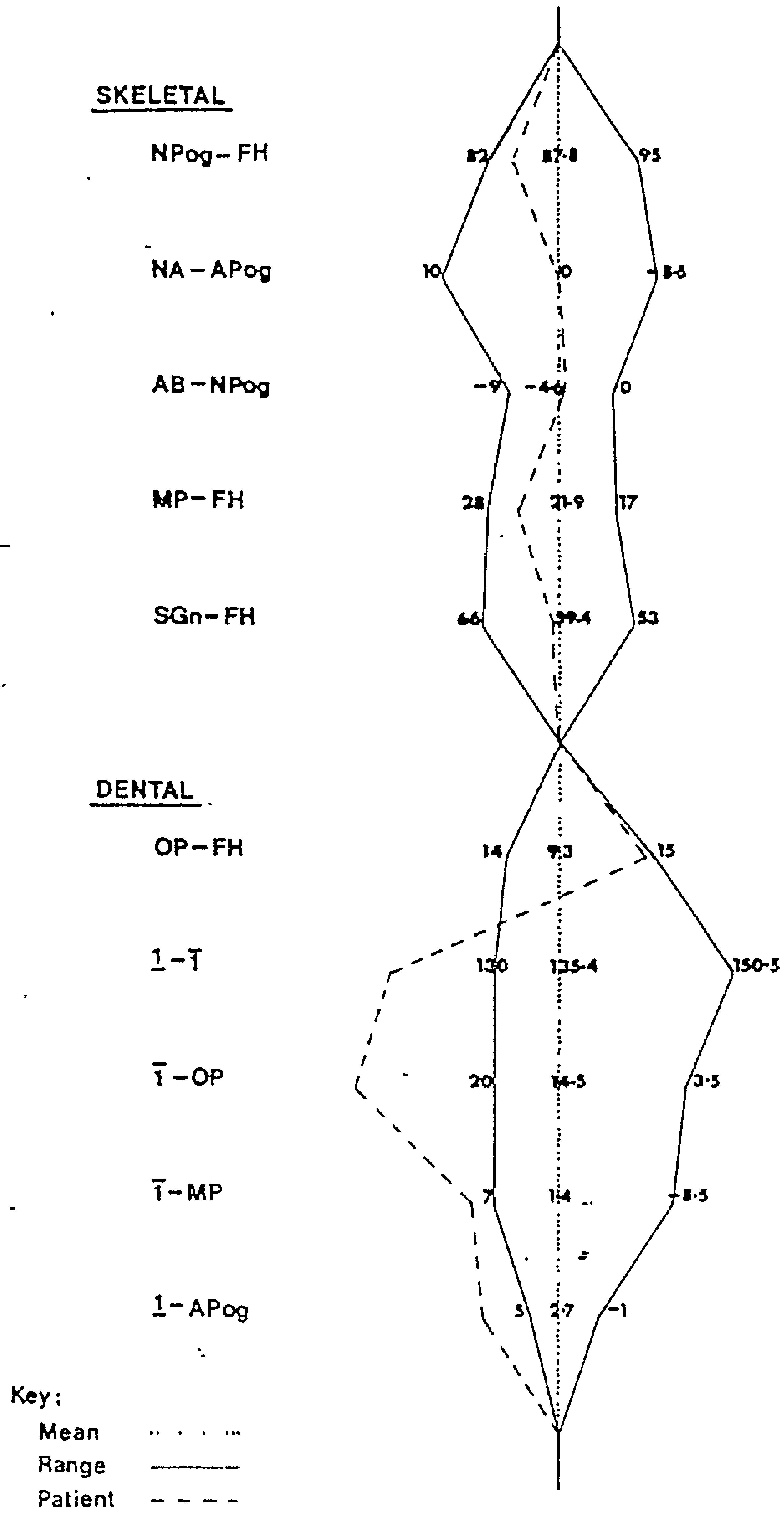


Fig. 2.1
The Downs analysis and associated Wigglegram. (from Brown, 1981).

The Steiner analysis (1953) is profile orientated and provides visualization of incisor position and facial profile (fig. 2.2). The antero-posterior skeletal discrepancy is obtained from the ANB difference (Riedel, 1952).

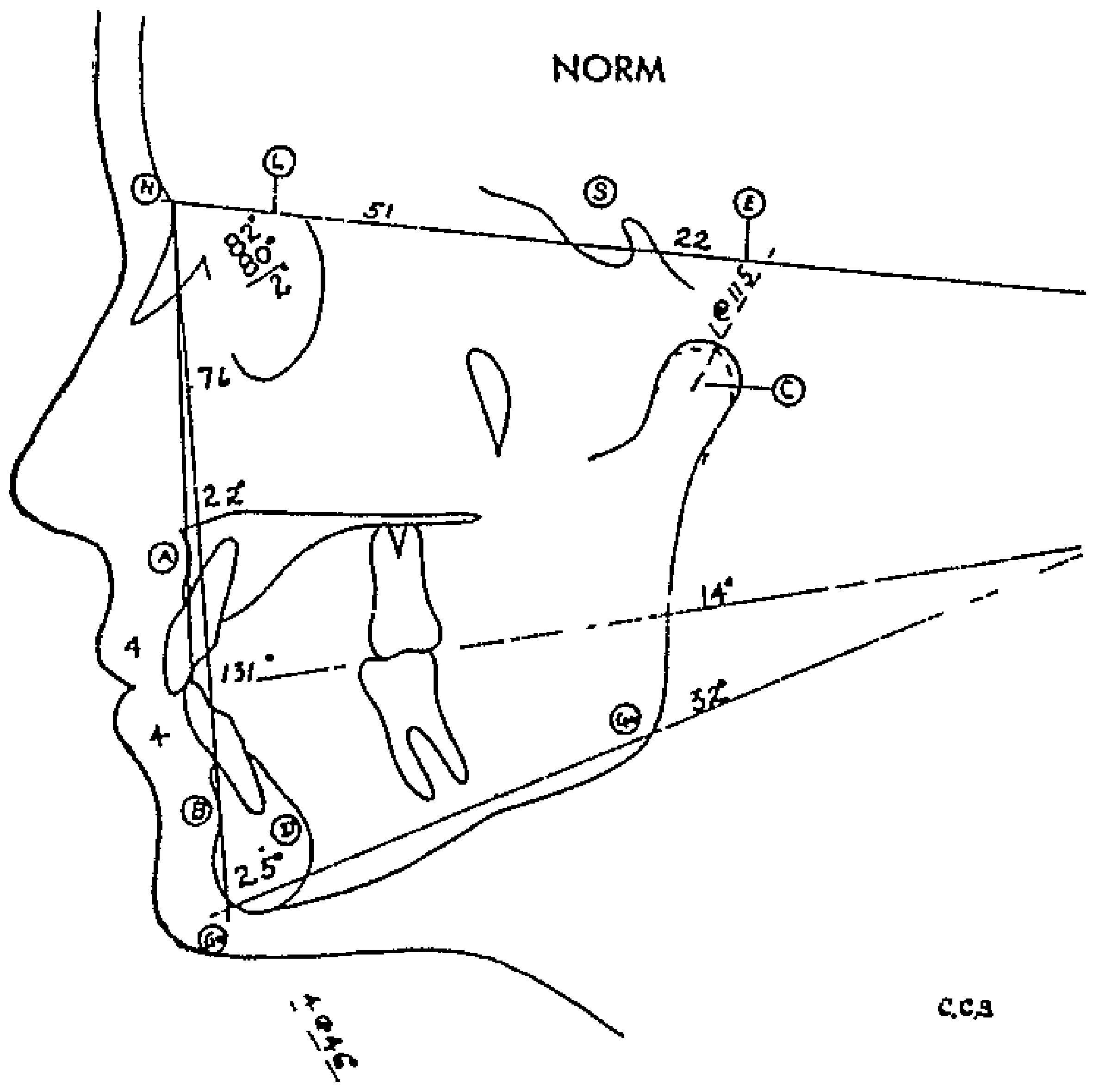
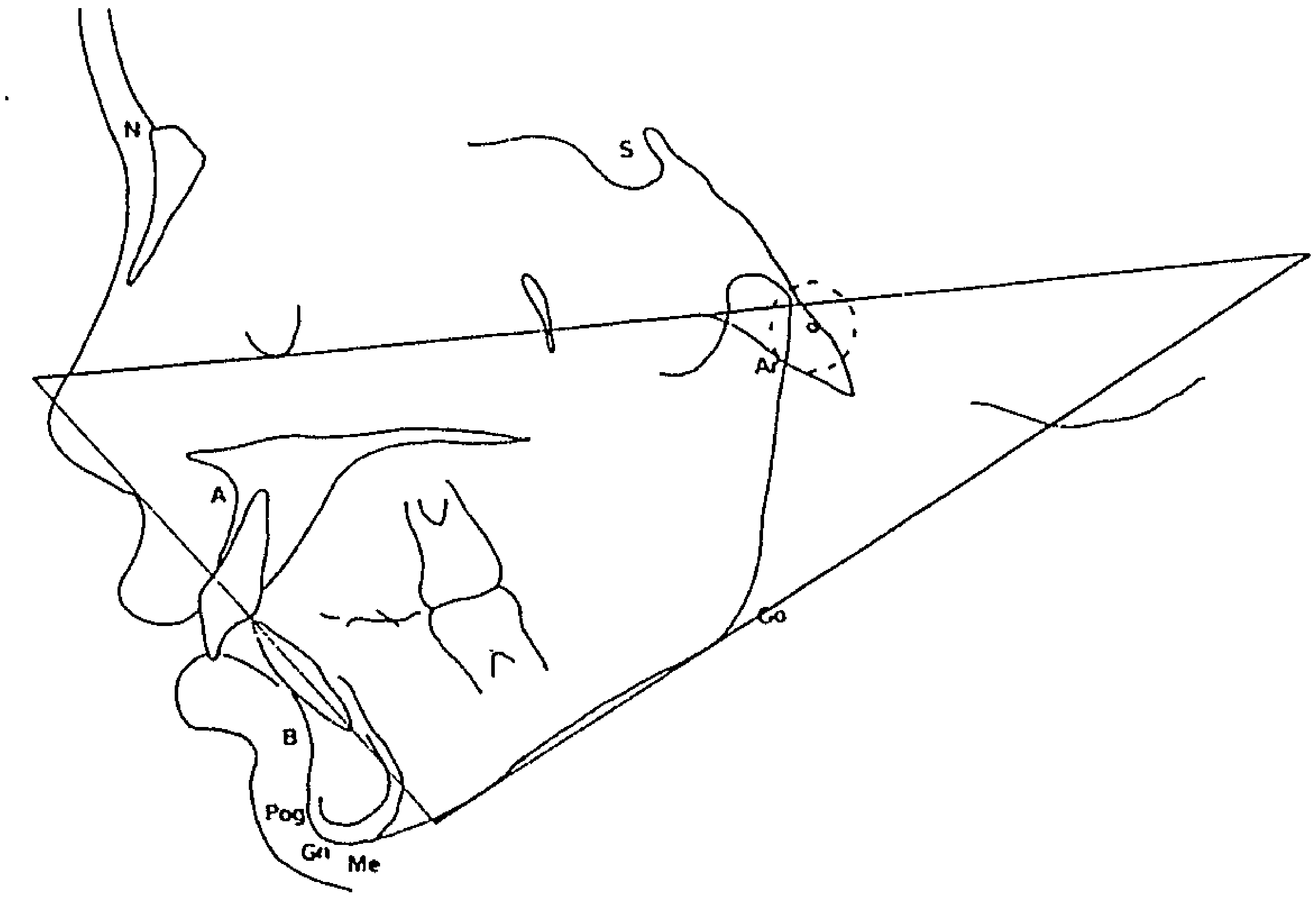


Fig. 2.2 The Steiner analysis, together with normal values (from Steiner, 1959)

The **Tweed analysis** (Tweed 1954) is basically a clinical treatment planning analysis. It establishes the prognosis of treatment on the basis of the Tweed triangle, which is formed by the Frankfort, mandibular and lower incisor axis planes. The angles contained by the triangle are used to calculate the optimal position of the lower incisors (fig. 2.3). Tweed stressed that this was only a treatment aid and not a total analysis.

Angular analyses do not have the problem of magnification of the x-ray images but they do have certain deficiencies. The lines are drawn in relation to a primary reference plane, on the premise that this remains constant. If this plane shows deviations from the mean, the analysis is not reliable. Measurements are often related to particular norms or mean values. These norms are subject to a number of factors such as age, sex, hereditary and ethnic predisposition and so on. They are based on averages, and in the individual case it is the deviation from the mean that is characteristic.



Tweed analysis.

Tweed analysis

If FMA=16–28°	Prognosis is good
If FMA=28–35°	Prognosis is fair
If FMA=35° and over	Prognosis is bad
If FMA=16°	Recommended IMPA=95° to give FMIA of 69°
If FMA=28°	Recommended IMPA=85° to give FMIA of 67°

This will produce an ideal FMIA of 65–70°

Appraisal of sample case

FMA	27·5°
IMPA	100°
FMIA	52·5°

Lower incisor uprighting to IMPA of 85° results in FMIA of 67·5° which is ideal.

Prognosis is good.

This analysis gives no indication of antero-posterior skeletal discrepancy.

Fig. 2.3 The Tweed analysis, showing a sample case. (from Brown, 1981)

2.2.2 Linear Analyses

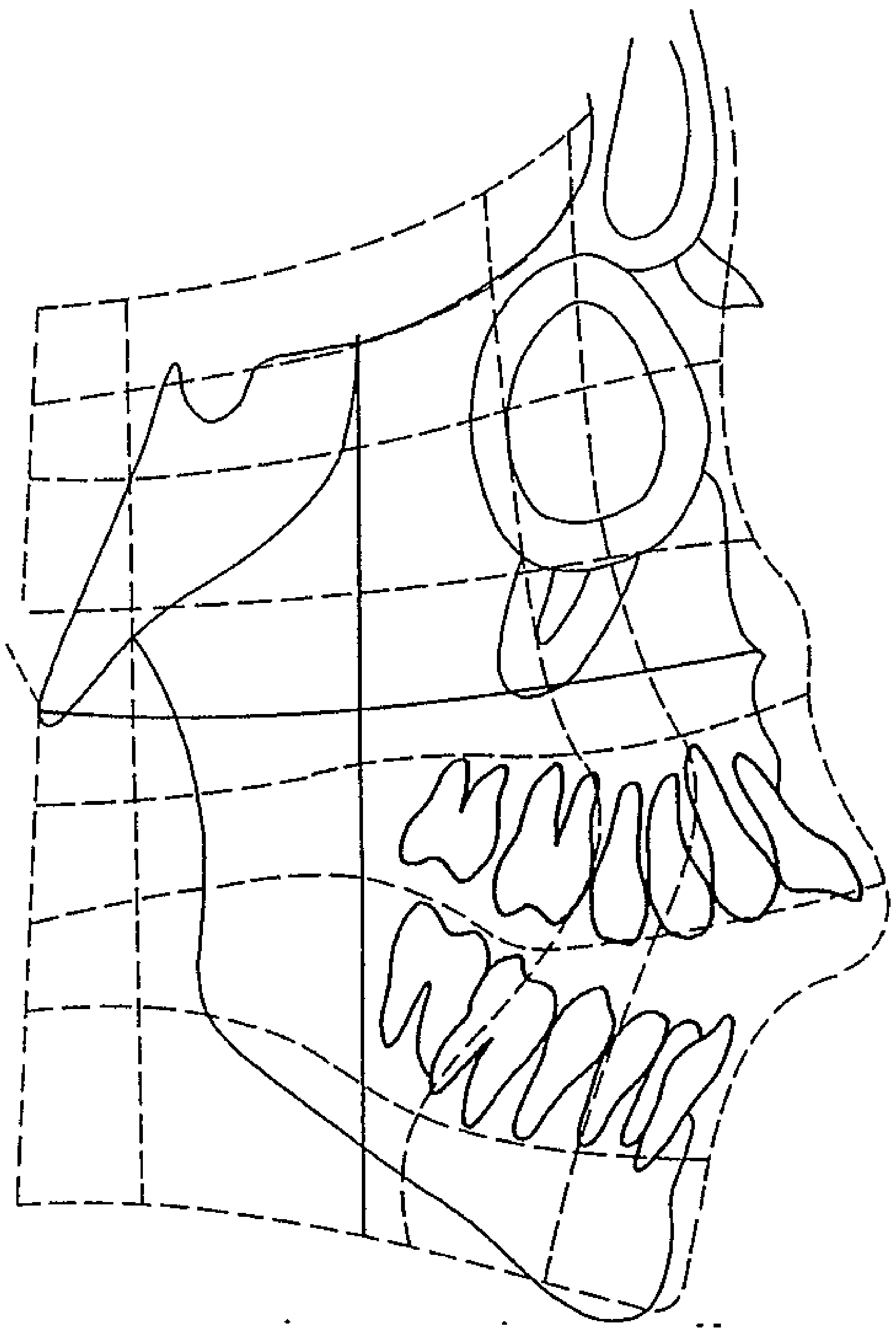
For linear analysis, the facial skeleton is analysed by determining certain linear dimensions.

2.2.2.1 Orthogonal Analyses

These involve projecting reference points onto a reference plane perpendicularly. There are two types known as geometrical or arithmetical. The de Coster method is a total orthogonal geometrical analysis (fig. 2.4). Here, the malocclusion is demonstrated by the deformation of the constructed quadrants (Rakosi, 1982).

For the arithmetical method, the reference points are projected onto a horizontal and a vertical reference plane and the distances between the points on these planes determined (fig. 2.5).

Fig. 2.4
de Coster's total orthogonal geometrical analysis.
(from Rakosi, 1982)



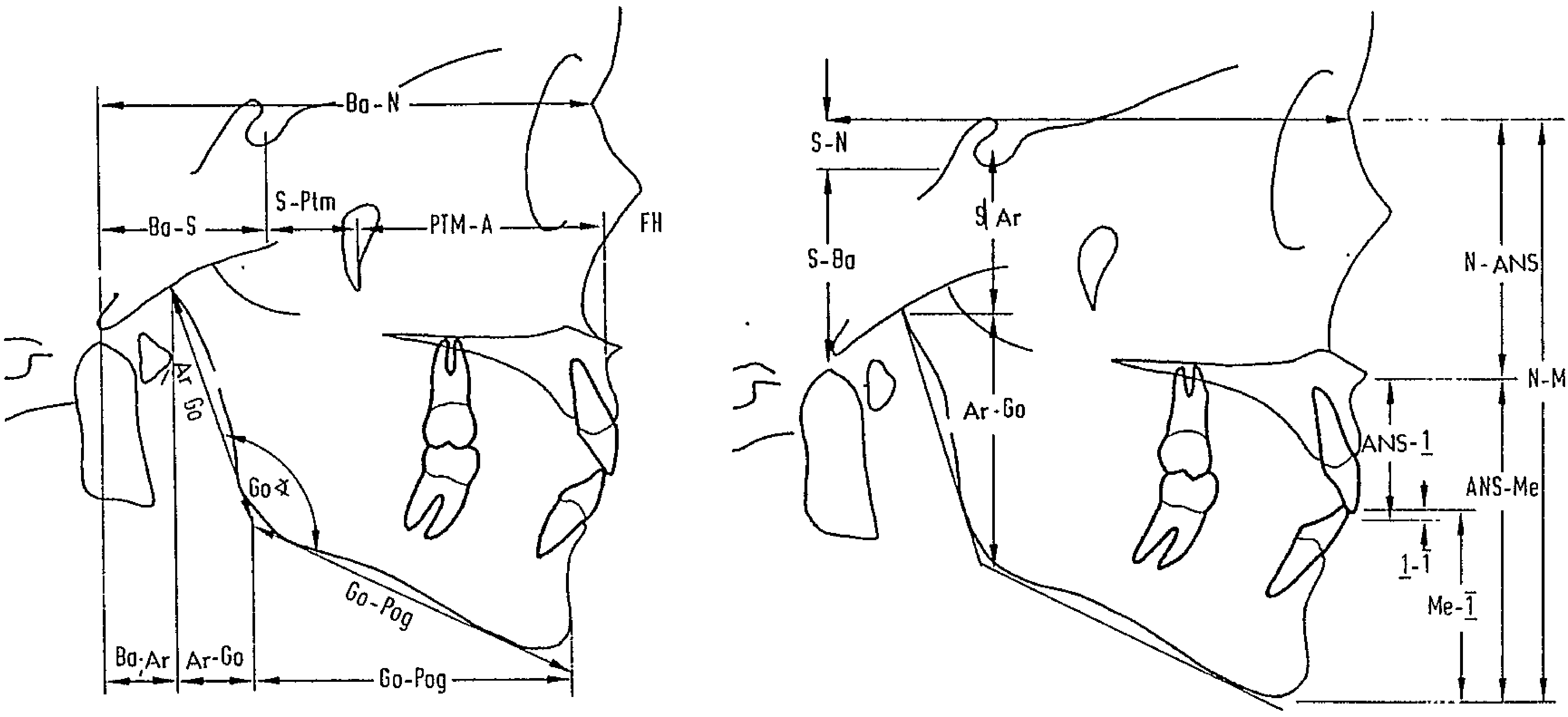


Fig. 2.5 A total orthogonal arithmetical analysis assesses skeletal relationships parallel and perpendicular to the Frankfort Horizontal. (from Rakosi, 1982)

2.2.2.2 Dimensional, Linear Analyses

These are based on the evaluation of certain linear measurements, either:

Directly - where the distance between two reference points is measured for the purposes of comparison with "norms",

or in Projection - the reference points are projected onto a reference line and then measured.

The following are some examples of dimensional, linear analyses:

The Wits' appraisal is an example of a projection method. Proposed by Jacobson (1975), it relates the jaws to each other by utilizing their common plane - the functional occlusal plane (fig. 2.6). Like Ricketts (1960, 1961), Jacobson defines the functional occlusal plane as passing through the midpoint of the cusps of the upper and lower molars and premolars. This is useful when results given by other methods are confusing, for example, when the ANB difference does not reflect a clinical assessment of anteroposterior dysplasia, because it is distorted by suspect SNA/SNB measurements due to variations in the position of sella or nasion in the cranium. However, this view is also challenged on the grounds that the occlusal plane can show great variation (Chang, 1987).

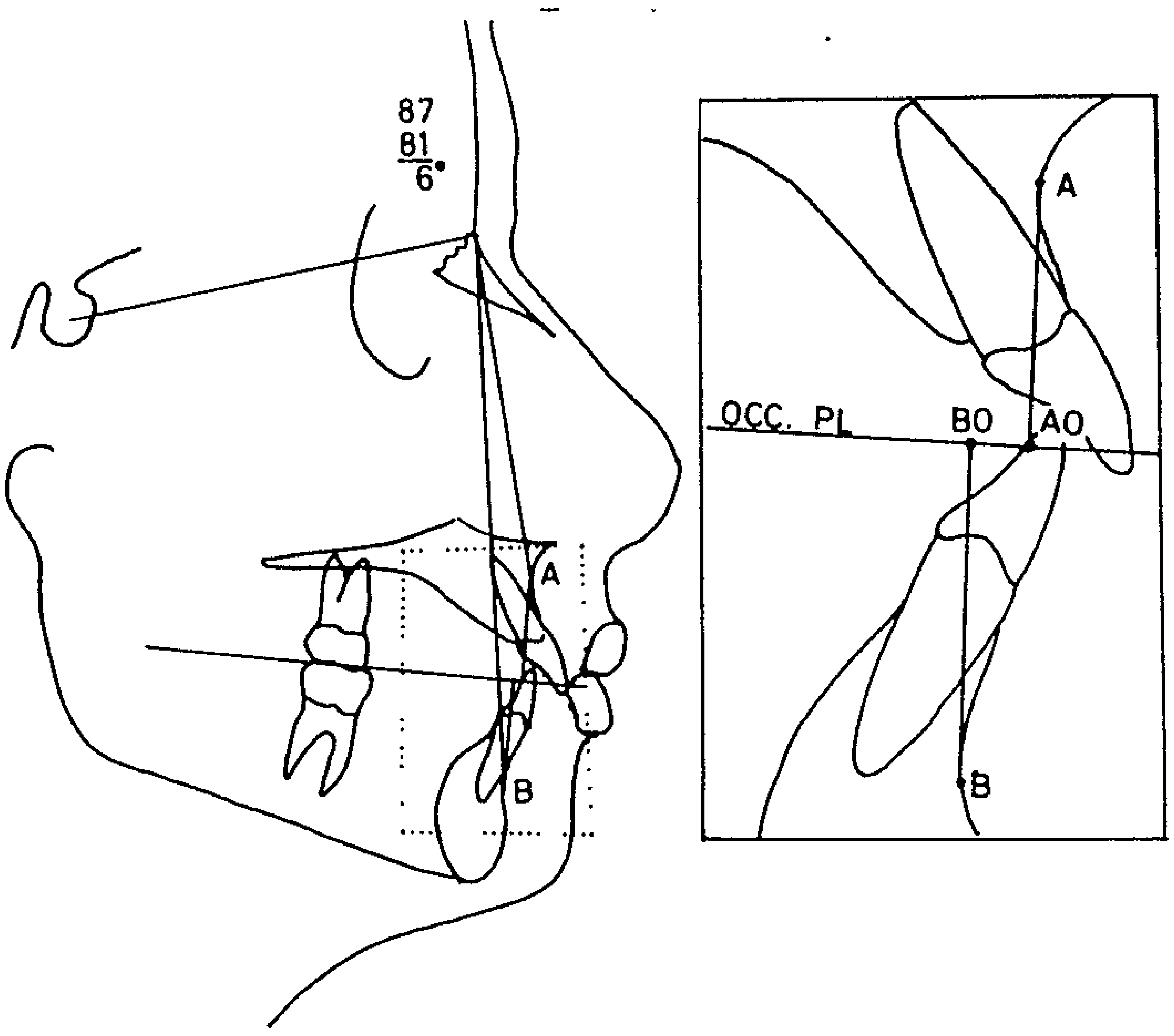


Fig. 2.6 The Wits' analysis. The Wits' reading is measured from AO to BO. (from Jacobson, 1975)

The Wylie analysis (1947) is purely an assessment of anteroposterior dysplasia to which he added a vertical analysis (1952). Here vertical and perpendicular lines are constructed to measure the distances between the various skeletal structures.

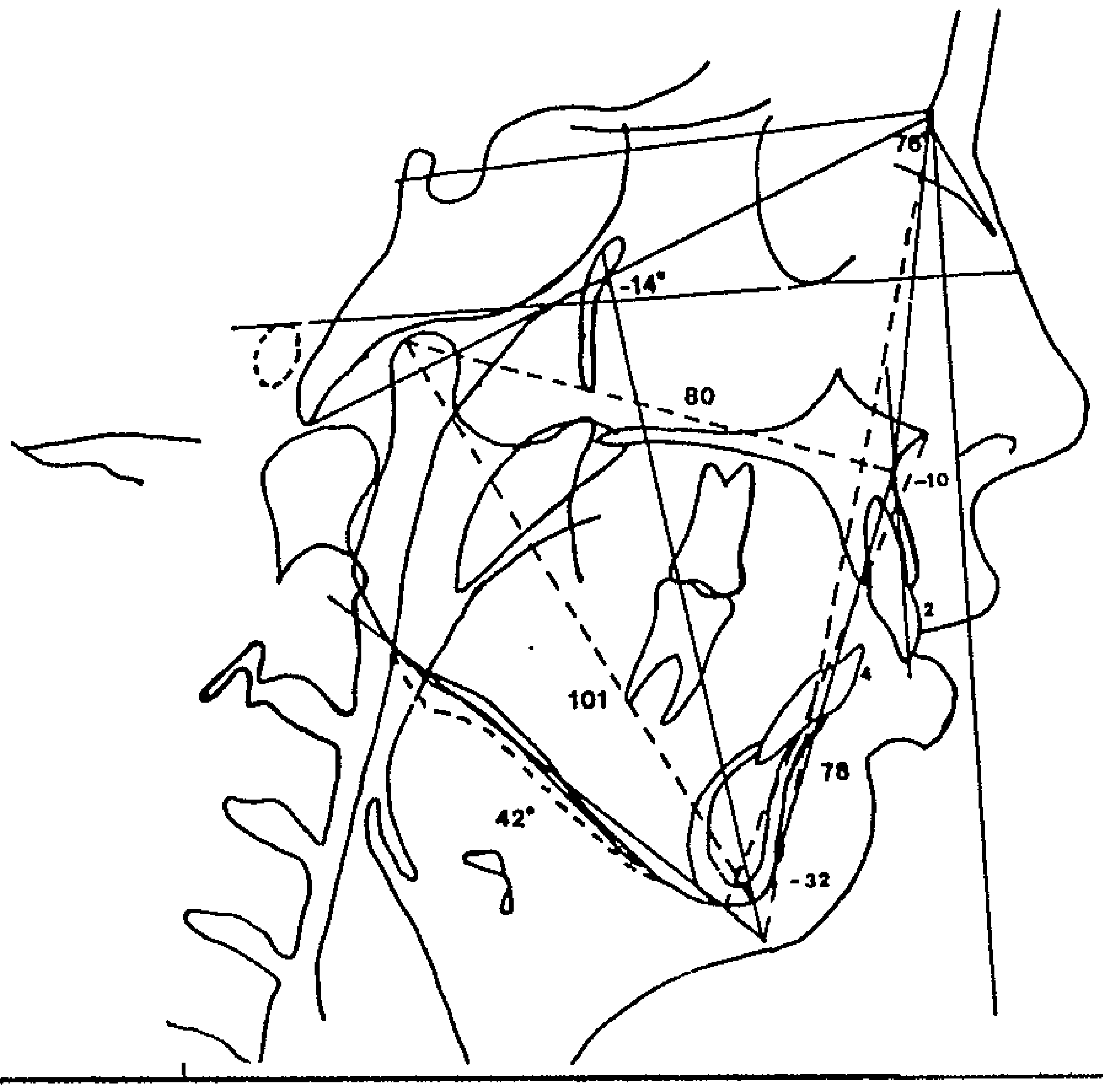
One may note from these definitions and examples that there are areas of overlap when categorizing various analyses, eg., the Wits' and Wylie analyses may also be classed as orthogonal analyses.

Ricketts' analysis (1960, 1961) uses angular measurements as well as linear values (fig. 2.7). The most noted of these is the relationship of lower incisor edge to A-Pogonion, a measurement which has become of vogue (Williams, 1985), but is now being questioned by authors such as Ellis and McNamara (1986) who claim inaccuracies due to the instability of both points A and Pogonion.

	Mean	Example
Facial axis (Ba–N to facial axis)	90±3°	89°
Facial depth (FP to N–Pog)	86±3°	83°
Mandibular plane to Frankfort plane	26±6°	27·5°
Convexity (A–N–Pog)	2±2 mm	0
$\overline{1}$ to A–Pog	1±2 mm	1·5 mm
Upper molar position (PTV–6 distal)	Age+3±2 mm	11 mm
$\overline{1}$ inclination to A–Pog	22±4°	28°
Aesthetic plane (position of Lip)	−2±2 mm	+2 mm

Fig. 2.7 The Ricketts analysis. (from Brown, 1981)

The McNamara analysis (1984) is based on linear measurements both in the antero-posterior and vertical directions (fig. 2.8). He felt that these are more relevant to surgical patients because angular measurements only give a relative picture whereas linear dimensions present an absolute view. According to him, angular measurements do not allow for discrepancies in their corresponding perpendicular planes. He also stresses the importance of accounting for variations in magnification of the x-ray image, when comparing with normative data, especially where linear measurements are involved.



Measurement	Female (n = 73) Normal	S.D.	Actual
Mandible to maxilla			
Effective mandibular length (mm) (condylion to gnathion)	120.2	5.3	101
Maxillomandibular differential (mm)	29.2	3.3	22
Lower anterior facial height (mm) (ANS to menton)	66.7	4.1	78
Mandibular plane angle	22.7°	4.3°	42°
Facial axis angle	0.2°	3.2°	−14°
Maxilla to cranial base			
Nasion perpendicular to point A (mm)	0.4	2.3	−10
SNA angle	82.4°	3.0°	76°
Effective midfacial length (mm) (condylion to point A)	91.0	4.3	80
Mandible to cranial base			
Pogonion to nasion perpendicular (mm)	−1.8	4.5	−32
Dentition			
Maxillary incisor to point A vertical (mm)	5.4	1.7	2
Mandibular incisor to A-Po line (mm)	2.7	1.7	4

Fig. 2.8 The McNamara analysis. (from Wylie et al, 1987)

Wylie et al (1987) report on 5 different analyses for surgical cases. Their study found that none of the analyses examined came to a consistent diagnosis and concluded that certain analyses were more applicable to specific deformities and surgical procedures. They emphasized that cephalometrics should be used in conjunction with facial photographs and study model analysis.

2.2.3 Coordinate Analysis

The concept of analysing cephalograms by way of coordinate geometry is not new. Moorrees et al (1975) report on such a system and also give an interesting account of its origins. They report that it was based on D'Arcy W Thompson's method of transformations of a coordinate system, from his work on growth and form in 1942.

A coordinate analysis can have its application both as a qualitative (descriptive) technique as well as forming the basis for a highly sophisticated scientific method. Simply, a coordinate system may be thought of as a grid of any dimension and of any configured divisions.

Moorrees et al (1975) report on a computerized mesh diagram analysis whereby a cephalogram is traced onto a grid. This is then compared with the norm which shows specific landmarks located in various grid squares (fig. 2.9). The discrepancies from the norm are depicted by drawing corresponding alterations of the grid (fig. 2.10). This so-called transformation grid was then used to compute treatment vectors. The procedure has been modified to use a computer to perform these transformations.

Fig. 2.9

Moorrees' Computerized Mesh Diagram (from Moorees et al, 1975)

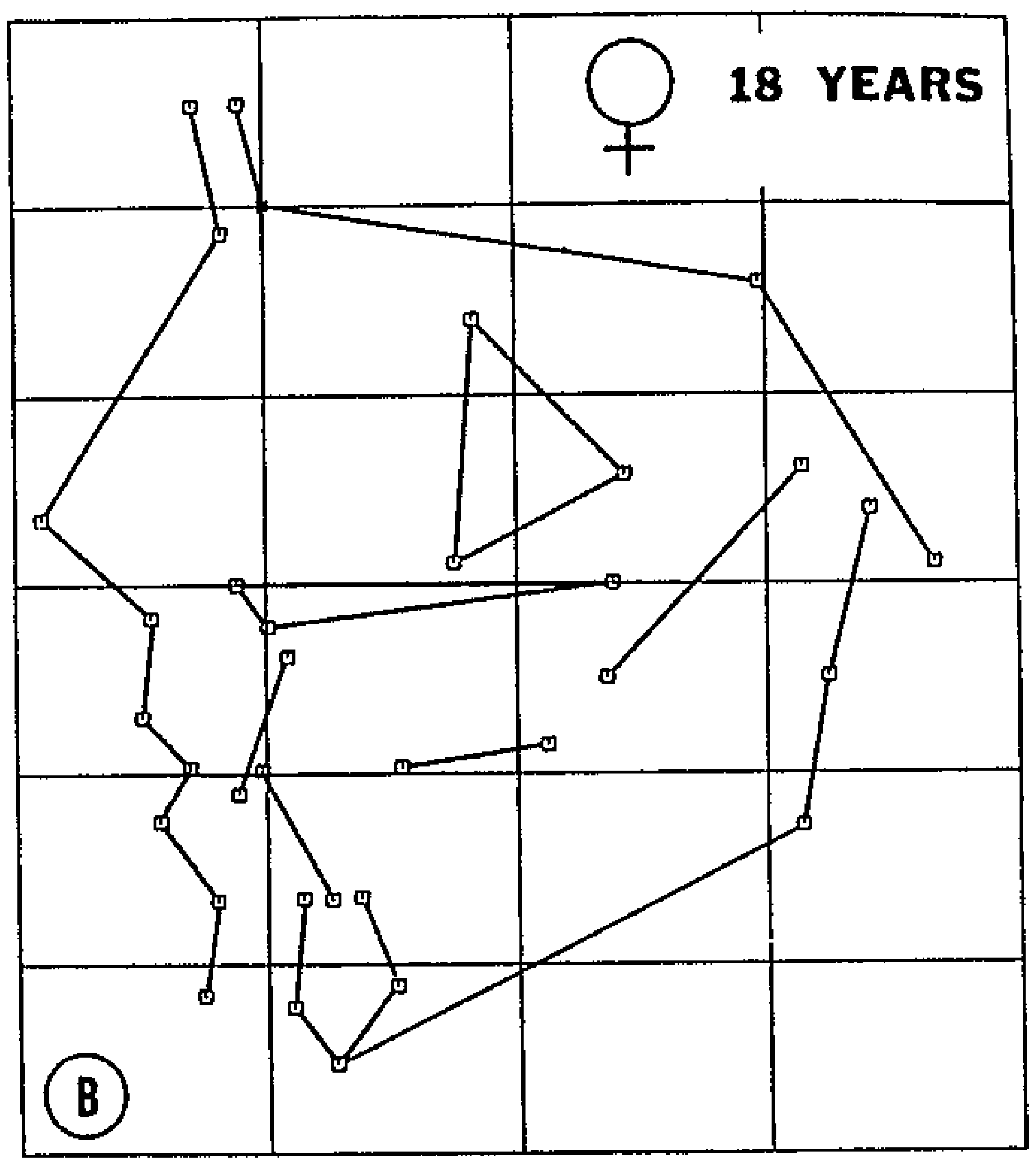
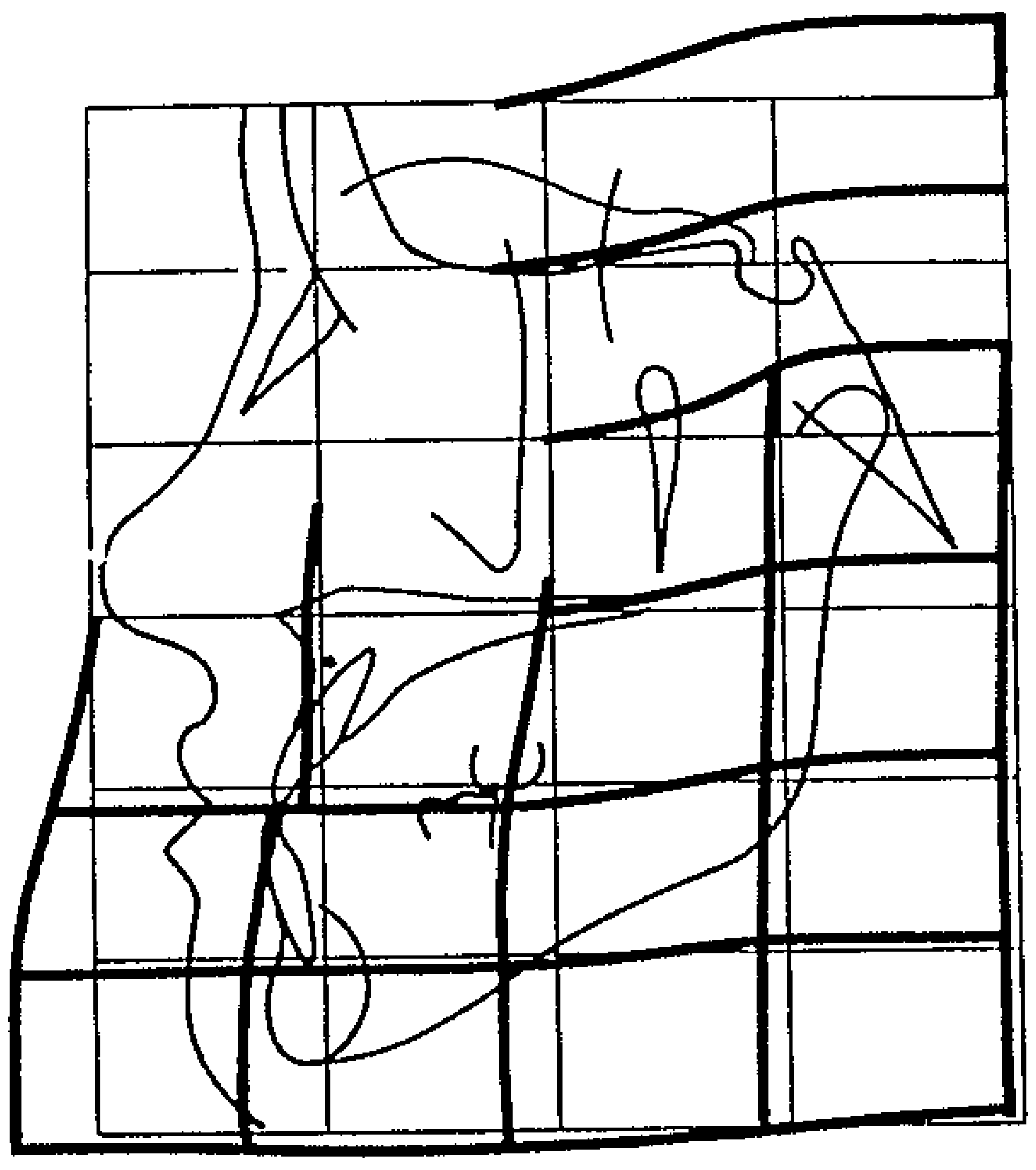


Fig. 2.10

Moorrees' Grid Transformation for a Class III malocclusion. (from Moorees et al, 1975)



The process of coordinate geometry may be carried further into the digitization of cephalometric points into X-Y coordinates. This will be discussed in further detail in Chapter 4.

2.2.4 Arcial Analysis

Viken Sassouni, in a prize winning essay in 1955 described a novel approach to studying cephalographs (fig. 2.10). He proposed the construction of 4 planes on the lateral cephalogram, after identifying the following points and plane:

Supraorbital plane - plane through the anterior clinoid process and roof of orbits

Sp - most posterior border of Sella

Si - most inferior point of Sella

Te - where the Key Ridge meets de Coster's line

Four planes are then constructed using these points.

a. Anterior cranial base plane - parallel to the supra-orbital plane and passing through Si

b. Palatal plane passing through ANS and PNS

c. Occlusal plane - between the mesial cusps of the molars and incisal edges of incisors

d. Mandibular plane - a tagential plane to the lower border of the mandible

In the ideal face, all these planes should converge to a point "O". This is the basis of Sassouni's arcial analysis. A number of observations may then be made regarding facial proportions, antero-postero and vertical relationships, and profile assessments. Sassouni also outlines eight facial types based on the divergent plane from "O" and also its vertical relation to "O" point.

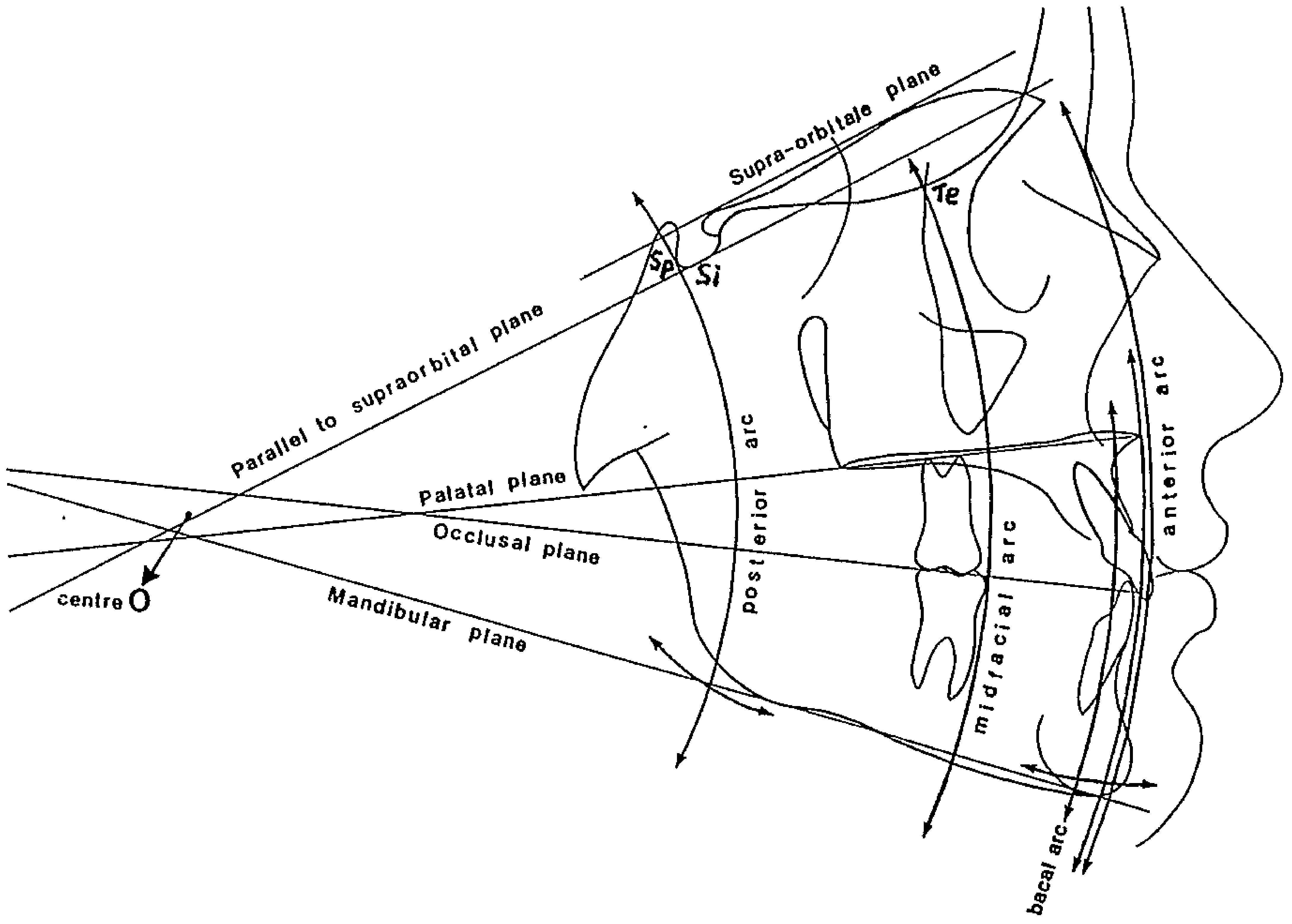


Fig. 2.11 Sassouni's arcial analysis (from Sassouni, 1954)

2.3 Comparisons

One of the problems which present when comparing various analyses, lie in the definitions which the different authors impart to lines and planes. Brown (1981) summarizes these variations by describing 8 analyses which between them use 3 definitions for the occlusal plane and mandibular plane.

The definitions for the occlusal plane include:

a. A line joining the bisectors of the molar and incisor overbites - Downs (1948) and Steiner (1953).

b. The functional occlusal plane which joins the bisectors of the molar and premolar overbites - Ricketts (1960, 1961) and Wits' (Jacobson, 1975) analyses.

c. Line joining the bisector of the molar overbite and tip of upper incisor - Bjork (1954).

The 3 mandibular planes are:

a. Tangent to the lowermost border of the mandible - Tweed (1954), Wylie (1947) and Ricketts (1960, 1961).

b. Line joining Gonion to Menton - Downs (1948).

c. Line joining Gonion and Gnathion - Steiner (1953).

Obviously these variations become important where the associated "norm" values are involved and thus any diagnostic procedure should state the specific analysis that is being used for the sake of validity.

Another criticism that is not dealt with comprehensively in the literature is the lack of mention of magnification factors. This is especially important with linear analyses. Most cephalometric machines employ a scale to determine a magnification factor. McNamara (1984) stresses this in his analysis and quotes corrected values in his normative data.

If one needs to be fastidious about following norms, then a number of compensatory and modification factors need to be employed with the quantitative linear and angular analyses. The tedious calculations which are then required, immediately call for computerization for practicality. Therefore, if one is to rigorously follow the "norms" in treatment planning then computerization should be seen as a necessary tool in cephalometrics.

The Sassouni analysis does not rely on quantitative measurements and comparisons with "norms". It relies instead on relating various parts of the head to each other and then establishing whether there is harmony between these parts. Sassouni (Davoody and Sassouni, 1978) in another study uses his analysis to compare what constitutes the norm in Iranian and American Caucasians. The absence of quantity measurements eliminates this form of measurement error. However, the technique is fraught with problems. For instance, establishing "O" point can vary immensely between examiners.

The technique is also rather tedious requiring additional equipment such as a compass and the construction of numerous lines and arcs which can obliterate the actual cephalometric tracing. The use of an overlay could overcome the latter. Nevertheless, once the lines and arcs are drawn analysis can be quite simple in that, it may just be "eyeballed" for qualitative judgement.

Sassouni (1955) also looks at anatomical morphology and claims that there are relationships between various morphological patterns of the Key Ridge, Palatal Plane and Mandibular Plane in different facial types.

On the point of qualitative analyses, the use of the Bolton Standards (Broadbent et al, 1975) templates must be mentioned. A series of normative acetate overlays based on the Bolton Study have been prepared according to age and sex, against which cephalograms may be compared both graphically and quantitatively.

Comparison of the various types of analyses, is difficult because each has its own merits. Some comparisons may be gleaned from the short discussions of the material presented but in summary, they are as follows:

a. Angular analyses - rely on relations to reference planes or comparison with reported norms. They do not have the problem of magnification error.

b. Linear analyses - linear dimensions are compared to normative data. They may be also used to calculate proportions. Linear dimensions are subject to image magnification problems which should be compensated for.

c. Coordinate analyses - may be qualitative by way of comparison with norms, eg., the Moorrees mesh analysis or the Bolton Standards templates. Coordinate geometry may also be used together with computers as a basis for computerized cephalometrics. Coordinate geometry together with computerization will also be the method by which 3-Dimensional imaging and analysis will enter orthodontics either by the digitization of 3 coordinates or the digitization of holograms, CAT scans or MRI (Magnetic Resonance Imaging).

d. Arcial analyses - are basically qualitative in that they provide a graphic representation of the cephalogram which may be compared with normal pictures.

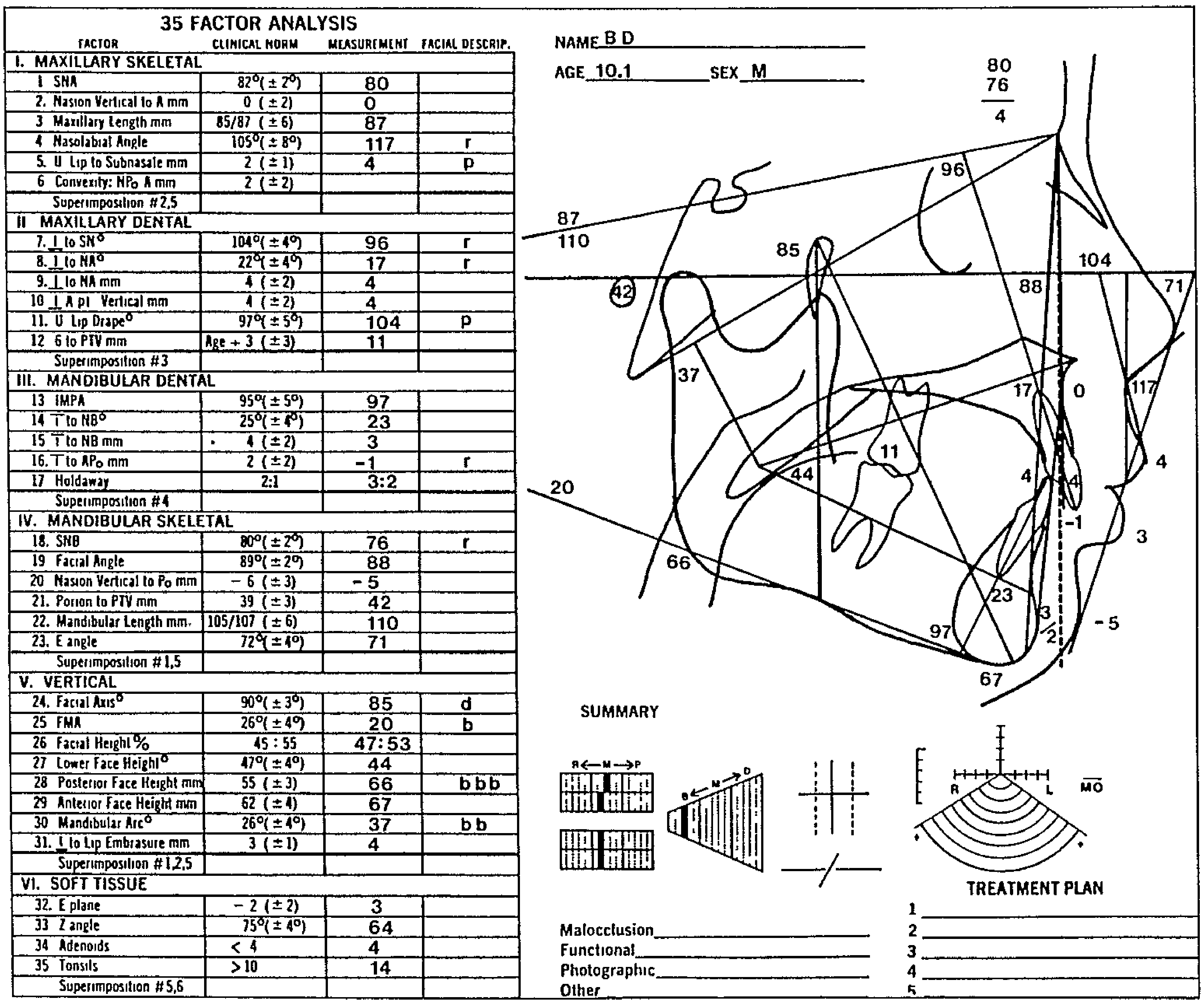
The validity of cephalometrics is also dependent on the reproducibility of the landmarks used and the reliability of the various analyses performed. A discussion on the errors inherent in cephalometrics will be presented in Chapter 5, together with a discourse on how these errors may be minimised.

2.4 Conclusion

An analysis will only supply the answers to a particular set of questions, and these answers will depend on correct application of the method and interpretation of results. Cephalometric analyses are continually being proposed with much reviewing on what has been done. The orthodontist can only sift through the vast material that is available for diagnostic purposes and use what is perceived as the most relevant method.

This chapter has reviewed some of the numerous cephalometric analysis that have been proposed over the years in orthodontic literature; each justified on their individual merits of diagnostic value, relevance to treatment planning, nature of problem (Wylie et al, 1987) and error handling. The list is certainly not exhaustive and has been compiled only to provide background information for the discourse on computerized cephalometrics.

The ideal cephalometric analysis would encompass the best of all these analyses. Owen (1984, 1986) attempts to do this with his



35 FACTOR ANALYSIS

FACTOR	CLINICAL NORM	MEASUREMENT	FACIAL DESCRIP.
I. MAXILLARY SKELETAL			
1 SNA	82°(± 2°)	80	
2. Nasion Vertical to A mm	0 (± 2)	0	
3 Maxillary Length mm	85/87 (± 6)	87	
4 Nasolabial Angle	105°(± 8°)	117	r
5. U Lip to Subnasale mm	2 (± 1)	4	p
6 Convexity: NPo A mm	2 (± 2)		
Superimposition #2,5			
II MAXILLARY DENTAL			
7. 1 to SN°	104°(± 4°)	96	r
8. 1 to NA°	22°(± 4°)	17	r
9. 1 to NA mm	4 (± 2)	4	
10 1 A pl Vertical mm	4 (± 2)	4	
11. U Lip Drape°	97°(± 5°)	104	p
12 6 to PTV mm	Age + 3 (± 3)	11	
Superimposition #3			
III. MANDIBULAR DENTAL			
13 IMPA	95°(± 5°)	97	
14 1 to NB°	25°(± 4°)	23	
15 1 to NB mm	4 (± 2)	3	
16. 1 to APo mm	2 (± 2)	-1	r
17 Holdaway	2:1	3:2	
Superimposition #4			
IV. MANDIBULAR SKELETAL			
18. SNB	80°(± 2°)	76	r
19 Facial Angle	89°(± 2°)	88	
20 Nasion Vertical to Po mm	− 6 (± 3)	- 5	
21. Porion to PTV mm	39 (± 3)	42	
22. Mandibular Length mm.	105/107 (± 6)	110	
23. E angle	72°(± 4°)	71	
Superimposition #1,5			
V. VERTICAL			
24. Facial Axis°	90°(± 3°)	85	d
25 FMA	26°(± 4°)	20	b
26 Facial Height %	45 : 55	47:53	
27 Lower Face Height°	47°(± 4°)	44	
28 Posterior Face Height mm	55 (± 3)	66	b b b
29 Anterior Face Height mm	62 (± 4)	67	
30 Mandibular Arc°	26°(± 4°)	37	b b
31. 1 to Lip Embrasure mm	3 (± 1)	4	
Superimposition #1,2,5			
VI. SOFT TISSUE			
32. E plane	− 2 (± 2)	3	
33 Z angle	75°(± 4°)	64	
34 Adenoids	< 4	4	
35 Tonsils	> 10	14	
Superimposition #5,6			

NAME B D

AGE 10.1 SEX M

SUMMARY

TREATMENT PLAN

Malocclusion__________

Functional__________

Photographic__________

Other__________

1 __________

2 __________

3 __________

4 __________

5 __________

Fig. 2.12 Owen's Diagnostic Block analysis (from Owen, 1986)

diagnostic block system whereby the measurements are compared to norms, and then a graphic representation of the discrepancies is mapped (fig. 2.12). However, Wylie et al (1987) in comparing five different analyses found a lack of consistency between analyses and also in their relation to treatment outcomes and thus concluded that cephalometrics should only be used in conjunction with other diagnostic aids.

CHAPTER THREE

COMPUTERS

3.1 A Brief History

Since human intelligence first began to evolve, our needs for data keeping have far exceeded our memories and the abilities of our fingers and toes to be used for data compilation. To this end, various devices of ever increasing sophistication have been employed through the ages to help us in this task.

This section describes a brief history of the evolution of computing. Some of the historical reporting is controversial and serves to highlight the rapid and independent advances that are so characteristic of computing (Dyson and Mcshane, 1988). The historical account which follows is derived from Millendorf and Kalisman (1986), Dyson and McShane (1988), Larsen and Rogers (1986) and Cranwick (1989).

The initial attempts at data collation were by the Sumerian merchants and trade people, from 4000 to approximately 3000 BC, when the recording of transactions first began. Paper had not yet made its appearance and the process of recording information was performed by engraving marks onto soft clay tablets which were then allowed to harden for a permanent, but extraordinarily bulky, record. The ancient Babylonians attempted to organize this huge pile of clay tablets by placing them in storage jars, which were then numbered and arranged in certain sequences.

The first attempts at actual calculations of numbers occurred around the year 3000 BC when the abacus was invented in India. Little improvement in mathematical computation and processing was achieved between 3000 BC and 1600 AD, at which time devices began to replace the abacus in commerce and business. In 1621, the slide rule was invented by William Oughtred. This device was modeled somewhat after a sliding system of marked poles produced by John Napier, the inventor of logarithms. The slide rule is based on logarithms and may be thought of as a very primitive and completely manual analog computer, in which the product and quotient are approximated.

In 1642, Blaise Pascal invented another manual device, this time based on rotational movements instead of linear parts sliding past each other. The mechanism by which Pascal's calculator worked is similar to that of odometers in cars. Here the four basic mathematical operators were based on addition and subtraction.

Gottfried Leibniz in 1694, produced a machine that could directly add, subtract, multiply and divide independently. However, this device received little acceptance.

It was another 200 years before any further advances were made in the field of computational devices, for in 1822, an English mathematician, Charles Babbage built a machine - the Analytical Engine that could automatically print various mathematical tables. This device was to be the last of a generation of purely mechanical entities for the calculation of numbers.

In the years prior to this, a Frenchman, Joseph Jacquard built an automatic weaving machine which used punch cards to set the patterns in the cloth. In 1887, Hollerith, a mathematical statistician for the census bureau utilized this idea of punch cards to add up and analyze the census data of 1890. He devised a system whereby the data was punched into cards which were then placed in holders arranged over pans of mercury. A system of pins were then devised to drop into the punched holes and make contact with the mercury, at which point an electric current would complete a circuit. The electricity would then operate a counter. This was the basis of a primitive computer.

The success of Hollerith's machine led to the formation of the Tabulating Machine Company in 1896. In 1915, it merged with another group to form the Computing Tabulating Recording Company, which in 1924 changed its name to International Business Machines (IBM).

With the increasing need to process and analyse ballistics and armament data quickly , the Harvard Mark I computer was produced in May 1944 - a cooperative effort between IBM and a Harvard University professor, Howard G. Aiken. Speed was still a problem as the machine still consisted of many slow-moving mechanical components.

3.2 Modern Computing

In 1946 at the University of Pennsylvania, Mauchly and Eckert produced the ENIAC (Electronic Numerical Integrator and Computer) for ballistic and aeronautics calculations by the military (Larsen and Rogers, 1986). This 30-ton machine covered almost 16000 square feet of floor space and was purely electronic, thus enabling it to work approximately 1000 times faster than the Mark I. These early giant computers were highly inflexible; the instructions were physically built into the computer, making them extremely specific for unique applications. New applications required substantial reprogramming, or virtual reconstructon of the unit.

The ENIAC had been claimed to be the world's first computer (Larsen and Rogers, 1986). However, in 1973 a court action in Minneapolis overturned the patent application by Mauchly and Eckert for their machine, claiming that their work had been derived from the subject matter of John Atanasoff. This gave credit to John Atanasoff and Clifford Berry for inventing the first computer in 1939 using the following definition - a machine that is automated, digital, electronic and runs under the control of a stored program (Dyson and Rogers, 1988).

In 1949, EDSAC was designed; this unit had an internal storage facility of programs and the ability to reprocess them by switching from one to another as the needs of the user dictated. The standard punch cards were still used to interface the computer with the person operating it.

The Sperry-Rand Corporation in 1951 began to replace the punch card with a magnetic tape that could be used for input and output. This innovation permitted a speed increase of up to 175 times, in addition to having greater reliability and a vastly increased memory capacity. The machine, called UNIVAC had a stored program capability and was the first commercial computer.

In 1947, Shockley, Bardeen and Brattain invented the transistor, an extremely small, highly reliable, low-power-consumption device that replaced the giant vacuum tube (Larsen and Rogers, 1986). This was coupled with the advent of teleprocessing, whereby information could be sent by electronic pulses along wires, over long distances, to allow an interchange of information between computers.

At this point, various transactions had to be concluded in orderly sequence; random sequence transactions were not possible with any type of speed or ease. This was rectified by the advent of disk storage, allowing one to find and manipulate a record from a point on a rotating disk in a fraction of a second.

This occurred in 1964, at which time integrated circuits and thin-film memory came to the fore - a set of technologies that allowed micro-miniaturization, giant capacity and high speeds. The integrated circuit matured throughout the 1970's when computers began to feature large scale integration of circuitries through to the very-large-scale-integration (VLSI) circuitries of today. Miniaturization became so advanced with circuitries being etched onto chips of silica that the complete central processing unit (CPU) of a computer could be put on one or a number of circuit chips called the microprocessor. These could be assembled with other small chips and called microcomputers (Millendorf and Kalisman, 1986).

In 1975 Edward Roberts designed the first personal computer - the Altair 8800, thus called,as it could be owned and programmed by the user at low cost. This machine which came in a kit form had no permanent memory and programming was via a series of switches. However,it was not until the appearance of the Apple personal computer by Stephen Wozniak and Steve Jobs in 1977 that personal computing took off the ground. The attraction of these machines was that they had both temporary (ROM - Read Only Memory) and permanent (RAM - Random Access Memory) memory as well as a BASIC interpreter (a computer language that uses English syntax). The personal computer was only made possible by the invention of the microprocessor in 1971 by Ted Hoff. He defined his invention as a semiconductor chip onto which was packed a host of processing information which could be used by a computer (Larsen and Rogers, 1986).

The past ten years, has seen some major breakthroughs in personal computing to the extent that personal computers today rival the performance of the large scale machines of the past. This treatise will therefore limit its discussion to personal computers, as its relative accessibility and power has made it both a viable and applicable tool in orthodontics.

3.3 Basic Principles of Computer Technology

In general, a computer is a machine that can receive process and present data. The computer converts numeric and symbolic data into binary code. This code is then processed by the computer, which is guided by the program residing in its memory. Two terms often used in computing terminology are "hardware" and "software". The term hardware refers to the physical entities of a computing system while software is the collective term for the sets of instructions that are used to drive the computer.

3.3.1 Hardware

Most computers have the following four hardware components (fig. 3.1):-

3.3.1.1 The Central Processing Unit

The (CPU) is a small silicon chip with a myriad of circuits imprinted on it. This unit is essentially the "brain" of the computer (Petroski, 1986). The configuration and specificity of the CPU imparts the processing power and speed to a particular computer. Most computers do not conform to the decimal system as we know it; they function with a combination of the hexadecimal (multiples of 16) and binary systems. The smallest unit that a computer recognizes is a bit. Bits are single choice functions in a binary system, that is, they can be read as either a zero or a one. In an eight bit system, when the computer reads a block of eight bits, it recognizes them as a single alphanumeric or symbolic character and is called a byte. In this hexadecimal system, a kilobyte (K), is 1024 bytes.

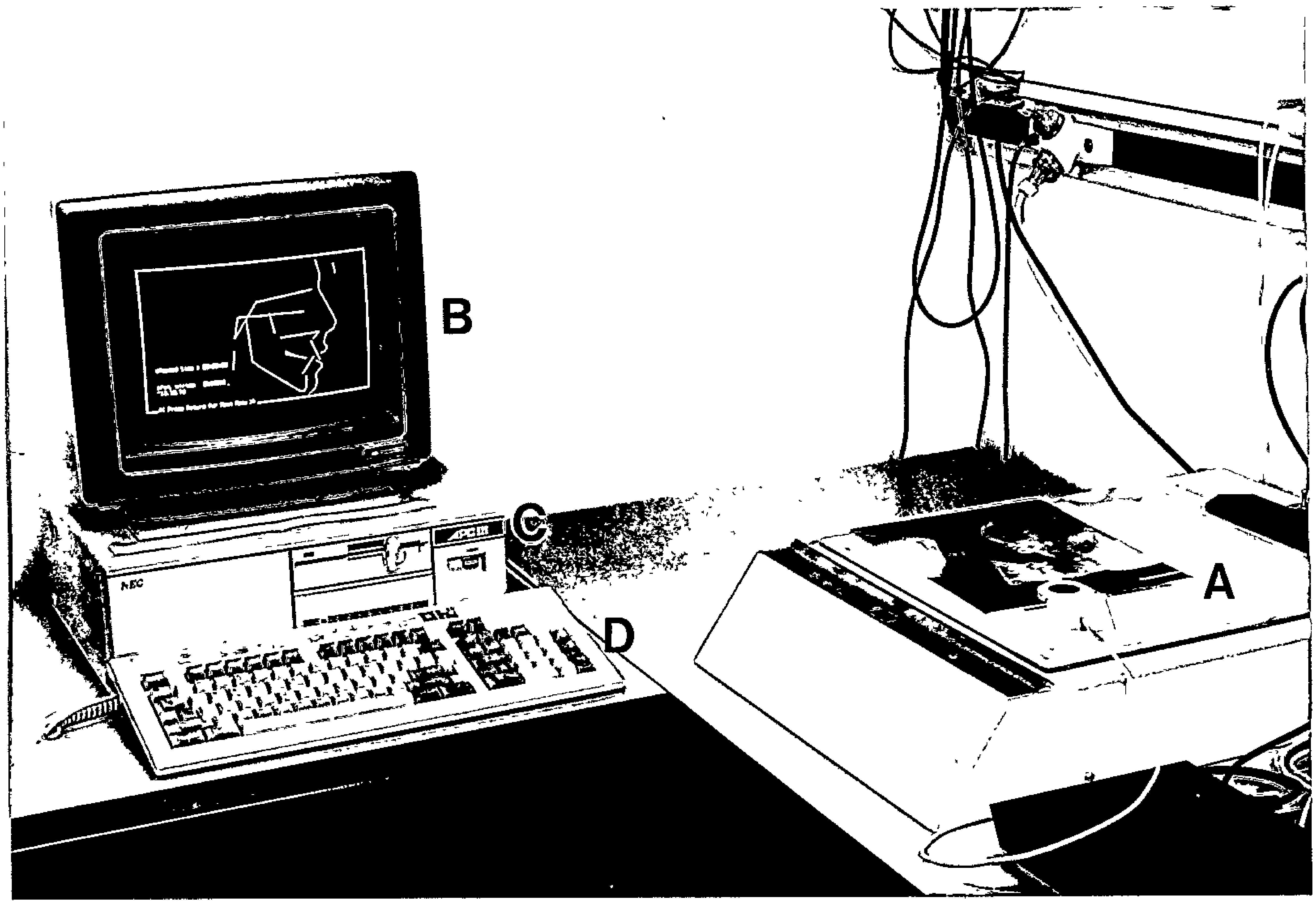


Fig. 3.1. Computer system as used for Cephalometric Analysis by the author
A. Scriptel™ tablet digitizer
B. Advanced Graphics Display screen showing a plot of digitized cephalometric points
C. CPU and disk drive systems
D. Keyboard

The number of bits in a system also indicates the capacity of the pathways that handle information within the computer. Therefore, a true 16-bit CPU is analogous to a highway system with 16 lanes in both directions. The current state of the art in personal computing embraces 32-bit technology.

Speed of operation is another variable feature of various CPU's and is measured in cycles per second (Hertz) or millions of instructions per second (mips), the latter relates to the efficiency of the machine and is more realistically applied to the larger and more powerful computers. The original 8-bit machines operated at 1 MegaHertz or 0.25 mips (Fischer, 1988) , while the faster 32-bit machines of today can operate at 25MHz or 5 mips (Thompson and Baran, 1988).

The amount of memory that may be addressed by a computer is another feature of a CPU and will be discussed under the next heading.

The latest in CPU technology uses transputers, whereby a number of microprocessor chips are used within the same computer to perform various specialised tasks such as graphics, video, sound and text handling. This process is also known as parallel processing (Obermeier, 1988).

3.3.1.2 Input Devices

These include typewriter style keyboards, optical scanners that can read bar-code or full text; or read/write devices, such as disk and tape drives. Also in development are voice recognition systems. Other input devices include the "mouse" which is a desktop control which allows rapid movement of the screen cursor. Video and tablet digitizers also fall into the category of entry devices as they convert analog signals from a video unit, stylus or cursor into digital data that can be processed by the computer.

3.3.1.3 Storage Devices

These include RAM and ROM chips, disk drives (floppy or hard), magnetic tape drives (now used as back up devices for hard disks) and compact disc (CD) drives and video/laser disc drives.

The acronyms RAM and ROM are two terms which are often heard when discussing computers. RAM or Random Access Memory is simply a collection of chips to which data may be written to or read from. RAM is volatile, that is, the information stored on it is lost when its power supply is removed. Application programs require a minimum amount of RAM for its various modules to reside on before they may be executed. As the cost of RAM chips plummet, computers have now increased their standard RAM configurations from 16K to 1024K, which is rapidly becoming the standard. As more RAM becomes available, computer programs become more sophisticated. ROM refers to read only memory and as distinct from RAM, these chips are permanent storages preset by the manufacturer to hold directions for the functions and interactions of various parts of the computer. As mentioned earlier a peculiar feature of different CPU's is the amount of RAM and ROM that they can address, thereby increasing its power.

Memory chips which may also be programmed by the user are termed EPROM's (Eraseable Programmable Read Only Memory) and these are used to hold programs which are frequently used.

Data storage has evolved from the humble punch card to the compact disc (CD) of the 80's. Compact discs can hold vast amounts of data, for example, the entire Encyclopedia Britannica on a single disc; but these are still at a stage of being ROM devices and at a huge cost.

More accessible are floppy disks ranging in capacities of 140K to 1440K (1.44 Megabytes), to hard disks which can hold upwards of 20000K (20Mb), the latter offer the advantages of greater speed and convenience in data storage and retrieval. The magnetic tape from which evolved the floppy disk is now often used as a backup facility for hard disks.

3.3.1.4 Output devices

These convert the digital signals of the computer into a form that may be perceived by the user. These range from video displays, as distinct from ordinary television with their higher resolution, to a host of hardcopy printing devices.

Intercomputer communication devices are another form of input and output devices. Computers may be connected to one another via cables as part of a network or they may be connected via telephone lines by a device known as a modem (modulator-demodulator).

3.3.2 Software

The term software as defined earlier may be instructions written in to chips (CPU or ROM) or on transportable disks. A computer system cannot function without the direction of a program. Programs instruct the different components of the computer system as to how they should interact with each other and process data. Some programs are written for only one type of machine or CPU, but most are written to be transportable to many types. There are three general levels of programs; the operating systems, languages and application programs.

3.3.2.1 Operating Systems

The disk operating system (DOS) is a program that is usually loaded automatically when "booting up" or turning on the computer. It contains information controlling the way files are written to the storage devices. It also contains background guidelines for disk formatting and the manipulation of data. Disk operating systems are specific for various computer manufacturers and the more popular of these today include Apple's ProDOS™ and Macintosh™ Systems, CP/M (Control Program for Microprocessors - Digital Research), MS-DOS™ and OS/2™ (for IBM™ and compatibles - Microsoft) and UNIX (a sophisticated DOS which allows true multiuser facilities - Bell Labs).

The different operating systems make compatibility between "brand" computers a problem. User-friendliness is a term referring to the ease of operation of a system by the user. The Macintosh system and the new OS/2 Presentation Manager from Microsoft allows a graphic interface for various data manipulation procedures, thus catering for the new computer user.

3.3.2.2 Languages

Languages are the form of communication between the computer programmer and the operating system. The most generic and fastest running language in any computer is "machine language". This is the only language or instruction set that the computer can understand at the "bit" level. Unfortunately, except to the most experienced programmer, these instructions bear no relation to the logic that is used to generate them. Various languages have been written which act as interpreters between the programmer and the machine language. These interpreters as they are appropriately called use symbols, mnemonics and English language commands. Once written in the interpretable language, the program is compiled into the machine language as it executes, or a separate program is used to compile the interpreter.

Computer languages themselves have undergone an evolution. The first generation language is known as machine language; assembly code is the next generation which immediately translates to machine language. The third generation comprises the interpreter languages, also referred to as high level languages because they are well removed from the "basement level" machine code (Powell, 1988). Almost parallel to these languages have been the generations of computer hardware which first went from valve technology, through integrated circuits made possible by transistors, to very large scale integration (VLSI) which allowed faster processing.

Languages that can be compiled include BASIC (Beginners All-purpose Symbolic Instruction Code), C Language, FORTRAN (FORmula+TRANslation), COBOL (COmmon Business Oriented Language) and Pascal (Macquarie Dictionary, 1985). Some of these are faster than others but are also more difficult to program. When the Altair computer was released in 1975, as mentioned earlier, programming was by manual switching until Bill Gates (the founder of Microsoft Corp.) and Paul Allen, developed a BASIC interpreter to allow programming by the novice user (Powell, 1986).

BASIC was originally developed by Kemeny and Kurtz at Dartmouth College in 1963 and its ease of use has led to its almost universal use in microcomputers. In the course of its development, many different versions of BASIC have evolved and in order to overcome this problem, the American National Standards Institute (ANSI) developed a standard version of BASIC known as ANS Minimal BASIC (Birnie, 1983). Today a number of different proprietary versions of this language are available with their own peculiar commands. However, programs written by these similar packages may be used interchangeably with minimal modifications, allowing a degree of portability of software between diverse hardware and operating systems.

The C language is a relatively new language and was originally designed for and implemented on the Bell Laboratories' UNIX operating systems. It is a relatively "low" level language (close to machine code) but has features and functions which allow the input-output facilities of the high level languages such as BASIC. (Kernighan and Ritchie, 1984). The power and speed afforded to programs written in this language have made it a popular choice among programmers. Its portability also allows for efficient program development. Appendix A contains examples of C language programs written by the author.

3.3.2.3 Application Programs

Application programs usually act as overlays to the language and operating system. While utilizing the functions of the operating system, they render the DOS and other CPU related functions transparent to the user. Such programs act as the tools of the computer and the data that is processed is stored as files specific to the program. The following is a brief description of the major categories of application programs.

a. Word Processors are programs that turn the computer into sophisticated typewriters in that they allow documents to be created, viewed and edited before they are printed. An evolution of this has been desktop publishing which takes word processing one step further to include complex page layout processes as in typesetting. Apart from the efficiency that results word processing also allows the storage of documents on disk for ease in storage and retrieval.

b. Databases - quite simply these programs may be thought of as electronic filing cabinets with extensive indexing facilities. Apart from having the features mentioned with word processors, they also present complex search facilities based on criteria defined by the user. Relational databases is a term referred to database programs which allow the linking or cross-referencing of files, such that modifications to one file results in the automatic updating of associated files.

c. Spreadsheets are programs which allow the organization of information into rows and columns. Each of these rows and columns can then be related by equations much as in a programmable calculator. Changing one value will then cause recalculation of all affected values. This allows the user to examine many "what if" situations. Visicalc™ is such a program that was released in 1979, and many claim this to be the event that gave credence to personal computers as business machines. Lotus 1-2-3™ is another such spreadsheet program that has picked up universal interest as an essential tool on IBM™ and compatible machines.

d. Communication programs - modems and networks require programs to allow the organized transfer of information. A universally accepted transfer file format between computers is the ASCII (American Standard Code for Information Interchange) text format. This file type may be read by all the various disk operating systems. Modems and communications programs also allow the user to access a host of public data bases and are therefore a convenient means of accessing topical information.

e. Special application programs include such things as graphics (2D and 3D), statistics, accounting and scheduling packages. Custom programs may also be written by the user using one of the interpretable languages for specific needs. Some application programs also act as programmable shells (a specialized form of language) for custom configuration to specific tasks, examples of this include, Lotus 1-2-3™ and dBASE IV™. The latest of these is Hypercard™ for the Macintosh™ which is being hailed with as much fervour as was BASIC on its release. Hypercard™ on the Macintosh™ range of computers uses English syntax and acts as a "scripting" device with the ability to bring together text, graphics and sound with minimal knowledge of programming (Daniels, 1988).

The evolution of hardware and software has been swift, resulting in bringing tremendous power to the desktop personal microcomputer (Kalisman and Studin, 1986). The foregoing has been a brief discussion on the vast subject of computing and has attempted to outline the evolution and fundamentals of computing. Advances are being made with such rapidity that the latest innovations discussed even within this treatise could soon be rendered obsolete. This may be a reason why the literature concerning computer applications in orthodontics is often scanty and seemingly outdated, a problem which is also made worse by delays and waiting periods before publication.

CHAPTER FOUR

COMPUTERIZED CEPHALOMETRICS

Computer processing of cephalometric radiographs using a digitizer has been pursued now for well over a decade, and the methods described in the literature have achieved various levels of automation, both in terms of hardware (equipment) and software (programs).

According to Bhatia (1985), Barret et al (1968) were the first to suggest the use of a digitizer or a similar machine in the measurement of cephalometric radiographs.

4.1 Digitization

Digitization refers to the process of expressing analog information in a digital form (Macquarie Dictionary, 1985). In this treatise and in its application to computerized cephalometrics, digitization refers to the resolving of headfilm landmarks into two numeric or digital entities - the X and Y coordinate. Three dimensional analyses would have a third quantity - the Z coordinate.

A digitizer is a computer input device which converts analog information into an electronic equivalent in the computer's memory (Powell, 1989). Tablet digitizers are used to process two dimensional images, and a cursor or stylus is used to input the information (Fig. 4.1). Any position of the cursor or stylus on the tablet is resolved in terms of two (X and Y) co-ordinates, one on the horizontal and the other on the vertical axis. This is based on the Cartesian coordinate system developed by Rene Descartes (1596-1650). By obtaining such coordinates for a number of positions (eg., cephalometric points) on the tablet, linear and angular measurements between the positions can be calculated by simple trigonometric manipulations (Bhatia 1985).

Sutton and Spratley (1981) described a mechanical digitizer based on two vernier calipers mounted at right angles to each other. Mounted on a light box, X and Y coordinates could be read off radiographs and entered on a programmable calculator for computations.

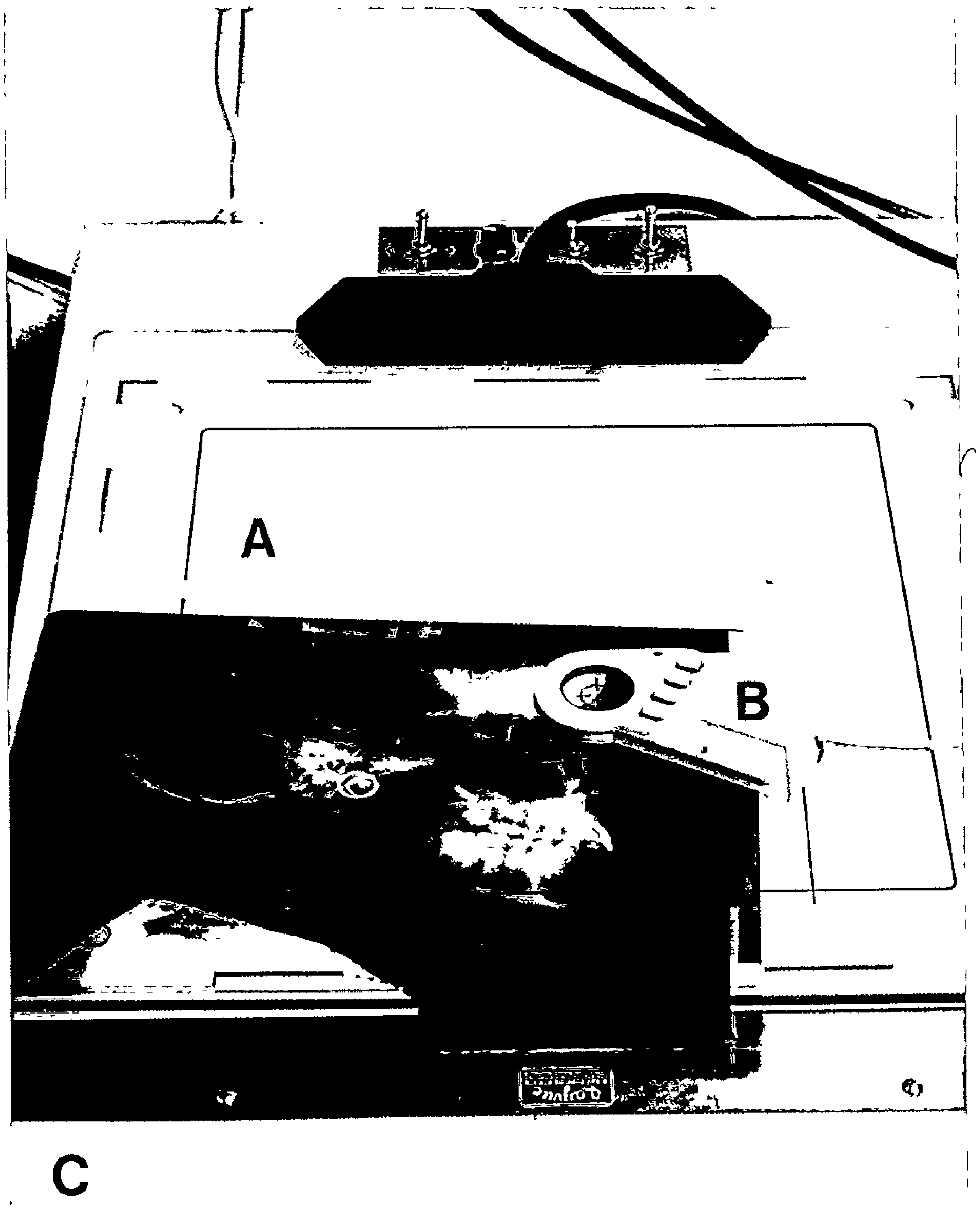


Fig. 4.1
The Scriptel™ Digitizing Tablet

A. Transparent, Energized Grid Surface

B. 4-Button Cursor

C. Fluorescent Lightbox

Digitizers employ a variety of technologies. Most common is the antenna-transmitter technique, in which evenly spaced horizontal and vertical wires within the tablet represent an x,y coordinate grid. The internal wires sense the magnetic (or electric) field emitted by the transducer located in the cursor or stylus. The horizontal wire closest to the transducer coil, registering the strongest signal, reports the x-axis data, while the closest vertical wire returns the y-axis data. Together, they represent the coordinate location of the cursor or stylus coil.

Some systems, such as the Scriptel™ digitizer shown in Figure 4.1, energize the grid instead of the cursor, whereby each internal wire holds a known signal (Diehl and Apiki, 1989). The more closely spaced the wires, the higher the resolution. The resolution of current digitizers is typically of the order of 0.025mm. This is of an order of magnitude far higher than the resolution of cephalometric landmarks and Richardson (1981) suggests that such a resolution afforded by computerization is often wasted on headfilm analysis.

Apiki and Diehl (1989) also recommend that a cursor with crosshairs (Fig. 4.2) is more accurate than a stylus in acquiring digitized information since it is often difficult to maintain a consistent angulation of the stylus to the tablet surface.

Richardson (1981) also suggested a further advantage of the cursor in that its crosshairs may be used to advantage, to "find" points on curved outlines. For example, the most inferior point on a curve may be located by running a horizontal tangent to the curve by the horizontal crosswire or by watching a digital readout on the computer for the lowest Y coordinate.

The tablets may be opaque, translucent or transparent. Digitizers are used extensively in engineering applications of computer-aided design, drawing and manufacture. However, the demand in such applications is mainly for opaque boards and therefore the digitizers which can be transilluminated - a requirement for radiographs - are still priced at a premium. Transparent or translucent boards are desirable for the analysis of radiographs and a discussion of the efficacy of the thus afforded direct digitization is given in Chapter 5.

Fig. 4.2 4-Button Cursor with Crosshairs to Pinpoint Cephalometric Landmarks.

The interface between the digitizer and computer is usually a serial communications port of the type used by modems and printers. Software routines which normally access these ports may be used to also access and poll the information from the digitizer.

A discussion on digitizers would not be complete without some mention of alternative data acquisition methods. Savara (1972), Riolo (1972), Cohen et al (1984), Jackson et al (1985), Cohen and Linney

(1986), Gatti and Amadori (1986) reported on the video digitization of cephalograms. Video digitization refers to the process of using a video camera to capture and convert an image into digital information (Ryan 1987). The processing power of the computer may then be used to "recognize" landmarks by pattern matching. The studies thus performed were limited by the low resolution of the video systems and the requirement of mainframe computers to perform the image analysis.

In light of today's technology, with higher resolution video systems and increased processing power of personal desktop computers, such image processing ideas may be more feasible and requires further investigation. The advent of artificial intelligence (Nainar, 1988; Linden, 1988) or expert system software also allows more accessible programming of such systems.

4.2 Literature Review

The evolution of computerization in cephalometrics has closely followed the progression and development of computing itself. This will be evident in the discussion of the various automated cephalometric systems that have been proposed over the years.

Barret et al (1968) outlined a system which used punch cards and magnetic tape to store digitized coordinate data. They also described the functions of a number of programs which were written to perform superimpositions, error checks, statistical analyses and measurements of the cephalometric data. It is interesting to note that very little was mentioned regarding the hardware and languages used in the computing system. This is typical of the papers which were written at the time on computers and reflected the mystical attitudes towards computers of the period. The 1970's saw publications and papers require a greater understanding of computer systems by their reader base and thus technical information was expected and became routine.

The digitizer, or "record reader" as Barret et al (1968) described it, could make use of rear illumination. Basically, this was of the pantograph type which used articulated arms equipped with a ruler and protractor. The coordinates had to be manually entered onto the recording media of punch cards or magnetic tape (Barret et al, 1968); or into programmable calculators (Sutton and Spratley, 1981). By today's standards, this process would have been considered laborious and tedious but the claim was that analytical procedures on the data accumulated, in the long term, would be simplified.

Systems used by Walker (1972) and Houston (1979) involved similar setups; recording digitized data onto punch cards or tape and fed into an off-site central computer.

Chebib et al (1976) improved on this method and used a telephone line (modem) to transfer data to and from a remote computer. A special set of programs called CRAP (Cephalometric Records Analysis Programs) written in BASIC (Beginners All-purpose Symbolic Instruction Code) were described and performed the storage, editing, description and analysis of cephalometric data. The programs were designed as patient-oriented diagnostic and patient control systems. The authors felt that the information gathered by such a system, apart from enabling standardized cephalometric analyses, could also be used as data for research studies. They also recognized the potential of such a system to be modified for the study of any other image which could be resolved into the X and Y coordinate form, eg., photographs, orthodontic models, etc. The system unfortunately required a telephone line for access to the main computer and the high cost of the hardware at the time (approximately US$10000) made it feasible only to large practices and institutions.

Bergin et al (1978) furnished the first written account of an independent, self-contained computer system with the digitizer directly linked to a minicomputer and controlled by a graphics terminal. The computer used was a NORD-1, 16-bit machine and a Tektronix digitizer. However, this board was opaque and therefore required a tracing to be made before the radiograph could be digitized. Nevertheless, the authors claimed that their method was about twenty minutes faster than an ordinary manual radiographic analysis. The programs used were written in FORTRAN (FORmula TRANslation). Freer (1980) described similar hardware systems.

Faber et al (1978) set out a more comprehensive hardware and software plan which made use of digitized cephalometric data and a data base of growth information to perform orthodontic treatment planning. A Summagraphics™ tablet was used together with a 16-bit Alpha computer and the programs were written in the BASIC language. No mention was made as to the source of growth information used in the database.

Houston (1979) outlined the logic and structuring of a computerized cephalometric system using programs written in BASIC and FORTRAN. Rather than present details of his system he discussed the problems which could arise in the handling of such data. Likewise, BeGole presented the logic of a suite of IBM 370 Assembler Language (1980a) and

FORTRAN (1980b) programs designed to manage and manipulate cephalometric coordinate data.

Thomas et al (1984) described a comprehensive cephalometric system involving both desktop computers (Apple //™ series) and mainframe machines. Using flow chart diagrams, they outlined the linkages between the various hardware components of the CEPHS computer system. Their paper only outlined the logic involved in their Applesoft™ BASIC and FORTRAN programs but did not include any program listings.

Bhatia (1985) addressed the problem that, although a number of articles such as the ones above have been written on computerized cephalometric systems, none of them actually detailed their systems in their literature. Their paper then proceeded to outline the particular system used, but once again, ironically, simply outlined the hardware used and the logic and integration of a number of BASIC program modules. The programs themselves cannot be used unless the program listings are supplied.

Similarly, Konchak and Koehler (1985) described the logic of a Pascal computer program for cephalometric analysis without providing a comprehensive listing of the program. Such articles only present the design or broad picture of a particular computer system and is of little practical use. A person who is capable of programming a computer would already be capable of performing the logic outlined in an article of this form. Conversely, an understanding of such logic is only possible by persons with a fairly thorough knowledge of good software structuring.

Birnie (1983) presented a paper describing the essential elementary trigonometric functions that form the basis of a program to analyse digitized data. These are described in the BASIC programming environ and therefore the article is an excellent starting point from which a comprehensive cephalometric analysis programme may be developed.

Killany (1985) suggested the use of a computer spreadsheet program to perform calculations on cephalometric data. He alludes to the use of templates - pre-prepared files - into which coordinate data may be imported but does not present the formulae used in the templates.

As mentioned earlier a number of authors, including Savara (1972), Riolo (1972), Cohen et al (1984), Jackson et al (1985), Cohen and Linney (1986), Gatti and Amadori (1986) have investigated automated systems of cephalometric data acquisition. Their work suggested that these alternative systems were comparable to traditional techniques. The studies also reflected the level of technology of the time, indicating that with advances in hardware and lowering of costs these alternative systems would become more feasible and perhaps even expected (Savara, 1972; Cohen, 1984).

The role of computers in surgical treatment planning using cephalometrics is also described by various authors including, Engel et al (1979), Bhatia and Sowray (1984), Harradine and Birnie (1985), Cutting et al (1986), Walters and Walters (1986), Vannier et al (1985), and Moss et al (1988). The latter two studies utilized computed tomography (CT) scans. In this application, computerization allowed the rapid and interactive display of visual treatment objectives (VTO).

4.3 In-House Computer Systems

The literature review of some of the more publicised systems have essentially been in-house systems developed by various groups to cater for their own needs. The Cheblb and Cleall system (1976) described above was quoted in a recent study by Alavi et al (1988) from the same centre at the University of Illinois at Chicago.

The system described by Bhatia (1985) was earlier outlined by Bhatia and Sowray (1984) with applications to diagnosis and treatment planning in orthognathic surgery.

In diagnosis, the system used by Bhatia and Sowray (1984) compared the digitized data to templates of norms both numerically and in graphic form. Graphically this is performed by superimposing the graphic image generated by the acquired X,Y coordinates onto a "normal" template. The template being a mean or composite tracing prepared from a sample of cases. The reference sample may be made up of cases with good occlusion, or profile, or simply of cases drawn from the population at large. Bhatia and Sowray (1984) stated with perception that a graphical analysis can provide a quick, overall visual assessment of the deformity, and is particularly useful when the clinician is either not fully familiar with the numerical forms, or has doubts about their clinical significance. An analogy may be drawn between this concept and the use of graphs and charts to summarize scientific data and findings.

The treatment planning aspect of their computer package uses mathematical manipulations of the cephalometric data. The computer is used to predict the possible results on the soft tissues from specific surgical movements of the hard tissues. Engel et al (1979) suggested a multiple regression method for predicting the post-operative soft tissue profile point by point, from the hard tissue profile. Such "what if" scenarios are the bane of spreadsheet computing that has become so popular with desktop personal computers. This statistical method is shown to give a more accurate assessment of the post-operative soft tissue position than the non-surgical prediction method of using the various soft-tissue-to-hard-tissue ratios (Engel et al, 1979). The predicted profile is finally plotted either to the Video Display Unit (VDU) or plotter.

4.4 Commercial Computer Systems and Services

The discussion thus far has been on computerized cephalometric systems developed by institutions for their own applications. Portability was made difficult by the specialized equipment and skill required in operating such devices. Admittedly, the appropriate time periods have to be kept in mind. Computer systems have advanced to such an extent that processors of mainframe standards are now found on desktops. The hardware alluded to in the literature, such as digitizers are now widely available commercially.

Whilst it is now within the reach of amateur computer programmers to set up a cephalometric digitization package, the early 70's saw some pioneering work by Ricketts in establishing a computerized cephalometric service.

4.4.1 Commercial Services

Computerized analytical services are available through a number of sources such as orthodontic laboratories, which offer various levels of diagnoses. However, none can match the facility provided by the RMO group with their massive database of analysed cases.

Ricketts (1972) identified the need or value of computerization in orthodontics with the claims that this technology simplified the following tasks involved in cephalometry, that is,

a. measurement
b. recording
c. evaluation
d. comparisons
e. sorting
f. storage
g. organization
h. information retrieval

His involvement with Rocky Mountain Data Systems Incorporated, stems back to 1969 (Ricketts, 1969) with that group providing a laboratory service for the analysis of cephalographs.

Ricketts (1972a) along with others (Walker 1973, 1972, Houston 1979) recognized the potential of computer technology in the quantitative analyses of the radiographs of the head in that the quantity, accuracy and utilization of data could be increased to a level which far exceeded that possible through manual methods.

4.4.1.1 The Rocky Mountain Data Systems Diagnostic Service

The Rocky Mountain Data Systems (RMDS) software is one that has evolved from the early 1970′s. The system whilst providing a service of computerized cephalometric analysis, also built up a database of cephalometric data which in turn could be called upon to provide information for its growth prediction facility. By 1975, the service had a database of 40,000 records (Schulhof and Bagha, 1975).

Now referred to as the Rocky Mountain Orthodontic Custom Processing Service (RMOCPS), the facility provides the clinician with a thoroughly comprehensive three-dimensional "visualization" of the patient (Rocky Mountain Orthodontic Digest 1988, p.12-14).

The clinician is expected to send patient records comprising head films, wax-bite and wax-occlusal registrations and for a fee of A$175, a host of analyses is presented to the orthodontist. This includes both lateral and frontal cephalometric analyses and an arch analysis. A comparison is then made with individualized norms with respect to the patient's age, sex race and size. Drawing on their own database, a growth prediction is then performed for the particular racial typing. The computer programs are also designed to detect abnormal craniofacial growth patterns. The probability of future third molar impaction is assessed as well as an analysis of the respiratory airways.

The facility offers three options:

1. Diagnostic records sent in by mail and returned by mail
2. Records sent in by telephone modem to RMO Diagnostics in Calabasas, California, processed and returned by mail
3. The "send-in" CADIAS™ Processing Service, by the RMO lab in Calabasas, California..

The CADIAS™ personal system is described in 4.4.2.1.

Treatment planning involves determining the degree of difficulty of a case and the course of action to take as a result of arch length discrepancy, predicted growth and orthodontic/orthopedic conditions.

The RMO Diagnostics systems provide "workups" which cater to the clinicians' personal preferences regarding extractions, convexity change, esthetics and limits of tooth movement. Anticipated treatment results are plotted for both headfilms and dental arches (RMO Digest 1988).

4.4.2 Personal Desktop Systems

A number of commercial programs are now available which cater to clinicians who wish to analyse cases on their own personal desktop computers. The availability of these has coincided with the boom in personal computing and is evidenced by the advertisements promoting such software in the various orthodontic journals since the mid 1980's. Only the more popular and successful of these will be discussed.

In describing these systems, a major shortcoming must be emphasized. Much of the information is derived from the promotional material involved in advertising the software and therefore is expected to be biassed. Additional information can only be gained by personally evaluating the packages or by interviewing practitioners who use such software. Personal evaluation is usually not possible because of the concern over software piracy (illegal copying or unlicensed use of software) and often the very specific hardware requirements. These will be discussed in detail with the individual packages.

4.4.2.1 CADIAS^{tm}

CADIAS^{tm} is an in-office system developed and used by Rudolf Slavicek (MD, DDS), of Vienna, Austria. This system is designed to aid in diagnosis, documentation, storage, treatment selection and treatment presentation. The program has two components - cephalometric analysis and temporomandibular joint diagnosis.

Information acquisition can range from the simple to the complex. The simplest form of data is a lateral radiograph and a rendition of the lower arch. The program allows printing of a detailed analysis with a choice of the Slavicek, Ricketts, Jarabak, Sassouni, Steiner or Bjork methods as well as a colour hard copy plot of the particular analysis.

The preferred method of treatment planning and presentation may be selected from a list of orthodontic and gnathologic-oriented analyses. Definition, norms, clinical deviations, change with age and method of application of any value may be viewed. The severity of deviations from the norm are colour coded on tracings and listed next to each value available on the system. Thus the degree of treatment difficulty can be quickly established.

After the diagnostic records have been processed, desired treatment objectives may be keyed in, for example, movement of point A or changing the incisor inclination or protrusion. The visual treatment objectives aspect of the program then incorporates these changes, projects the soft tissue profile and grows the lateral dimensions along the averages for two years for growing patients (Ricketts 1957, Schulhof and Bagha 1975). Leeway space is taken into account when dealing with the deciduous and mixed dentition.

The patient's data is then reviewed and approved and the information simultaneously stored on a hard disk and on a removable floppy disk. A statistical package when combined with CADIAS^{TM}, can produce four colour transparencies, and allow educational presentations of case data.

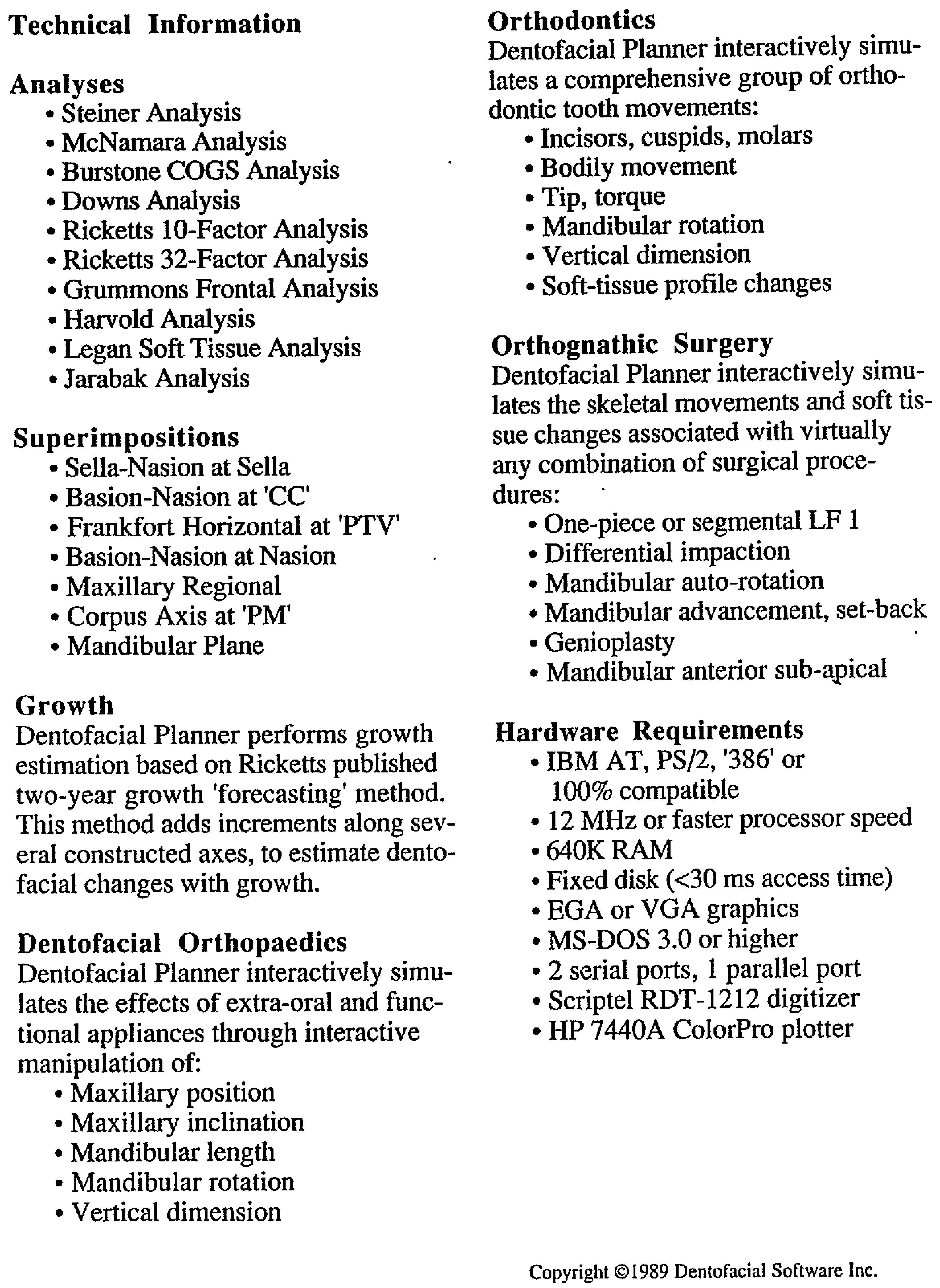
The vast RMO database may be accessed by this program via modem. A full featured package such as this comes at a premium of A$12000, excluding hardware.

A demonstration of this system was viewed at the 11th Australian Orthodontic Congress. Unfortunately, the personnel conducting the display could not provide any technical information being themselves orthodontic auxillaries who were merely trained to perform cephalometric tracings. The system was demonstrated on an IBM™ compatible, MS-DOS™ machine and used a rear illuminated, Houston Hipad™ digitizer with a single button cursor. A plotter was used to create the hard copies of the analyses.

4.4.2.2 Dento-Facial Planner™

A program such as the CADIAS™ is probably too extensive and costly outside an institutional environment. The following three systems are more accessible to the single user.

The DentoFacial Planner™ package has been available since 1985. The program, written by Richard Walker (DDS) of the University of Toronto, was advertised in 3 versions for the three major computer systems of the time, being the Macintosh™, Apple //™ and IBM™ computers. Figure 4.3 is a reproduction of the technical sheet outlining the features of the latest version of DentoFacial Planner™. Only an MS-DOS version seems to be offered at present and the cost is about US$1900.



Technical Information

Analyses

- Steiner Analysis
- McNamara Analysis
- Burstone COGS Analysis
- Downs Analysis
- Ricketts 10-Factor Analysis
- Ricketts 32-Factor Analysis
- Grummons Frontal Analysis
- Harvold Analysis
- Legan Soft Tissue Analysis
- Jarabak Analysis

Superimpositions

- Sella-Nasion at Sella
- Basion-Nasion at 'CC'
- Frankfort Horizontal at 'PTV'
- Basion-Nasion at Nasion
- Maxillary Regional
- Corpus Axis at 'PM'
- Mandibular Plane

Growth

Dentofacial Planner performs growth estimation based on Ricketts published two-year growth 'forecasting' method. This method adds increments along several constructed axes, to estimate dentofacial changes with growth.

Dentofacial Orthopaedics

Dentofacial Planner interactively simulates the effects of extra-oral and functional appliances through interactive manipulation of:

- Maxillary position
- Maxillary inclination
- Mandibular length
- Mandibular rotation
- Vertical dimension

Orthodontics

Dentofacial Planner interactively simulates a comprehensive group of orthodontic tooth movements:

- Incisors, cuspids, molars
- Bodily movement
- Tip, torque
- Mandibular rotation
- Vertical dimension
- Soft-tissue profile changes

Orthognathic Surgery

Dentofacial Planner interactively simulates the skeletal movements and soft tissue changes associated with virtually any combination of surgical procedures:

- One-piece or segmental LF 1
- Differential impaction
- Mandibular auto-rotation
- Mandibular advancement, set-back
- Genioplasty
- Mandibular anterior sub-apical

Hardware Requirements

- IBM AT, PS/2, '386' or 100% compatible
- 12 MHz or faster processor speed
- 640K RAM
- Fixed disk (<30 ms access time)
- EGA or VGA graphics
- MS-DOS 3.0 or higher
- 2 serial ports, 1 parallel port
- Scriptel RDT-1212 digitizer
- HP 7440A ColorPro plotter

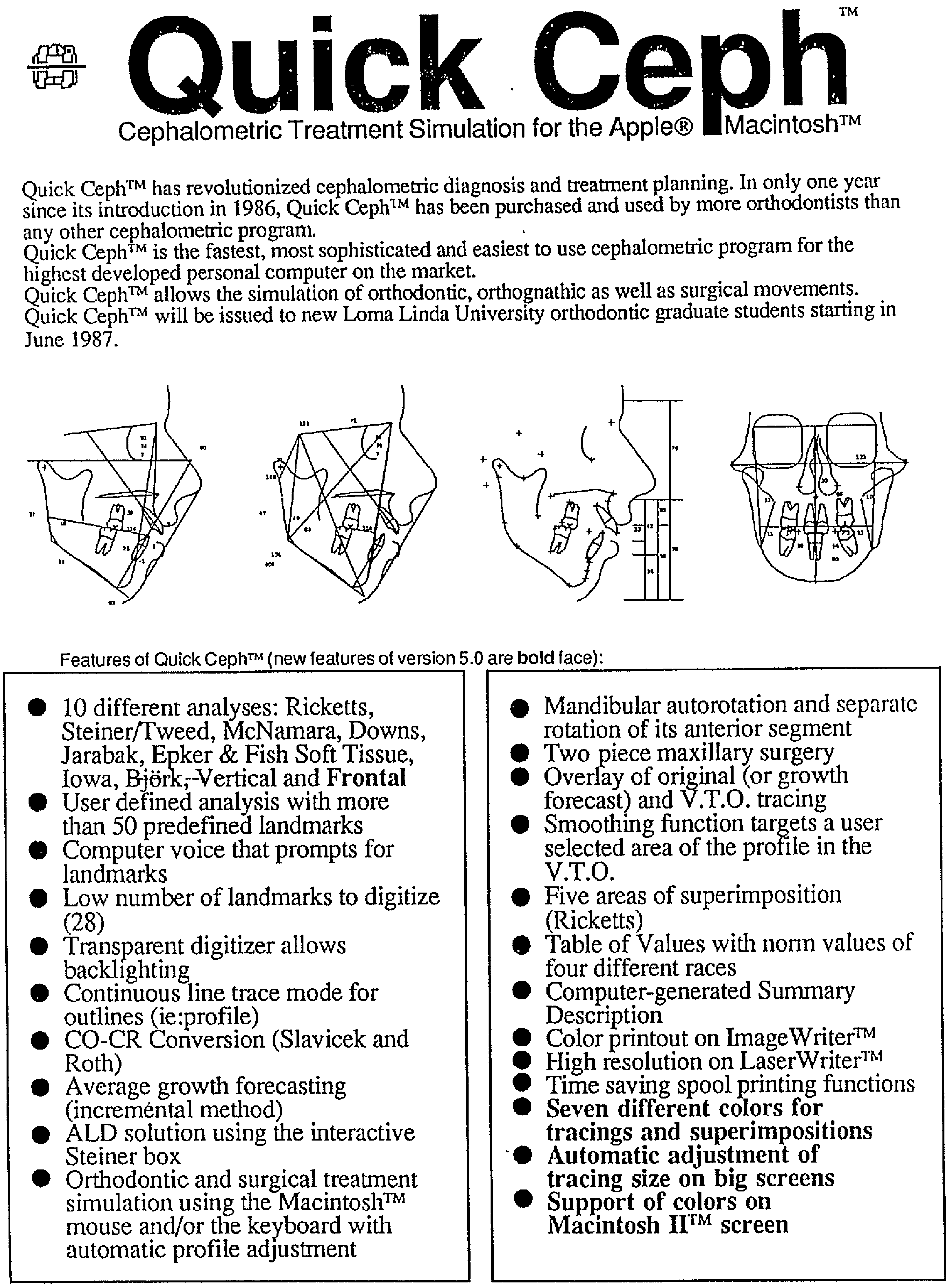
Fig. 4.3 Features of the Dentofacial Planner™ program.

This package is described as a cephalometric analysis package which allows surgical VTO's, user definable points and landmarks and a wide range of cephalometric analyses. The latest release caters for some of the advanced features found on the latest personal computers, these being Video Graphics Array (VGA) screen displays and the use of a math coprocessor to improve the speed of floating-point mathematical calculations.

4.4.2.3 Quick Ceph™

The Quick Ceph™ package was written by an orthodontics post-graduate student at the Loma Linda University in California, USA. The program is now marketed by Ortho Processing and continues to be updated by its author. This is currently the only program that runs on the Macintosh™ computer. Copy-protection is afforded by way of modifications to the Scriptel™ digitizer, and therefore, the package must be purchased as a unit of hardware and software, each costing US$995.

Being a Macintosh™ based program it incorporates many of the features of that machine such as windows and pull down menus. Figure 4.4 is a reproduction of the promotional leaflet for Quick Ceph™. The program works in colour and hard copies may be produced on a laser printer. Analytical features are similar to the others packages mentioned and it also allows for the exporting and importing of ASCII text files for compatibility with other machines.



Quick Ceph™

Cephalometric Treatment Simulation for the Apple® Macintosh™

Quick Ceph™ has revolutionized cephalometric diagnosis and treatment planning. In only one year since its introduction in 1986, Quick Ceph™ has been purchased and used by more orthodontists than any other cephalometric program.
Quick Ceph™ is the fastest, most sophisticated and easiest to use cephalometric program for the highest developed personal computer on the market.
Quick Ceph™ allows the simulation of orthodontic, orthognathic as well as surgical movements.
Quick Ceph™ will be issued to new Loma Linda University orthodontic graduate students starting in June 1987.

Features of Quick Ceph™ (new features of version 5.0 are **bold** face):

- 10 different analyses: Ricketts, Steiner/Tweed, McNamara, Downs, Jarabak, Epker & Fish Soft Tissue, Iowa, Björk, Vertical and **Frontal**
- User defined analysis with more than 50 predefined landmarks
- Computer voice that prompts for landmarks
- Low number of landmarks to digitize (28)
- Transparent digitizer allows backlighting
- Continuous line trace mode for outlines (ie:profile)
- CO-CR Conversion (Slavicek and Roth)
- Average growth forecasting (incremental method)
- ALD solution using the interactive Steiner box
- Orthodontic and surgical treatment simulation using the Macintosh™ mouse and/or the keyboard with automatic profile adjustment
- Mandibular autorotation and separate rotation of its anterior segment
- Two piece maxillary surgery
- Overlay of original (or growth forecast) and V.T.O. tracing
- Smoothing function targets a user selected area of the profile in the V.T.O.
- Five areas of superimposition (Ricketts)
- Table of Values with norm values of four different races
- Computer-generated Summary Description
- Color printout on ImageWriter™
- High resolution on LaserWriter™
- Time saving spool printing functions
- **Seven different colors for tracings and superimpositions**
- **Automatic adjustment of tracing size on big screens**
- **Support of colors on Macintosh II™ screen**

Fig. 4.4 Features of the Quick Ceph™ program.

4.4.2.4 PCDIG™

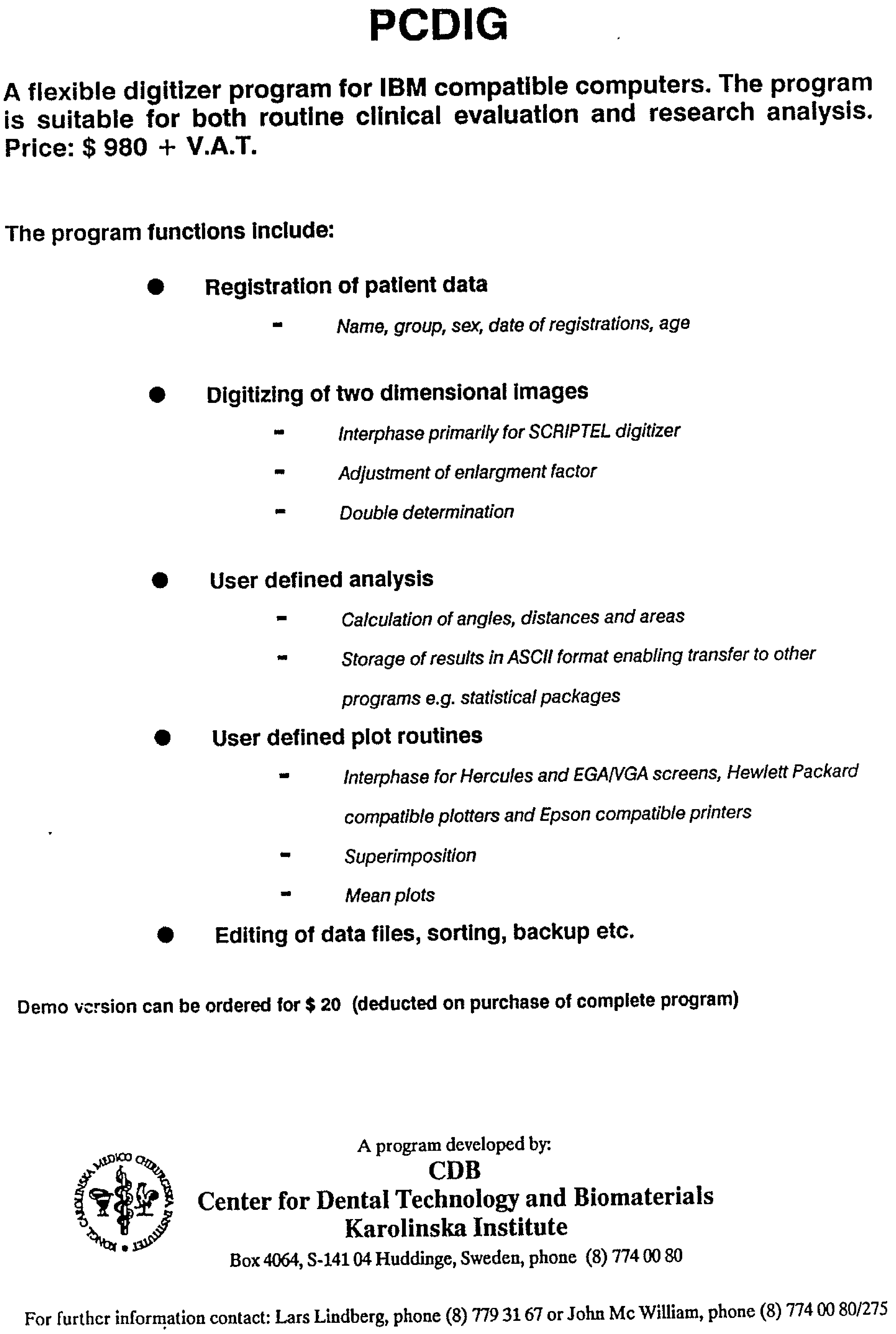
This is the latest entrant in cephalometric analysis software and comes from the Karolinska Institute in Sweden. Unfortunately at the time of writing, additional information in the form of a demonstration disk is still being expected. A promotional leaflet (fig. 4.5) describes the program as purely a cephalometric analysis package for two dimensional images which runs in the MS-DOS environ and interfaces with the Scriptel™ digitizer. The highlighted features include the usual cephalometric analyses, user definable analyses, superimpositions and mean plots. Storage of the results is in the ASCII (American Standard Code for Information Interchange) format for compatibility with popular desktop applications such as spreadsheets and statistical programs. The advertised cost is US$980.

4.4.2.5 Non-Cephalometric Software Applications

This section covers the use or application of standard non-specific software which may be customized for the purposes of digitization and cephalometric analysis of headfilms. Briefly these include:

a. Computer languages such as BASIC, Pascal, FORTRAN and C which currently incorporate routines and syntax that specifically communicate with digitizing interfaces. The user or programmer then includes these routines into a custom application. Likewise trigonometric functions pertinent to cephalometrics are also available.

b. Specialized data acquisition software which may be used to digitize information directly into other software applications such as databases and spreadsheets. Examples of these include Lotus Measure™ and HotDIJ™ (Byte, 1988).



PCDIG

A flexible digitizer program for IBM compatible computers. The program is suitable for both routine clinical evaluation and research analysis. Price: $ 980 + V.A.T.

The program functions include:

- **Registration of patient data**
  - *Name, group, sex, date of registrations, age*
- **Digitizing of two dimensional images**
  - *Interphase primarily for SCRIPTEL digitizer*
  - *Adjustment of enlargment factor*
  - *Double determination*
- **User defined analysis**
  - *Calculation of angles, distances and areas*
  - *Storage of results in ASCII format enabling transfer to other programs e.g. statistical packages*
- **User defined plot routines**
  - *Interphase for Hercules and EGA/VGA screens, Hewlett Packard compatible plotters and Epson compatible printers*
  - *Superimposition*
  - *Mean plots*
- **Editing of data files, sorting, backup etc.**

Demo version can be ordered for **$ 20** **(deducted on purchase of complete program)**

A program developed by:
CDB
Center for Dental Technology and Biomaterials
Karolinska Institute
Box 4064, S-141 04 Huddinge, Sweden, phone (8) 774 00 80

For further information contact: Lars Lindberg, phone (8) 779 31 67 or John Mc William, phone (8) 774 00 80/275

Fig. 4.3 Features of the PCDIG™ program.

c. Spreadsheets such as Lotus 1-2-3™ and Microsoft Excel™ may be used to develop templates into which digitized data may be imported and analysed for dimensional and statistical purposes.

d. Database development systems such as dBASE IV™, Clipper™ and Foxbase™ which apart from storing digitized data for archival purposes can also analyse the data with their newer and enhanced functions.

e. Artificial intelligence and expert system languages such as Turbo Prolog™ which may be used for the development of diagnostic tools calling upon digitized data. In this field, would come the possibility of developing truly automated headfilm recognition systems which may one day see the computer performing landmark identification - a refined form of the work on image recognition by Riolo (1972) and Cohen, Ip and Linney (1984).

f. Image analysis software such as the Bioquant system which is a powerful general purpose image analysis package which may be customized for cephalometric purposes.

g. Computer aided-design (CAD) packages such as AutoCAD™ and its programming language AutoLISP™ which may be used for both displaying and manipulating digitized data for visual treatment objectives and surgical work-ups.

4.5 Discussion

The foregoing traces the development and evolution of various cephalometric software packages up to the present day.

Some of the more important features which have been noted to be essential in a program of this nature need to be highlighted. Fortunately the developers of all the programs reviewed have recognized these aspects. This indicates an incorporation of the popular demands of the users, referred to in computer jargon as "wish-lists". The Quick Ceph™ program is unique in that it only runs on the Apple Macintosh™ and therefore only works with its own preferred peripherals. The characteristics include:

a. MS-DOS™ compatibility except for Quick Ceph™.

b. Compatibility with a wide range of hardware configurations and peripherals such as video monitors, digitizers, printers and plotters.

c. User definable analyses are available in all the packages except for the latest version of DentoFacial Planner™. This facility was provided in older versions of the program and may have been dropped for streamlined performance.

d. All packages interfaced with the Scriptel™ digitizer which today seems to be the unequalled tablet of choice because of its transparent surface and ability to emulate other digitizers. The cursor has four buttons and the popular model is sufficiently sized at 12" X 12" for cephalometric work. The only other current popular choice, and one supported by the programs is the Houston Hipad™ which is translucent. The disadvantages of this board include the difficulty in modifying its settings which are all optioned via its cabling. Opaque boards will also function, but as pointed out by Richardson (1981) these require the additional process of manual tracings, in an otherwise efficient cephalometric analysis.

The Quick Ceph™ program restricts itself to the Scriptel™ board as a means of copy protection.

e. All programs have a graphics facility to display the digitized images. The resolution of the images depend on the computer hardware configuration. Curved lines appear jagged on screens with resolutions below 1024 X 728 pixels. Currently, the best images at an economical level, are those afforded by the VGA (Video Graphics Array) screens at 720 X 350 pixels. However, hardcopy output by laser printers and plotters ensure smooth representations of curves.

f. Superimpositions are performed according to Bjork's protocol (Bjork and Skieller, 1983). Superimposing on SN and palatal plane is relatively straightforward as the points involved may be located quite reliably between radiographs. However, overlays based on the stable structures of the mandible are difficult as these are ideally located subjectively by patterns of best fit. Although this is theoretically possible using image processing algorithms, the reviewed packages rely on fiducial points marked by the user - a further source of errors.

g. All the packages are able to store their coordinate data and results in the ASCII (American Standard Code for Information Interchange) text format, which is universally recognized by all computers and operating systems. The format also allows other software applications such as spreadsheets, databases and expert system packages, to import such information. However, although the system allows a degree of universality, storage in this format is not space intensive and as large amounts of data are accumulated, may pose a problem in search and retrieval procedures.

None of the packages offer any degree of programmability by the user. Although analyses may be custom defined, modifications at a higher level are not permitted as is possible with many popular desktop programs. The reason for this may be the restricted market of these programs wherein such enhanced features call for more extensive programming. The fact that these programs have an ability to export their data into other packages probably caters for such demands.

It is debatable as to whether a more space intensive system of data storage should be pursued when weighing up the benefits of universal readability of the data and efficient storage means. The author utilizes a method of binary encoding for patient and coordinate data. Appendix A outlines how this relatively simple but fast encoding process is performed. Data stored in this manner takes up only 33% of the space utilised by a similar ASCII file (250 bytes versus 750 bytes). When required, such information being of such a small volume may be decoded quickly if required within another program. For compatibility, the dBASE™ file format may be recommended as it is currently used by many business and other database applications, including dental practice management systems. However, further investigation and development work is required to incorporate binary encoded or compressed data into such files (Strehlo, 1989).

CHAPTER FIVE

RATIONALIZING COMPUTERIZATION IN CEPHALOMETRICS

The advent of computing and the availability of computers to research institutions from about the 1950's saw these new tools as an efficient means of handling and analysing scientific data.

The early hardware systems were mainly used to perform statistical manipulations of data that were acquired and fed into the computer using punch cards. Punch cards were also used to introduce programs to the computer.

Data acquisition devices of the 1950's and early 1960's were mainly of the manual type with electronic forms appearing in the latter half of the 60's. In their applications to cephalometrics, radiographs were manually traced and digitized (Walker 1972) and the X, Y coordinate information was then fed into the computer via punch cards. Walker (1972) also mentions the use of a scanning and recording device (the Benson Lehner OSCAR) which could record coordinates from digitized tracings after the information was converted by an analog-digital converter. Although the manual procedures of recording and feeding of data into the computer were laborious, the subsequent facility of being able to rapidly retrieve and analyse this material was a distinct advantage.

This chapter discusses the rationale for applying computers in the discipline of cephalometrics. Over the last thirty to forty years orthodontics has steadily developed and improved its skills. There have been many innovations, particularly at the mechanical level. The profession's armamentarium of appliances and application of materials is very impressive and has progressed at such a rate that in some instances, sufficient evaluations have not been performed (Hume, 1988).

These advances in technical skills have overshadowed, and may to some extent have retarded, the equally necessary advances at the biological level such as a deeper understanding of facial growth and development. This particular aspect calls for long-term biological studies of changes caused by growth and treatment. Cephalometrics provide the foundation for objective measurements of craniofacial changes over relatively long periods of time.

Ricketts (1969) looked at the way diagnosis in orthodontics has evolved towards encompassing computerized cephalometrics. Along with Barret et al (1968), Walker (1972) and Savara (1972), he recognized the computer as the channel by which the advances in communicating data and measurements, could be brought together.

Concomitant with the development of various computerized systems for analysing headfilms, much has been written as to how this technology has aided the research and use of cephalometrics. Some of these points are discussed below.

5.1 Improved Reliability

Baumrind and Frantz's classic study (1971a, 1971b) on the reliability of headfilm measurements highlight a number of key sources of errors in cephalometrics. These may be divided into system errors and random errors (Cohen, 1984).

Some of the more pertinent terms which are involved when discussing these errors are listed below together with their definitions from the Macquarie Dictionary (1985).

a. Accuracy - the condition or quality of being free from error or defect.

b. Error - the difference between an observed or approximately determined value and the true value of a quantity.

c. Reliability - capable of being depended upon with confidence.

d. Reproducibility - capable of being duplicated or replicated.

5.1.1 Landmark Identification

Since the first observations by Richardson (1966), authors including Baumrind and Frantz (1971a), Midtgard et al (1974), Broch et al (1981), Stabrun and Danielsen (1982), Cohen (1984), el-Mangoury et al (1987) and Vincent and West (1987) have investigated the reliability and reproducibility of cephalometric landmarks. The errors involved in landmark identification stem from a range of factors including the radiographic process, radiographic image and the subjectivity of the examiner.

The radiographic process comprising a diverging x-ray beam introduces two problems, that of magnification and a gradation of enlargement between structures located at the centre of the beam and those at the periphery. The magnification factor can range up to 15 per cent at the peripheries and this has to be taken into account when comparing measurements to norms (McNamara, 1984). McNamara's (1984) normative data are based on an enlargement factor of 7-8 per cent (Fig. 2.8). The enlargement factor may be kept constant by maintaining the distances of the x-ray source, subject and film. Bergersen (1980) addressed this problem of enlargement and distortion and presented a set of compensation tables that may be applied to both lateral and frontal cephalograms.

The divergence of the x-ray beam also creates dual images of structures located either side of the midsagittal plane, these include porion, gonion and orbitale (Grayson et al, 1988). These are system errors and may be calculated from the geometry of the apparatus and by the use of standard scales in the field of view (Cohen, 1984).

Image quality can also contribute to system errors, McWilliam and Welander (1978) looked at the use of rare-earth phosphor intensifying screens to reduce x-ray dosage to patients and found that they did not adversely affect the reliability of cephalometric measurements.

Oka and Trussel (1978) commented on the research work being carried out on the enhancement of x-ray images by electronic means; as a method of improving the reliability of cephalometric radiography.

The paper by Baumrind and Frantz (1971a) went on to outline a number of causes of errors in landmark identification. Grouped under random errors, these include:

a. the reproducibility of a landmark being greater if it is located at a sharp point such as the incisal edge, as distinct from points such as menton which lie on a gentle curve.

b. the concept of the non-circular envelope of error. This is best explained by considering points such as menton and pogonion (Fig. 5.1). Menton is more consistent in the y-coordinate as it is located on a relatively horizontal plane whilst pogonion is more consistent in the x-coordinate being located on a near vertical line (Vincent and West, 1988).

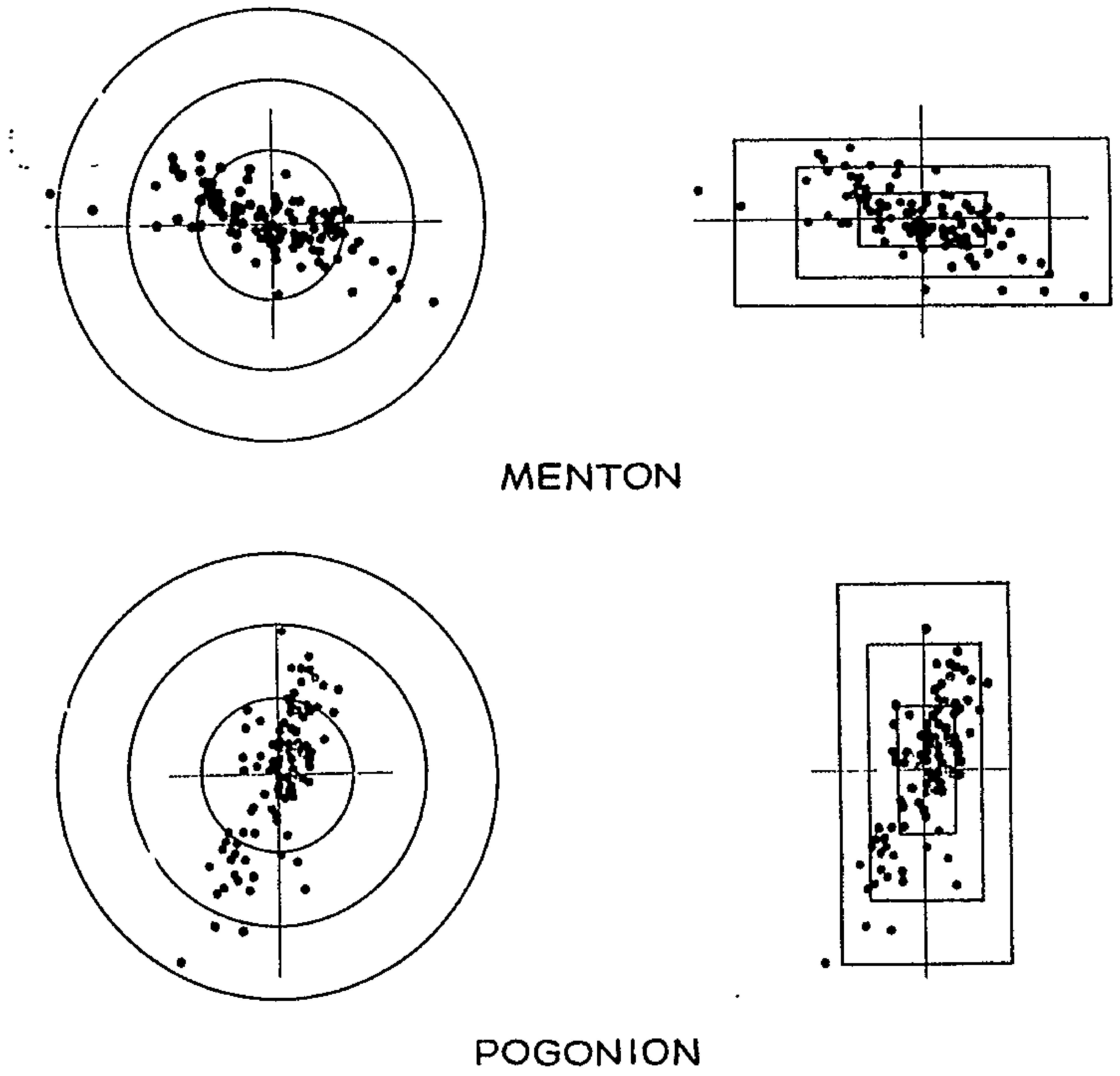


Fig. 5.1 Scattergrams of Menton and Pogonion, depicting non-circular envelope of error.
(from Baumrind and Frantz, 1971a)

Likewise, all landmarks have a characteristic envelope of error when repeatedly identified - the resulting scattergram following the curve along which the point lies (Stabrun and Danielsen, 1982). Accordingly, Cohen (1984) recommended the use of measurements taken at right angles to the plane of the greatest error. In the example for menton, vertical dimensions would be more reliable than horizontal ones. Relatively more reliable points, such as, the upper incisal edge and sella, have a more circular envelope of error (Fig. 5.2).

Fig. 5.2 Scattergrams of Sella and Upper Incisal Edge. (from Baumrind and Frantz, 1971a)

c. film contrast in the region of the landmark is another influencing factor - points on the surface of the skull such as nasion are more easily located than points such as basion which are in the confines of the skull and blurred by visual "noise" (Baumrind and Frantz, 1971a).

d. the recognized definition of the point can lead to errors between examiners. Examples of these include, orbitale, which may be defined as the most inferior point of the most prominent or anterior of the images of the orbit, and porion which may be anatomic or machine-based.

e. the problem of subjectivity is raised by Cohen (1984) whereby personal estimation can be highly variable with regard to points such as sella, which are dependent on the averaging perception qualities of the examiner.

f. head posture and positioning can affect the quality of the radiograph whereby bilateral landmarks such as gonion, if not superimposed on each other, need to averaged. Naturally, this could also be due to facial asymmetry. In actual landmark identification, the orientation of the radiograph itself is important for definitions such as the most inferior or superior point on a curve. A consistent mechanism of orientation should be employed for all films to maintain consistency in landmark definitions.

Grayson et al (1988) in studying three dimensional cephalograms addressed an important and unquestioned aspect of the lateral headfilm - the fact that many points such as menton which are identified singly as being in the midsagittal plane are in fact perceived as lateral points.

The crux of the foregoing discussion is that the reliability of headfilm studies may be improved by careful radiographic technique and double determination of landmarks (Baumrind and Franttz, 1971b). This procedure can only be made viable by computerization (Baumrind, 1972a; Savara, 1972; Richardson, 1981; Houston, 1979, 1982, 1983). The emergence of video digitization as a means of fully automated coordinate data acquisition may well ease the relatively labour intensive steps of manual digitization. Image enhancement schemes (Oka and Trussel, 1978) would reduce system errors as would newer imaging techniques (Moss et al, 1988). The image processing systems as described by Cohen et al (1984), Jackson et al (1985), Cohen and Linney (1986), Gatti and Amadori (1986) coupled with artificial intelligence (Linden, 1988) could also eliminate the subjectivity factor in identifying cephalometric landmarks.

5.1.2 Analytical Procedures

The various cephalometric analyses have been discussed in Chapter 2. The diagnostic value of a headfilm may be increased by the variety of analyses performed on it - using various measurements to validate and cross-check each other. An example of this is the confirmation of measurements based on the SN line by examining its own length and angulation relative to the Frankfort Horizontal. Likewise the Wits′ appraisal is dependent on the cant of the occlusal plane. Bishara et al (1984) stress this point in their soft-tissue studies and conclude that a number of soft tissue parameters should be used to for an accurate evaluation of the soft-tissue profile.

This suggests that an operator who is only interested in one minor aspect of a headfilm such as the ANB angle should for the sake of accuracy be measuring and taking into account the length of SN and its cant to Frankfort Horizontal to determine the true nature of the relative skeletal and dental discrepancies.

Baumrind and Frantz (1971a) also emphasized that faults in landmark identification are compounded when two or more of these points are used in a particular measurement. They quantified the error by claiming that in a sixteen point analysis the probability of locating all sixteen points within two standard deviations of each landmark is 0.95^{16}, or 44 per cent. They further emphasized that replicating the process improved the accuracy to 98 per cent. The magnification factor, although not a problem in angular measurements, needed to be accounted for in the linear dimension. Their second paper (1971b) discussed percentage errors and emphasized that short linear measurements are more prone to errors.

On an empirical level, the author has found that certain constructed points such as gonion and Xi point may be located or placed with improved reproducibility if constructed geometrically from other more reliable digitized landmarks. For example, the construction of sella from its skeletal contours (Bjork and Skieller, 1983), thereby avoiding the problem of subjectivity. Similar observations on reproducibility have been noted for orthogonal analyses (Rakosi, 1982) including the Wits' analysis whereby perpendicular lines need to be constructed.

This discussion further emphasizes the need for some form of automation, if only to eliminate the laborious steps involved in the validation of analyses, and geometric and arithmetic procedures.

5.1.3 Tracing Superimposition

Apart from the diagnostic value of analyzing individual headfilms, tracings of cephalograms may be superimposed for an assessment of growth and treatment changes. Although Baumrind et al (1976) felt that the errors involved in superimpositions tend to randomize out in large samples, they concluded that with individual cases, that is, in the clinical situation involving smaller samples and smaller time scales, these errors could only be reduced by the replication of tracings. Baumrind and Miller (1980) outline their system of performing repeated tracings using a system of fiducial points and four replications of each film. They claim that such a lengthy procedure whilst minimising errors is only feasible with automation.

On a technical note, Heath (1980), Birnie (1983) and Johnson (1987) present some excellent programming routines and useful formulae for superimpositioning techniques.

Sluiter et al (1985) suggested an alternative method of computerized superimpositioning. In contrast to the technique of punching holes as fiducial landmarks (Baumrind and Miller, 1980; Vincent and West, 1988; McWilliam, 1982), they suggested direct digitization of arbitrary reference points on the borders of superimposed radiographs and then calculation of the vector displacement and rotation of these points. Whilst this technique exploits and highlights the computational capacity of the computer, an assumption is made that the head posture remains reproducible over successive films.

The author is currently experimenting with a further method of manipulating successive digitized tracings "on screen" as in a digital extension of adjusting consecutive manual tracings. Once again this utilizes the power of the computer to calculate treatment and growth vectors.

5.1.4 Manual Tracing versus Digitization

Having established that cephalometric errors may be minimised by the replication of landmarks and by the gathering of a number of landmarks for cross-verification - the question needs to be asked whether computerization as applied to cephalometrics is an essential requirement for research and clinical studies (Richardson, 1981).

It is surprising that very little research has been performed with regard to actually comparing the reliability of conventional tracing methods and digitization. This is representative of the phenomenon whereby current advances in most disciplines seem to take place with minimal evaluation - a characteristic which occurs as a result of the rapidity of change, lack of manpower to investigate new products, the rush by manufacturers to release their wares on the market and finally the demand by end-users and consumers for the latest offerings (Hume, 1988; Bramble, 1988). The result of this is that new ideas are often evaluated in actual treatment situations (Bramble, 1988). Examples include, orthodontic supply companies which invite practitioners to evaluate new debonding procedures (Ortho-Cycle, 1989). The application of this argument to computing may not be as dramatic but it serves to highlight the blind acceptance of new technology. On the subject of software, orthodontic journals should encourage the publication of reviews of cephalometric software and product comparisons - a feature of many generalized computer publications.

Richardson (1981), Cohen (1982) and Houston (1982) in comparing manual tracings to digitized information were almost all in agreement that there was very little to choose between the two methods when discounting the time factor. The difference lay in the speed with which the computerized systems could perform the procedures. They also found that direct digitization made replication more feasible, thereby minimising errors.

Interestingly, Cohen's (1984) data favoured the digitization of tracings over direct digitization from the radiographs. Houston (1982) suggests that the reliability of tracings could be matched by increased replication in digitization.

5.2 Clinical Application

Proceeding from the previous section, it may be argued that in the single event measurement of a headfilm, either method of manual tracing or direct digitization is reliable. However, the benefits of digitization become more obvious in the long term and are summarised in the following:

a. minimisation of errors by double determination.

b. conducive to gathering a larger number of points from a single headfilm.

c. establishment of a reliable source of data for superimpositioning investigations, once again a benefit of the use of a larger database of landmarks.

d. extensive analyses may be performed with various lines and reference planes cross-checking each other. This point is further emphasized by the work of Wylie et al (1987) who claimed that various analyses seemed to be more relevant to specific deformities and surgical procedures.

e. patient education and rapid depiction to patients of growth and treatment changes based on computer graphics from digitized data.

f. an instructional device for students at undergraduate and postgraduate levels. However, instruction in cephalometrics should begin with manual tracing methods, so that identification skills, pattern recognition and measurement abilities are developed to gain a better appreciation of the computerized methods.

g. A system which may be delegated to and reliably used by auxiliary dental staff.

h. the building of normative data and growth study databases in a uniform manner at an individual, national and international level (Ricketts, 1972; Savara, 1972 and Sloan, 1980).

i. as with tracings, digitized data may be graphically represented but with the added advantage of performing and displaying visual treatment objectives (VTO). These VTO's may be performed for both orthodontic (Thames et al, 1985) and orthognathic surgery cases (Engel et al, 1979; Bhatia and Sowray, 1984; Harradine and Birnie, 1985; Cutting et al, 1986; Walters and Walters, 1986; Vannier et al, 1985; and Moss et al, 1988). Computerization here is not to be seen as providing more accurate treatment ideas but rather as a means of expediting the technical processes (Thames et al, 1985).

5.3 Cost Effectiveness

The cost/benefit aspect of computerization in cephalometrics is a subject that has not been properly nor directly addressed in the literature. The investigations above, whilst discussing the efficiency and reliability of computer applications in the analysis of headfilms more or less assume, and indirectly suggest, that this in itself makes computerization effective.

The author will, therefore, attempt to analyse the cost efficiency of applying this high technology to cephalometrics. Investigations of this nature must take into account the fact that actual figures can rapidly become obsolete and irrelevant in the time scales involved in computing. This may be one of the reasons that actual costs are rarely quoted in the literature. The figures quoted below therefore are only to be used in a comparative form and the costs outlined are expected to fall - once again a characteristic of the costs involved in computing

(Davies, 1989). The statement that these costs are declining needs some qualification - that is, whilst numeric values may remain constant, it is the effective cost of technology that drops when taking into account inflation and the rapidity and level of advancements involved (Davies, 1989 and Cohen, 1989).

5.3.1 Monetary Costs

A computerized cephalometrics system may be divided into the two elementary components of any microcomputer system, that of hardware and software. The hardware comprises the computer with its barest essentials, that is, a central processing unit, screen display, disk storage, a keyboard input device and a data acquisition device with its interfacing unit to the computer (Fig. 3.1). The computer involved is expected to perform tasks such as practice management, wordprocessing and various other automated functions and consequently represents a shared expense.

The data acquisition device then, is the only specific hardware requirement that is unique to a cephalometric package. Current technology sees the two dimensional tablet digitizer as being the most economical and accessible method of digitizing headfilms (Diehl and Apiki, 1989), consequently this method of digitization will be used in the following analysis with the extra cost of scanners, image enhancers and video digitizers to be added for increased sophistication.

Tablet digitizers range in price from about $800 for opaque boards to about $6000 for rear illuminated translucent or transparent digitizer modules. The median price currently is about $2000 for translucent and transparent boards with dimensions of 12" X 12" which are adequate for the standard cephalogram.

Software costs for cephalometric programs range from about $1000 to $12000 for the complete software package from Rocky Mountain Data Systems. Once again the median price is approximately $2000. Additional costs are incurred in upgrades and some software packages have an upfront upgrade fee which is paid yearly.

Current Australian taxation legislation allows accelerated depreciation on computer hardware as a capital asset and a complete deduction on the cost of software used for professional purposes. Government institutions have a further cost advantage in not being liable for sales tax, although in this respect software is now exempt from sales tax.

Assuming an outright cash purchase of a digitizer and cephalometric software, the cost to an operator in the first year would on the average be about $4000. Tax deductions based on the highest marginal tax rate, would reduce this amount to $1000 (software) and $1800 (hardware), for a net effective cost of $2800. If only 200 patients or cephalograms are analysed in a year, then each digitized analysis would cost about $14. A clinician would probably take up to half an hour to perform a comparable manual analysis and even on a net income of say $60/hour, the cost saving are obvious. This would be a "worst case" scenario based on the first year of use and the expense would be rapidly reduced over subsequent years.

Naturally, these costs are further diminished by rental and leasing schemes which apart from a lower initial outlay provide additional taxation relief. This argument when applied to a group practice with shared costs and a greater volume of diagnostic records appears even more favourable. Depending on the importance or number of cephalographs analysed, different circumstances could justify the more expensive hardware and software options purely on costs.

The section has only emphasized monetary costs. However, previous discussions have alluded to the improved diagnostic qualities of a digitized and computer analysed cephalogram which then increases the value of a particular radiograph, having subjected the patient to x-rays.

5.3.2 Time Value

With computerization, the time involved in recording and analysing a headfilm by the clinician may be dramatically reduced. The rate determining step in computer analysis of headfilms is in the data acquisition process and once familiar with a sequence of landmarks, the author has found that digitizing 56 sequential points takes just over 2 minutes. Bergin et al (1978) timed their process at 1 minute for 31 points.

Highly optimised software can analyse and graphically display such data in negligible time. Additional time is required for hardcopy printouts of analyses and graphic plots; with laser printing currently representing the state of the art in both speed and quality of output. Once again the printing hardware would be a shared cost unless a plotter is used or demanded by the software.

Having established that the most time intensive process is that of data acquisition, there are two options available; either fully automated digitization as with scanning or video digitization (Cohen et al, 1984; Jackson et al, 1985; Cohen and Linney, 1986; and Gatti and Amadori, 1986) or delegating the task to a trained technician or dental auxiliary. The technology option would depend on availability of such a system and ultimately the interest of the operator.

The training of an auxiliary to perform the digitization process according to Bergin et al (1978) should only take an hour with greater accuracy coming from supervision and volume of throughput. Supervision by the clinician is important, as a thorough knowledge of anatomy is essential for reliable landmark identification. Increased throughput will also aid in reliability as the operator makes use of experience and global information to clarify areas of uncertainty (Cohen, 1984).

The benefits of computerized cephalometrics, therefore, far outweigh the monetary costs involved. With the costs being minimal and with computerization being of greater service to the operator, it stands to reason that this is not a cost to be borne by the patient. An informal survey conducted by the author of various practices utilizing computerized cephalometrics, confirms this conclusion. Computerization of this form in an institutional situation would see even greater cost effectiveness through the volume of usage and its potential both as a research and clinical tool.

CHAPTER SIX

SUMMARY AND CONCLUSIONS

In closing, the important features of using computers in cephalometrics will be reviewed, concluding with some thoughts on where the current impetus of technology might lead the specialty.

Thus far, computerization in cephalometrics has progressed alongside the level of mainstream computing. The 1960's saw cephalometric systems being implemented on mainframe machines and also on-site establishments. However, these systems were primarily restricted to large scale computers even into the early 1970's and were mainly used for research purposes. The advent of personal computing in the late 1970's heralded systems which were more accessible. The computer explosion of the 1980's up to the present day has now established computers in cephalometrics as a routine armamentarium in research fields and in practice situations.

The digitizer, the essential interface between the radiograph and computer system, having undergone many refinements, remains the linkage of choice. That is not to say that other mechanisms have not been attempted. Video digitization, scanners and computed tomography offer much more sophisticated and efficient methods of data acquisition but until these become economically feasible, will continue as experimental systems. The use of x-rays themselves as the primary source for creating the medium of headfilms would soon be reviewed as improved imaging techniques such as, Magnetic Resonance Imaging, emerge.

The historic patterns observed in this treatise indicate that such advances only require a matter of time before they are implemented and become commonplace.

As mentioned earlier, computerized cephalometrics has managed to parallel the advances in computing - much of it taking place independently and with commercial interests in mind. However, one of the unfortunate consequences of this progress has been the lack of any standardization between the various proprietary software packages. This lack of guidelines has been rife in the computer industry in general but fortunately consumer pressure has ensured that steps are being taken to overcome these problems.

Dental software whilst in its relative infancy, continues to progress independently. Dental records and cephalometric data are now stored in proprietary formats which ensure that a particular piece of software is used and upgraded to maintain compatibility with existing data. The user is then faced with an enormous task of converting data, if another hardware or software system is contemplated. Data conversion is never a major problem as routines can always be written to effect these. However, this presents extra costs and time, and users thus tend to persist with an existing computer system. The incompatibility problem also prevents the pooling of data for databases.

In summary then, computerized cephalometrics presents the clinician with the following benefits:-

1. An efficient and reliable method of cephalometric data acquisition.

2. A rapid mechanism of performing various analytical procedures on cephalograms, such as, the calculations of distances, angles, areas and construction lines in orthogonal analyses.

3. Rapid computation and presentation of visual treatment objectives for both orthodontic and orthognathic surgery patients.

4. Increased diagnostic value of a particular radiograph based on the large amount of information that may be gained for little effort. A wider range of analyses may be performed than would be feasible manually. This in effect provides a means of cross-checking the validity of a particular measurement.

5. Improved diagnostic and treatment planning facilities by linkages with expert system rules; accessing tried and published material or literature.

6. Minimization of errors -

    a. in data acquisition, by the ease of double determination and averaging procedures.

    b. in analytical calculation procedures.

7. Communicating to patients, the objectives and limitations of treatment in a graphic format. This would apply to both

orthodontics and orthognathic surgery. Patients could also be shown the effects of growth and treatment either by superimposing pre-treatment and post-treatment computer plots or by manipulating single-event, pre-treatment graphic plots.

8. Compact archival storage of both coordinate data and cephalometric data on electro-magnetic media; and the possibility of dispensing with the storage of radiographic media, once improved scanning or video digitization procedures become feasible.

9. Rapid retrieval of the above archived material .

10. Establishment of a central or practice database for normative and growth study data. Thus regional or racial norms may be developed and built upon. Epidemiological data may also be acquired from such databases, should a study or research project be embarked upon.

11. Finally, computerization in cephalometrics maintains the science of cephalometrics abreast with current technology, thereby enabling it to profit from related advances in data acquisition, image analysis and computer-aided manipulation of images - the latter being especially applicable to orthognathic surgical options.

Conclusions

This treatise has traced the history of computerized cephalometrics, highlighting the rationale for using computers in cephalometrics. Some of the more popular cephalometric analysis packages have been discussed and some suggestions as to how a cephalogram digitization program may be written is supplied in the Appendix. The problems of incompatible data formats are raised and the procedure of writing to a compressed data format is also suggested. The need to evaluate the cost, benefits and relative merits of new technology is also addressed.

It has been established that computerization in cephalometrics is an efficient, reliable and important advance to such study. Any further improvements to increase its efficiency and reliability will appear as computer hardware systems continue to improve; universally applicable and user-customizable software is written; newer modes of data acquisition emerge and, finally, as improved imaging techniques are developed. Primary to all this is the establishment of a set of guidelines so that the archiving of these digital records is performed in a uniform manner such that any data acquired may be used by centralized databases.

The foregoing has placed much weight on the use of cephalometric radiographs and the application of computers to increase their diagnostic value. However, one must bear in mind that cephalometrics should only be used as one of the many aids in the total clinical diagnosis of the orthodontic patient.

It is interesting to note that whilst computer technology and all that is associated with it has seen tremendous advances and changes over the past two decades, the caution advocated in the pioneering days is still relevant. Salzmann in an editorial in 1972 on computerization in orthodontics, warns that the computer and its programs are only an extension of the human brain that has programmed it, and went on to say, "The orthodontist still cannot abdicate to the computer his role in diagnosis and treatment planning" (Salzmann, 1972) - how very apt even in this day of artificial intelligence, neural networks and expert systems.

Wilton Krogman as Moderator of a symposium on the use of computers in orthodontic analysis and diagnosis in 1972 also expounds this very viewpoint. The following is a quote from his opening address at the symposium and is a most felicitous conclusion to this treatise, being dramatic, emphatic and cautionary about the application of computers to cephalometrics.

> "Years ago,as I reviewed the transition from craniometry to cephalometry, I wrote: "The skull is dead, long live the head." Maybe it is now cogent to say: "The head is dead, long live computerized roentgenographic cephalometry".
> Well, so be it, in this age of technologic advance of mass, retreat of individuality.
> One thing must be said, firmly and clearly: A digitized craniofacial printout, no matter what its analysis, is only a guide. It is not an answer. Two factors still reign supreme: The orthodontic patient and the orthodontic clinician - the one with occlusal problems, the other with professional skills and insight" (Krogman, 1972).

APPENDIX

This appendix contains computer program listings written and developed by the author.

The first two C language source code listings are written for the Apple //™ series of computers and require compiling and linking by the Manx Aztec C™ compiler for operation. The digitizer used is an opaque Powerpad™ tablet with dimensions of 12" X 12". Any contact with the digitizer surface results in polling of coordinate information. The C language was chosen for its universality and portability and speed of execution.

Program logic and comments are included within the programs and are enclosed thus:

/* the conventional C format for comments */.

Listing 3 is an Applesoft BASIC™ digitizing program developed for the Apple // computer and the Apple Graphics Tablet™.

Listing A.1

This is a patient data entry system which prompts for patient particulars and then stores them in binary format (ASCII text in the Apple // environ) in a file with the suffix ".JMC". The data creates a header section of 26 bytes which is then followed by digitized coordinate data to be stored as integers, ie., 4 bytes per coordinate pair. The header consists of the following:

5 bytes	Surname	
3 bytes	First name	both encoded and compressed at three letters per byte
4 bytes	Patient file number as a long integer	
4 bytes	Date of birth	dates compressed in the form
4 bytes	age at x-ray	5 bits day; 4 bits month; 7 bits year
2 bytes	Treatment stage	1 character per byte

Decoding involves a reversal of the encoding process listed.

```
/* --------------------- Listing A.1 ------------------ */
/* ------  Copyright (c)  1989  Dr John Mamutil  ------ */

#include <stdio.h>

main()
{

static char surname[16],
     first_name[10],
     stage[2];
char filename[12];
long atol(), drn;
extern char *scan();
char temp[15];

int d_of_b[3],   /* date of birth */
    d_of_x[3];   /* date of x-ray */
    length,
    i,
    t;


static struct two_bytes
       {
unsigned int b1:5;
unsigned int b2:5;
unsigned int b3:5;
       }letter[8];

struct date                   /* bit fields for date */
       {
       int d1:5;
       int d2:4;
       int d3:7;
       }dob,xray;

static struct pat_data              /* file header data type */
       {
       struct two_bytes letter[8];
       long drn;
       struct date dob;
       struct date xray;
       char stage[2];
       }p;

FILE *fptr;

printf("Copyright (c) 1989 Dr John Mamutil\n");

start:

setmem(&p,25,0);                /* free header memory */
                                /* patient particulars input routine */
```

```
scan("Surname           :",temp);
strcpy(surname,temp);
scan("name              :",temp);
strcpy(first,temp);
scan("DRN               :",temp);
p.drn=atol(temp);
           /* similar date input routine to go here */
scan("Stage             :",temp);
strcpy(p.stage,temp);


                   /* generate filename from patient info */

sprintf(file,"%.1s%.1s.%ld%.1s.jmc",surname,first,p.drn%1000 0,p.stage);
length = strlen (surname);

                   /* encoding sequence for data */
  if ( length/3)
  for (i=0;i< (length/3);i++)
    {
          t= (toupper (surname[i*3+0])) -64;
      p.letter[i].b1=t;
          t= (toupper (surname[i*3+1])) -64;
      p.letter[i].b2=t;
          t= (toupper (surname[i*3+2])) -64;
      p.letter[i].b3=t;
    }
   if ( length%3==1)
  {
           t=toupper (surname[length-1]) -64;
        p.letter[length/3].b1=t;
  }

   else if ( length%3==2)
  {
           t=toupper (surname[length-2]) -64;
        p.letter[length/3].b1=t;
           t=toupper (surname[length-1]) -64;
        p.letter[length/3].b2=t;
  }

 length = strlen (first);
   if ( length/3)
   for(i=5;i< (length/3)+5;i++ )
     {
           t= (toupper (first[(i-5)*3+0])) -64;
       p.letter[i].b1=t;
           t= (toupper (first[(i-5)*3+1])) -64;
       p.letter[i].b2=t;
           t= (toupper (first[(i-5)*3+2])) -64;
       p.letter[i].b3=t;
     }
   if ( length%3==1)
  {
           t=toupper (first[length-1]) -64;
```

```
      p.letter[(length/3)+5].b1=t;
         printf("%d  %d  1  \n",t,l);
}
  else if ( length%3==2)
{
         t=toupper (first[length-2]) -64;
      p.letter[(length/3)+5].b1=t;
         t=toupper (first[length-1]) -64;
      p.letter[(length/3)+5].b2=t;
}


            /* write to file */

fptr=fopen(file,"w");
fwrite(&p,25,1,fptr);
fflush(fptr);
fclose(fptr);



}

        /* input routine */

char *scan(message,field)
char *message;
char *field;
{
int s;
printf(message);      /* prompt message */
s=read(0,field,16);
field[s-1]=0;
}
```

Listing A.2

This is the source code for digitizing x,y coordinate data from the Powerpad™ digitizer interfaced to the Apple // computer via its 16 pin Input/Output port. This listing includes call routines written in Apple 6502 assembly code. These routines are included purely for completeness.

```
/* --------------------- Listing A.2 ------------------ */
/* ------  Copyright (c)  1989  Dr John Mamutil  ------ */


main()
{
int *sense,
    *x_coord, *y_coord;     /* coordinate pointers */

             /* address of pointers */
sense=8;
x_coord=7;
y_coord=6;


printf("Power_Pad_test\n");
printf("Copyright (c) 1989 Dr John Mamutil\n");

init_pad();                 /* initialize digitizer */

sensor:
get_sense();                /* poll the digitizer */

while(*sense)               /* if sense; $08 >0 then no point found */
  {
  init_pad();
  get_sense()               /* initialize and poll the digitizer */
  }

get_x_y();                  /* found point sense=0 */

if(!*x_coord && !y_coord) /* ie, if coords are 0 */
  goto sensor;

                            /* display coordinates */

printf("x = %d   .....  y = %d\n" , *x_coord, *y_coord);

  goto sensor;

}
```

```
/*  assembly routines  :  Listing 2 continued */

init_pad()
{
  #asm
              lda     $c05a
              lda     $c058
              lda     $c059
              lda     $c058
              rts
  #endasm
}

get_sense()
{
  #asm
              lda     #$00
              sta     $08
              ldx     #$ff
              ldy     #$ff
   .equal
              lda     $c063
              bpl     .plus
              dey
              bne     .equal
              dex
              bne     .equal
              inc     $08
   .plus
              rts

  #endasm
}


get_x_y()
{
  #asm
              lda     $c05b
              lda     $c05a
              jsr     .getbyte
              sta     $06
              jsr     .getbyte
              sta     $07
              lda     $c059
              lda     $c058
              rts
   .getbyte
              ldx     #$07
   .breq
              lda     $c05b
              lda     $c05a
              lda     $c061
              asl
              ror     $08
              dex
              bne     .breq
              lda     $08
              eor     #$ff
              lsr
              rts

  #endasm
}
```

Listing A.3

This is an Applesoft BASIC digitizing program for the Apple // computer and the Apple Graphics Tablet™ (Apple Computer, 1979). This digitizer uses a stylus, is opaque and has dimensions of 12" X 12". Its interface is a custom interface card. The REM statements are comments which explain the logic of the program (Mamutil, 1987).

```
 10  REM  ***************************************
 20  REM  *   X,Y DIGITIZER (Skeleton Program)   *
 30  REM  *  Copyright (c) 1987 Dr John Mamutil  *
 40  REM  ***************************************
 50  DIM VX(100), VY(100) :  REM array dimensioning
 60  TEXT : HOME
 70  POKE 34,14            :  REM setup header window
 80  PRINT "X,Y Coordinate Generator"
 90  PRINT : PRINT "by Dr John Mamutil"
 100  PRINT : PRINT "<R> saves to Ram"
 110  PRINT : PRINT "<V> saves to Disk"
 120  PRINT : PRINT "<C> complete Correction"
 130  PRINT : PRINT "<Q> Quit"
 140 D$ =  CHR$ (4)
 150  PRINT D$ "PR#1"     :  REM the next 3 lines initialize digitizer
 160 XO = 645:YO = 6084
 170  PRINT "S1 ,XOFF=";XO;",YOFF=";YO;",R,Q"
 180  PRINT D$ "PR#0"     :  REM screen output
 190  PRINT D$ "IN#1"
 200 N = N + 1
 210  PRINT  CHR$ (7)     :  REM Bell
 220  INPUT ""; X, Y, S  :  REM wait for digitizer input
 230 VX(N) = X: VY(N) = ABS (Y): PT$(N) = PT$
 240  VTAB 16: PRINT VX(N);" ",VY(N)"    "
 250  IF PT$ = "" THEN PT$ = "1st Point"
 260  PRINT "Next Point","Status","Points Digitized" :  REM sample
 270  PRINT PT$, S, N - 1                           :  REM landmark
 280  IF S < 0 THEN 350                             :  REM prompting
 290  IF S = 3 THEN 310
 300  IF S > 0 THEN 220      :  REM activity pending stylus tip status
 310  FOR WT = 1 TO 499: NEXT
 320  READ PT$
 330  DATA Porion, Sella, Nasion, Completed !   :  REM landmark names
 340  GOTO 200
 350  PRINT D$ "IN#0"
 360  PRINT D$ "PR#1"
 370  PRINT D$ "PR#0"
 380  PRINT D$ "PR#3"            :  REM exit digitizer
 390 M = 20.1
 400  FOR Q = 1 TO N
 410  PRINT Q, VX(Q)/M, VY(Q)/M, PT$(Q)    :  REM print coordinate data
 420  NEXT Q
 430  PRINT "Directory : <R> RAM or <V> Disk?"
 440  GET P$: PRINT P$
```

```
450  IF P$ = "Q" OR P$ = "q" THEN  END
460  IF P$ = "C" OR P$ = "c" THEN  RUN
470  INPUT "Save to Filename:";F$          :  REM write to file
480  IF P$ = "R" THEN N$ = "/RAM/" + F$
490  IF P$ = "V" THEN N$ = "/v/o/" + F$
500  PRINT D$;"open";N$
510  PRINT D$;"write";N$
520  FOR Q = 1 TO N
530  PRINT Q, VX(Q)/M, VY(Q)/M
540  NEXT Q
550  PRINT D$;"close";N$
```

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