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THE ESTABLISHMENT OF SOFT TISSUE THICKNESSES AND PROFILES FOR RECONSTRUCTION OF THE ADULT MALE ZULU FACE

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A Thesis Submitted to the Faculty of Dentistry, University of the Witwatersrand, Johannesburg, for the Degree of Doctor of Philosophy.

Johannesburg 1993

DECLARATION

I do hereby declare that this thesis is my own work and that it has not been previously presented for any degree or examination at another University.

William Alexander Aulsebrook

Date

ABSTRACT

Three-dimensional forensic facial reconstruction involves the building up in clay of the soft tissues of the human face onto an unidentified skull to suggest the identity of its owner.

Early researchers physically punctured the facial tissues of cadavers at known anthropological landmarks to measure their depth. Later workers used radiography, ultrasonography and magnetic resonance imaging for collecting both depth and surface data on the head and face.

The aims of this study had three major thrusts:

1. To form a new measuring system using radiography and ultrasound for measuring the depth of the soft tissues in the face. This was named the Depth System.
2. To create a geometric head-centre supporting a polar coordinate system that can be used for locating and measuring hard and soft tissue profiles of the skull and face in terms of small linked line-segments that can be transformed and manipulated. This was the Profile System.
3. To produce soft tissue norms for the living adult male Zulu. These were a table of mean facial soft tissue depths and a set of standard hard and soft face profiles.

The sample consisted of 55, healthy, live Zulu males aged 20 to 35.

From their lateral and oblique cephalometric radiographs two different sets of data were collected: a set of soft tissue depth measurements at fixed anthropological landmarks for the depth system and a set of selected significant geometric polar co-ordinate points located along the hard and soft tissue profiles for the profile system. Diagnostic ultrasound was used to augment the data for the depth system by measuring depths of the intervening soft tissues between the radiographic planes.

From the data a table was compiled of mean soft tissue thicknesses at 57 selected landmarks for the depth system and a set of standard hard and soft profiles for the male Zulu face for the profile system. Methods were devised to adapt the standard soft tissue profile to an unidentified skull and to construct an estimated soft tissue profile from a table of regression lines.

To test the effectiveness of the profile system, a visual perception test was carried out. This clearly indicated that the Profile System had a distinct advantage over the Depth System.

****

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****

DEDICATION

To two superb examples of the human race:

WILLEMINA ELIZABETH VERHOEF

and

WILLIAM AULSEBROOK SNR.

CONTENTS

Page

DECLARATION..... ii

ABSTRACT..... iii

ACKNOWLEDGEMENTS..... v

DEDICATION..... viii

TABLE OF CONTENTS..... ix

LIST OF TABLES..... xiv

LIST OF FIGURES..... xv

****

CHAPTER I. SUBJECT AND LITERATURE

A. Subject matter..... 1

1. Replacement of tissues..... 2

2. Identikit-type systems..... 2

3. Superimposition..... 4

4. Forensic facial reconstruction..... 5

B. Review of the literature..... 6

1. Superimposition..... 6

2. Forensic facial reconstruction..... 13

a. Anthropological evaluation..... 14

b. Clinical examination and open dissection.... 15

c. Puncturing methods of measurement..... 16

d. Ultrasonic methods of measurement..... 22

e. Radiographic methods of measurement..... 23

f. MRI methods of measurements..... 32

CHAPTER II. AIMS AND OBJECTIVES

A. Aims..... 37

1. A new depth system..... 39

a. The use of diagnostic ultrasound..... 39
i. Accuracy of ultrasound..... 41
ii. Biological effects of ultrasound..... 42
b. The use of cephalometric radiography..... 43
i. Accuracy of radiography..... 43
ii. Biological effects of radiography..... 44
2. A new profile system..... 44
a. Selection of a headworld..... 51
b. Selection of a coordinate system..... 55
c. Selection of points..... 56
3. Establishing facial tissue norms..... 58
B. Objectives..... 62

CHAPTER III. METHODS: METHODOLOGY

A. Experimental concept..... 64
B. Selection of subject..... 68

CHAPTER IV. METHODS: CEPHALOMETRIC RADIOGRAPHY

A. Equipment..... 73
B. Method of taking radiographs..... 74
C. Accuracy and error control..... 79
1. System error..... 79
2. Operator error..... 82
a. Accuracy of landmark identification..... 83
b. Constancy of measurements..... 84
c. Analysis of operator error..... 84
D. Landmarks for the depth system..... 88

1. Landmarks on the lateral cephalogram..... 89

2. Landmarks on the oblique cephalogram..... 94

E. Landmarks for the profile system..... 102

1. How to locate a point..... 103

2. Points on the soft profile..... 109

3. Points on the hard profile..... 114

4. Coding the triples..... 116

F. Recording radiographic measurements..... 118

1. Measurements for the depth system..... 120

2. Measurements for the profile system..... 121

CHAPTER V. METHODS: ULTRASONIC PROBING

A. Equipment 125

B. Preliminary ultrasonic investigations..... 126

1. Accuracy and error control..... 127

2. Variation in depth readings around a landmark.. 129

3. Comparing accuracy of ultrasound & radiography. 133

C. Landmarks..... 141

D. Recording ultrasonic measurements..... 145

CHAPTER VI. RESULTS: DEPTH SYSTEM AND PROFILE SYSTEM

A. The depth system..... 151

1. Accuracy of ultrasound compared to radiography. 151

2. Dual measuring system of radiography and ultrasound..... 154

3. Establishing standards for soft tissue depths.. 155

4. Comparing American standards of tissue depth with those of the present study..... 159

B. The profile system..... 165

1. The Standard profile..... 166

2. The Estimated profile..... 168

CHAPTER VII. RESULTS: FACIAL RECONSTRUCTIONS.

A. Reconstructions using the depth system..... 174

1. Reconstruction using RSA data..... 174

2. Reconstruction using USA data 178

B. Reconstruction using the Profile System..... 179

1. Constructing standard profiles..... 179

2. Constructing a mean profile..... 182

3. Constructing an estimated soft profile..... 183

CHAPTER VIII. RESULTS: VISUAL PERCEPTION TEST

A. Choice of systems for comparison..... 187

B. Designing the test..... 188

C. Drawing the profiles..... 191

1. Making the real profile..... 191

2. Making the American profile..... 192

3. Making the mean profile..... 192

4. Making the estimated profile..... 192

5. Making the test booklet..... 193

D. Selecting the test subjects..... 193

E. Conducting the test..... 196

F. Results of the test..... 197

G. Discussion..... 201

H. Further confirmation..... 204

I. Conclusions..... 206

CHAPTER IX. SUMMARY, CONCLUSIONS AND SUGGESTIONS

A. Summary..... 207

1. The depth system..... 207

2. The profile system..... 208

B. Conclusions..... 210

C. Suggestions for future studies..... 212

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REFERENCES..... 216

APPENDIXES:

A-1 Glossary of terms..... 265

A-2 Health questionnaire..... 275

A-3 Informed consent form..... 278

A-4 Ultrasonic error control..... 279

A-5 Radiographic data sheet (depth system)..... 280

A-6 Radiographic data sheet (profile system)..... 281

A-7 Ultrasonic data sheet (depth system)..... 282

A-8 Visual test data sheet..... 283

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LIST OF TABLES

Page

1. Radiographic operator error: coefficients of variation on Subject 1..... 86

2. Range of coefficients of variation: for radiographic observations at 10 landmarks..... 87

3. Ultrasonic operator error: Coefficients of variation on Day 1..... 137

4. Mean depths, standard deviations, minimums and maximums for this study. (lateral radiographic measurements)..... 156

5. Mean depths, standard deviations, minimums and maximums for this study. (oblique radiographic measurements)..... 157

6. Mean depths, standard deviations, minimums and maximums for this study. (ultrasonic measurements)..... 158

7. Comparing American standards of tissue depth with those of the present study: Lateral radiographic measurements..... 160

8. Comparing American standards of tissue depth with those of the present study: Oblique radiographic measurements..... 162

9. Comparing American standards of tissue depth with those of the present study: Ultrasonic measurements..... 163

10. Polar coordinates for the standard face..... 167

11. Table of regression lines..... 184

12. Results of the Visual Perception Test..... 198

LIST OF FIGURES

		Page
1.	Features and subfeatures of the hard and soft profiles	38
2.	Surface contours that determine the landmark selection	40
3.	Soft tissue variability between depth markers	45
4.	Two different profiles through the same points	47
5.	"Head world", showing polar vectors and the EAMAC line	57
6.	Geometrical "objects" comprising the profile	59
7.	Shadow lines on the face and skull	66
8.	The use of profiles to draw caricatures	67
9.	The ala-tragus spirit level	77
10.	Lateral and oblique radiographic planes	81
11.	Radiological landmarks: lateral cephalogram	90
12.	Radiological landmarks: oblique cephalogram	91
13.	Translocated meridia of the face	96
14.	Varieties of curves	104
15.	Simplifying compound curves with simple arcs	106
16.	Shape divided into curve, angle and line	108
17.	Feature modules and shape triples	110
18.	The arc-determinator (AD)	112
19.	The control point locator (CPL)	113
20.	Relationship between circles that form curves	115

21. Acanthion and its three soft tissue points..... 117

22. The viewing and tracing of radiographs..... 119

23. The use of the protractor and ruler..... 122

24. The polar coordinate plotter (PCP)..... 123

25. Record sheet for radiographic profile data..... 124

26. Regional data point (RDP) disk and its use on the face..... 130

27. Traversion map..... 132

28. Ultrasonic data record sheet..... 135

29. Ultrasonic error - morning against afternoon readings..... 139

30. Ultrasonic error - coefficients of variation over five days..... 140

31. Ultrasonic landmarks on the face..... 142

32. Angulation of the ultrasonic probe to the skin..... 148

33. Radiographics versus ultrasonics #1: showing strong linear relationship..... 152

34. Radiographics versus ultrasonics #2: one as a percentage of the other..... 153

35. Bi-variate scattergram #1: distance against distance..... 170

36. Bi-variate scattergram #2: angle against angle..... 171

37. The stages in facial reconstruction..... 175

38. Making the midline template..... 177

39. The standard Zulu face (male Zulu)..... 181

40. Example of a visual test sheet..... 194

41. Comparison of real and composite profiles..... 205

CHAPTER I

SUBJECT AND LITERATURE

A. SUBJECT MATTER

Essentially this study is concerned with examining the thickness and the form of the soft tissues of the human face and how these tissues are spatially related to the underlying skull.

A detailed knowledge of this interactive dependancy is of value in treatment planning in the fields of orthodontics and maxillo-facial prosthetics as well as cranio-facial, maxillo-facial and plastic surgery. In these disciplines one must be able to predict the effect of tooth and bone repositioning, or its removal, upon soft tissues. This is particularly important when the end result is to be both functionally and aesthetically acceptable. Also resting heavily on this knowledge is the practise of forensic facial reconstruction. This is the science of reproducing the facial features of an individual for the purposes of identification.

Forensic facial reconstruction can be divided into four categories (after Caldwell, 1986): the repositioning and replacement of damaged or distorted soft tissues onto a

skull; the use of photographic transparencies and drawings in an identikit-type system; the technique of superimposition, which is the comparison of two known images; and three dimensional reconstruction of a face over the skull by using modelling clay.

1. Replacement of tissues

Readapting damaged or distorted tissues back onto a skull can either be carried out on the recently dead by pathologists and morticians, or on the long dead by skilled experts. Examples of the former are seen in the works of Spitz et al. (1970) and Drake and Lukash (1978). Fleming et al. (1979) found that the identification of a murdered victim was facilitated when they fitted artificial eyes and spectacles to the badly distorted face. Work on the long dead is typified by the work of Wilder (1904) and (Gillman (1934) who rehydrated mummified tissues. These forms of reconstruction though of distinct value are only distantly related to this study.

2. Identikit-type systems

In identikit-type systems an attempt is made to recreate the facial likeness of a person, resting entirely on the verbal descriptions of a witness. Systems of this type have become quite sophisticated and depend on the use of

drawn or photographic overlays of features or on sketches rendered by an artist. Although there have been occasions where drawings have been fitted to unidentified skulls (Haglund and Reay, 1992) the technique is usually applied to identification of the living, as in a search for an assailant or a missing person.

The method depends heavily for its success on a number of factors. Firstly the clarity and the recall of the mental image held by the witness. This is often registered under conditions of great stress. It can also be dulled through time. Then there is the ability of the witness to verbally transfer this image to a police artist or technician. Even if the witness is educated and perhaps even erudite, words can never be a match for a visual image. The verbal description must now be translated by the artist into a mental image of his own. If the end result is a drawing, the final image will be directly dependant on the talent and skills of the artist. Should the system use photographic overlays of features the technician must then select a series of images that when composed will best match his own mental concept of the face. At the end of the session the witness must in turn decide if the photographic composite or drawing conforms with the original image he had in mind.

Finally if both are satisfied the picture may have to be circulated and an appeal made to others to go through the same mental and visual process of identifying the person being sought. Systems of this kind depend entirely on the translation of subjective impressions into objective conclusions, a notoriously difficult undertaking. Except for the common function of visual recall, on the part of the witness, there is little relationship between this type of reconstruction and that investigated in this study.

3. Superimposition

Two-dimensional superimposition techniques are considered reconstructions in that they attempt to supply a face for a found skull by comparison and matching of two already existent images, one of the skull and the other of a face that is thought to belong to the owner of the skull. An attempt is made to establish a close enough correlation between the images to state with a reasonable degree of confidence that both belong to the same individual. The method is one of comparison rather than reconstruction. Nevertheless, a number of the systems for measurement and quantification are of interest, when compared to those suggested in this thesis. The subject of superimposition is therefore included in the review of the literature.

4. Facial reconstruction

Three dimensional or plastic facial reconstruction on the other hand is a reproductive process that builds up the appearance of a face from the skull. It is concerned with one known factor and one unknown one, and can be defined as the modelling in clay of the soft tissues of the face and head on an unidentified skull in an attempt to reproduce the likeness of its owner. The method is dependant on a knowledge of the significance of certain morphological features of the skull, as well as the use of tables of mean values of facial soft tissue thicknesses measured at selected anatomical landmarks. Rhine (1990) suggests that the term reconstruction should be replaced by the word reproduction. There is validity in his argument but until such time as this replacement gains ground the more familiar and accepted word reconstruction will be retained throughout this study.

Many anthropologists have remodelled the facial features onto the skulls of prehistoric man and famous personages. With experience one can determine the race group and sex of skulls quite accurately. Estimating age is a little more difficult. Reproducing a face that resembles that of its previous owner is quite another matter. Neave (1989a) mentions that in the past artists have of necessity been "supported and championed by a senior member of the medi-

cal profession". In the field of facial reconstruction the anthropologist and the sculptor have often formed a partnership where the artist acted under the instructions of the scientist. Examples of these "paired experts" as Stewart (1979) calls them are (name of artist is second): His and Seffner; Kollmann and Büchly, Krogman and McCue, Snow and Gatliff; Stewart and Steppat.

B. REVIEW OF THE LITERATURE

1. Superimposition

According to Glaister and Brash (1937), superimposition was used as early as 1867 by Welcker. Brown (1983) quotes Furahata and Yamamoto (1967) as identifying the owner of a skull by reconstruction and superimposition as early as 1925, and Pearson (1934) as using superimposition during the years 1926 to 1934.

In retrospect, superimposition can be seen to have passed through three phases. The first made use of viewing boxes slide projectors and overhead projectors. The next phase introduced video technology and its power to electronically superimpose. The third incorporated the analytical potentials of computer graphics.

In all systems of superimposition two images are involved in the process. The first is of the unidentified skull. The second image, that of the face, can be derived from many sources, the most common being the photographic portrait (McKenna et al., 1983; Roberts, 1983; McKenna, 1985; Pesce Delfino et al., 1986b; Thomas et al., 1986; Helmer, 1986a, 1987a; Seta and Yoshino, 1988; İşcan, 1988b; Colonna et al., 1988a, 1988b). Glaister and Brash (1937) used a handpainted portrait for the source. Radiographs can also be used for the second image (Cai and Lan, 1988). Gassouni (1959) advocated the storage of cephalometric radiographs of all military personnel for purposes of identifying the war-dead. One unusual source for a face image was a death mask or face impression left in the clay in which the deceased had been buried (Iten, 1987). Pearson and Morant (1934) used busts, masks and painted portraits for a facial reconstruction of Oliver Cromwell. A three-dimensional facial reconstruction was used for comparison by Koelmeyer in 1982. A photographic image of a face was projected onto the skull of a child by Malinowski and Porawsky (1970) and a realistic sculpture of Jean Paul Jones made by the sculptor Houdin was used by Eckert, in 1982 as the source of the face image for superimposing over the skull image.

As computer technology improved it rapidly took its place in the field of superimposition. Techniques of graphic

imaging employed specialised software such as the package designed for Shape Analytic Morphometry (Pesce Delfino et al., 1986a, 1987a, 1987b, 1988, 1989; Colonna et al., 1988). Ubelaker and O'Donnel (1992) placed tissue depth markers on the skull. Then, onto a computer image of the skull, they added the soft parts of the face harvested from an FBI database of hand drawn features. Credibility of the system was tested by using the method on human remains in a collection at the Smithsonian Institute (Ubelaker et al., 1992).

The complexity of the equipment setup varies considerably. Iten (1987) used split-plane video superimposition with two cameras and a mixer with three monitors, one for each of the cameras and a third for the resulting mixed image which was recorded onto video tape. Dorion (1983) outlined three methods of superimposition. Two involved the use of beam splitters, front-surfaced mirrors, still and video cameras. In the third a life-sized transparency was mounted directly in front of the skull and the combination photographed. Pesce Delfino et al. (1986) and Helmer and Beutner (1987b, 1988a, 1989c) used software controlled video-computer interfacing.

Before comparing any common features in the two images, certain primary geometric demands have to be met. The images must represent views of the subject taken from the same angle. They must have the same magnification, and

should preferably have the same lighting in each case. One of the fundamental difficulties in superimposition is the orientation of the skull to match that of the face in the second image. Some clever setups have been suggested. Iten (1987) devised a method of determining the antero-posterior tilt of the head by relating the subject's eye level with his external auditory meatus. He decided the turn of the head by the ratio of the distances between the centres of each eye and the midsagittal plane. The photographic distance was calculated by the amount of perspective distortion, and the size was decided by the zooming ability of the video camera. Chandra Sekharan (1973, 1988b) orientated the skull as follows: antero-posterior tilt was determined by relating two horizontal lines drawn on the photograph of the side view of the face (at the outer canthus of the eye and the external auditory meatus) to two parallel wires on a mechanical device held against the skull. The left-to-right tilt was calculated by measuring the angle between the midsagittal and the vertical plane. In 1988, Seta and Yoshino mounted skulls and adjusted their spatial orientation through the use of a remote contol joy-stick. McKenna (1988) utilised a specially designed goniometer to mount skull and camera in a twin relationship for obtaining correctly orientated photographs of the skull. Brockelbank and Holmgren (1989) built a jig based on the Royal Berkshire Hospital halo frame for positioning the skull.

To correctly match skull and face images, both should be the same size. Lan and Cai (1988) used computer technology to determine the photographic angle and size of the head. Maat (1989) discussed the positioning and magnification of faces and skulls. Glaister and Brash (1937), Prinsloo (1953) and Janssens et al. (1978) used the known sizes of various objects in the photograph to scale the face. Sognnaes (1980) and McKenna et al. (1983) used the known sizes of anterior teeth in a found skull to decide the magnification factor for a photograph of the deceased showing front teeth. After further study McKenna (1985) concluded that photographic superimposition based on landmarks and measurements of the dentition can have a positive value in personal identification. Chee and Cheng (1989) used the known size of interpupillary distances for scaling.

In assuring that the lighting in the two images correspond Seta and Yoshino (1988) controlled the angle and intensity of lighting by the use of 34 fluorescent tubes.

Important sites for comparison are the auditory canals, eyesockets, cheek bones, jawbone, root of nose, teeth, chin, skull contour, "and others" (Iten, 1987). Helmer (1987b) compared head proportions and landmarks for eyes, nasal apertures, mouth and external auditory meatus. An

interesting addition was the estimation of what the overlying tissue thicknesses should be, by using the wooden depth markers employed in three dimensional reconstruction. Chai et al. (1989) specified 34 landmarks lying on eight reference lines common to the skull and face.

Validity of superimposition

In an attempt to quantify a comparison, Cocks (1970) used a simple method of comparing triangulated anthropological points marked on the face photograph and skull. Brown in 1983, correctly points out that finding the points on a face photograph can be difficult and this could result in misidentification. Helmer and Grüner (1987b) compared the distances and axes rather than points of similarity and Helmer et al. (1989b 1989c) quantified the individuality of human skulls by using craniometric measurements and their probability distribution on 52 European skulls. In all cases they feel that skulls are comparable in their individual.ty to fingerprints. Cai and Lan (1988) correlated facial markings with the underlying skull and expressed the relationship in terms of correlation indices and regression equations. In a computerised approach Colonna et al. (1988a), and Pesce Delfino (1987a, 1987b, 1988, 1989) employed Shape Analytic Morphometry. This provided coefficients of upper degree equation, their standard deviation and standard error and variance and

covariance matrices. Accessory routines supplied the standardisation of positioning, normalisation and the size of the image to be analysed. Nickerson et al. (1991) utilised digital superimposition to compute a near optimal fit between a three-dimensional skull surface mesh and a two-dimensional digitised photograph of the face.

Commenting on the work of the time De Vore (1977) claimed that photographic superimposition was of better use in exclusion rather than inclusion. On a more promising note Brown et al. (1981) inform us that the Australian courts accepted video-superimposition as an identification tool. İşcan (1988a) in his comprehensive summary of the major works on forensic anthropology quotes (Krogman and İşcan, 1986) as pointing out that a skull-to-photograph superimposition is an important comparative technique whose origins go back to the 1880s when family portraits were superimposed on skulls. Although electronic video-superimposition is the technique of choice, Iscan still claims it to be at best a supplemental form of identification. Cai and Lan (1988) on the other hand feel that their correlation indices and regression equations are an attempt at producing superimpositions based on legally accepted anthropology thus increasing their acceptability in the courts.

In a study on 224 subjects Chan et al. (1989) feel similarly about their work and the acceptance of the court. Koelmeyer (1982) produced a video-recording of a superimposition that led to it being accepted by the court as corroborative evidence for establishing identity. İşcan (1988b) warns us that the dissolve sequence between the skull image and the face image must be shown to the court in such a way that the examiners are able to discern the relationships between the two images rather than simply the one image merging into the other.

2. Facial reconstruction

There have been many researchers working in different fields who have contributed useful information on the three-dimensional spatial relationship between the skull and the soft tissues of the face. Pertinent literature on this extensive subject is therefore reviewed under the following headings:

- Anthropological evaluation
- Clinical examination and open dissection
- Puncturing methods of measurement
- Ultrasonic methods of measurement
- Radiographic methods of measurement
- Magnetic resonance imaging methods of measurement

a. Anthropological evaluation

The anthropology of the head and face of Man is a vast field. Since this study revolves around the Negroid subject only a small part of the related literature is reviewed in this section.

The study of the American Negroid skull and face has received much attention over the years (Hrdlička, 1928; Todd and Tracy, 1930). Cobb (1942) pointed out that the American Negroid is a blend of three stocks, the African Negroid, European White and American Indian. He suggested that because of this variability in the combination of physical traits one cannot describe a typical American Negroid, and a survey of Central African and West Coast African peoples was therefore indicated as a more sound basis for further analysis of the rather complex American Negroid.

In the Southern African context there have been numerous studies conducted into the skull characteristics and the facial appearance of the various Negroid groups. Some workers studied the Negroid race as a whole (Pearson, 1926; Gear, 1929; Shaw, 1931; Orford and Wells, 1936; Dart, 1938; Galloway, 1941; Jacobsen, 1967; De Villiers, 1968) while others conducted comparative studies between different Negroid types (Cassel et al., 1943; Keen, 1947;

Rightmire, 1970). Still other researchers investigated the anthropological characteristics of specific groups of Negroids (Shrubsall, 1898, 1899; Broom, 1923; Pearson and Davin, 1924; Todd and Tracy, 1931; Dart, 1937; Galloway, 1937; Keen, 1951; Eriksen, 1954; Musiker, 1954; Williams, 1954; Tobias, 1954, 1955; Toerien and Eisenberg, 1961).

b. Clinical examination and open dissection

As far as surface measurements go, Farkas (1981) is known for his work on external facial dimensions and proportions, Powell and Humphreys (1984) for their deliberations on face proportions, and Patterson and Powell (1974) for their facial analyses in cosmetic surgery. Freihoffer (1980) recorded intercanthal distances of 100 patients as varying between 28 mm and 35 mm. This represents a 12.5 percent range either side of the mean and emphasises the wide variation in Man's measurements.

The calliper has long been established as an efficient tool for measuring skulls (Pearson, 1934). However the somewhat crude method of pinching a fold of skin with callipers and reading off its thickness falls short of the accuracy demanded by facial reconstruction (Chumlea and Roche, 1986; Jones et al., 1986). Reports on the preference for using skinfold callipers as opposed to ultrasound, advocated by Borkan et al. (1982), were based

on the need to measure the amount of subcutaneous fat in loose skin folds (Booth et al., 1966). Closely adapted tissues like muscle cannot be measured for depth in this way.

Many wor. ers have investigated the anatomy and thickness of soft tissues as seen through open dissection. Research into the support of the nose was carried out by Virchow (1912) who dissected the nasal cartilages. Schultz (1918) examined the relationship between the external nose, bony nose and the nasal cartilages in Caucasoids and Negroids. Mahalanobis (1928), in his search for standardisation in measuring the living, quotes Martin (1914) as claiming that in the subjects Martin investigated, the nasion was situated at some considerable distance above the most depressed part of the nasal bridge. Montagu (1935) conducted further study into the relationship between the soft and hard tissue nasions. Straatsma and Straatsma (1951) investigated the anatomical relationships between the lateral nasal cartilages, nasal bone and cartilagenous nasal septum. Klaff (1956) dissected and described the basic anatomy of the nasal septum and Glanville (1969) examined the relationship between the nasal shape, prognathism and the maxilla in both Negroids and Caucasoids. Mooney and Siegel (1986) studied the racial variation in the anterior nasal spine. Meng et al. (1988) and Burke and Hughes-Lawson (1989) reported on the growth changes

in nasal profile of young girls and boys and Hoffman et al. (1991) recorded new data on the relationship between inter-alar widths and pyriform aperture widths of adult Caucasoid males. Sutton (1969) measured the thickness of the soft tissues overlying the bony zygions of 208 cadavers. He found that in 92 percent of cases the overlying soft tissue was in excess of that layed down in the literature, namely 6mm. It is gathered that the writer was referring to the findings of Kollmann and Büchly. Weijs and Hillen (1986) and Gionhaku and Lowe (1989) examined the relationship between jaw muscle volume and craniofacial form. Dykes and Marks (1977) measured skin thickness at the histological level and Dumont (1986) examined mid-facial tissue depths in children. Lebedinskaya (1957) using open dissection described the relationship between the eyes and their sockets. Whitnall (1911) first discussed the tubercle on the malar bone for the attachment of the tarsal plates. This was followed up by the work of Di Die (1942) on the tubercle. Stewart (1983) discussed the significance of Whitnall's tubercle in relation to facial reconstruction and Chandra Sekharan (1988a) examined 95 Indian skulls, concluding that Whitnall's tubercle lies at 10.55 mm (with a deviation of .96 mm) from the point at which the zygomatico-frontal suture crosses the lateral orbital margin.

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c. Puncturing methods of measurement

Certain workers used a variety of piercing instruments to physically penetrate and record the thickness of soft tissues at selected sites on the face.

Welcker (1867, 1881, 1883) is generally accepted as being the first to register soft tissue depth measurements in this way. He used the thin blade of a double-edged knife to penetrate the tissue. On encountering bone, the tissue depth was indicated on the blade (probably by using the thumbnail) and recorded. This routine was performed at seven anthropologically significant landmarks and a table of average soft tissue depths was compiled from a sample of 13 Caucasoid cadavers. From these measurements Welcker (1883, 1888) modelled the faces of Schiller and Kant over their skulls. His (1895) working with Seffner, an artist, rebuilt the facial features of Johann Sebastian Bach. He acquired his data on depth measurements by using a thin sewing needle fixed into a handle as a depth gauge. Much like present day reamers used in endodontic treatment, the shaft was fitted with a rubber stopper. As the oiled needle was inserted into the tissues the stopper was displaced up the shaft and away from the tip by an amount equal to the tissue depth at that point. The 24 cadavers used for these measurements were Caucasoid males and females, aged 17 to 72 years.

Kollman (1898) worked with the sculptor Büchly. They also elected to use a needle for measuring tissue depth but omitted the rubber disk. Instead, the needle shaft was blackened in a candle flame before being inserted into the tissues. The amount of carbon rubbed off the needle by the moist tissues gave an indication of the depth of penetration. Although the most useful reference points for measurements were originally established by Welcker (1883) and His (1895) it is the standards based on the work by Kollman and Büchly (1898) that are today still so well known to reconstructionists.

Additional small batches of measurements of soft tissues were recorded by Birkner (1905) on 6 beheaded Chinese criminals, Fischer (1905) on two Papuans and Von Eggeling (1909) on 2 Hereros. Harslem-Riemschneider (1922) added further data for another 14 Papuans and Melanesians, and Zeidler (1921) for 3 African Negroids. In a rather mixed collection of data, Stadtmüller (1925) supplied measurements on 2 New Hollanders, 1 Javanese, 13 Melanesians, and 2 Camaroons.

Not contributing to facial tissue measurements but nevertheless offering helpful advice and suggestions for the modelling process of reconstruction were a number of workers, two of whom were Holl (1898) and Wilder (1912).

In 1914 Virchow (1914) reconstructed one side of the face only in order to check on the thickness of the modelled side. Gerasimow (1971) offered useful information on how to ascertain from close examination of the skull surface just where and by how much to build up the facial soft tissues. His methods rely heavily on personal experience and artistic ability.

Workers in the field of facial reconstruction gradually became aware that it was necessary to mount specialised studies into recording the facial soft tissue depths and facial form of the three major groups of Man: Mongoloid, Caucasoid and Negroid.

In 1948, Suzuki collected data on the thickness of the soft parts of the Japanese face, recorded on 55 cadavers (48 male and 7 female). Ages and states of health at the time of death were varied. Measurements of tissue thicknesses were taken at the same places as those used by previous workers with a extra sites added. Landmarks at the trichion, pteryion and the superior temporal line were new. These sites are normally covered by hair.

Rhine and Campbell (1980) measured facial soft tissue depths for 59 American Black male and female cadavers ranging widely in weight and of varying ages in order to "sample from the broadest possible range". Like Suzuki

they measured points in the cheek area in an attempt to gain information in that somewhat unpredictable "terra incognita" as the authors so appropriately describe it. In addition, they watched for changes in the different age groups and by recording bilateral sets of points they hoped to ascertain whether or not any asymmetry existed. Results showed greater tissue thickness in their sample than was observed in whites. In addition a symmetry bias was indicated in favour of thicker soft tissues on the right side of the face.

Using the same landmarks as they applied to the Negroid face, Rhine and Moore (1982) updated the measurements on Caucasoids. They collected data on 73 American White male and female cadavers of widely different ages ranging from emaciated to obese. Although not tightly controlled the study and measurements were welcomed, as previous figures on White faces dated back to Kollman and Büchly's work in 1898. Robetti et al. (1982) added to this information on tissue depths measurements, at 12 points on the faces of 200 Caucasoid cadavers, aged from 11 to "over 55 years".

On the question of what measurements to use when dealing with subjects of mixed population groups, Aulsebrook and van Rensburg (1988) suggested an approach to the remodelling of what they called composite faces. These are cases where the features of the skull are a progeny of two (and

perhaps more) different population groups. In the case studied, the composite face was a mixture of Negroid and Caucasoid features. Questions arose as to which of the sets of mean tissue depths should be used, Caucasoid or Negroid, and whether or not the two sets should be combined and recalculated to form a new set of intermediate mean values for Coloured persons. Instead it was decided that the two sets of figures should be used separately in those areas where they were considered most appropriate. Firstly an anthropometric evaluation of the skull was carried out to determine the racial tendency of any one area on the skull. Then the appropriate set of soft tissue depth values was selected for restoring that particular area.

d. Ultrasonic methods of measurement

Diagnostic ultrasound was first introduced into the world of medicine in the 1950's. Its initial use in biology was for measuring fat in livestock (Whittingham (1962).

The longitudinal waves of ultrasound are different from other electro-magnetic waves in that they require a solid or a liquid medium for their transmission (Giancarlo, 1974; Jones and Frost, 1984). This makes them suitable for investigating the amount and type of soft tissue (Booth et al., 1965; Haymes et al., 1976; Rukavina and

Mohar, 1979; Lieberman, 1979; Baker and Krause, 1981; Cole et al., 1981; Borkan et al., 1982; Jones and Frost, 1984).

From a literature search it appears that Lebedinskaya et al. (1979) first utilised ultrasound for measuring soft tissue depths of the face for the purposes of facial reconstruction. Hodson et al. (1985) measured depths at 20 standard anthropometric sites on 50 healthy American White children, aged 4 to 15 and grouped according to sex and age. Hall (1989) utilised ultrasound for obtaining tomographic slices of information of facial soft tissues prior to surgery.

e. Radiographic methods of measurement

Two dimensional cephalometric radiography studies

The radiographic cephalometer was introduced to dentistry by Broadbent (1931). Orthodontists soon began using it for the study of aberrant dentofacial patterns. A comprehensive review by Moss (1972) of 20 years of cranial analysis between 1950 and 1980 covers a time during which cephalometric radiography played a major role in orthodontics.

Relating to orthodontics, Downs (1956), Subtelny (1959), Sassouni (1955, 1969), Burstone (1959), Ricketts (1968),

Holdaway (1983), Saxby and Freer (1985), are but a few of the prolific writers who have commented on the effects of bone and tooth repositioning on the soft tissue of lips, chin and the nose. Much attention has been given to the study of the nose (Rosen, 1967; Clements, 1969a, 1969b, 1969c). Contributions like those of Macho (1986, 1989) and George (1987), are examples of the constant search for a formula for reconstructing the nose. Chaconas (1969) conducted a radiographic study into the relationship between the growth of the nose and the positioning of maxilla and mandible and Gill et al. (1988) examined the racial identity of the mid-facial skeleton in both American Indians and Whites. There is little doubt that cranio-facial and plastic reconstructions in cosmetic surgery have benefitted much from improved radiographic planning (Broadbent, 1957; Sattenspiel, 1984). In questioning normal aesthetic values and ethnic norms Pogrel (1991) pointed out that the computerised analyses of Björk (1947), Steiner (1953), and Ricketts (1960) show considerable individual differences, depending on the derivation of the original patients. Sassouni (1969) in trying to avoid normal values, simplistically classified faces into four types: two with vertical disproportions and two with antero-posterior disproportions. The amount of work done on the physical relationship of the skull to the facial tissues in the field of orthodontics is con-

siderable. Since this type of research is fundamentally geared to orthodontic analyses and tooth repositioning in the young patient it is not pursued any further in this review except perhaps to refer the reader to the work of Peck et al. (1992).

Gradually more extensive yet concentrated studies were carried out on the facial hard and soft tissues of the major race groups, as well as certain nationalities. Engel and Spolter (1981) suggested cephalometric and visual norms for a Japanese population, Park et al. (1989) examined the cephalograms of Korean adults and Cooke and Wei (1989) layed down cephalometric standards for Southern Chinese and British Caucasoids.

Despite the comments of Cobb (1942) on genetic complexity Drummond (1969) set out means and norms for the American Negroid based on his cephalometric analyses. He compared them to established equivalents for American Caucasoids and noted that in the Negroids there is a distinct bimaxillary dental protrusion, a bony maxillary protrusion, a large strong tongue and loose flaccid lips. Many workers have noted the racial characteristics of the American Negroid face. Altemus (1963) duplicated Burstone's study (Burstone, 1958) and arrived at a conclusion that Blacks had larger mean values than the other race groups in all areas except for glabella, menton, and incision. Stomion

and subnasale were thinner and the soft tissue chin extensions were similar to Caucasoid values. Fonseca and Klein in 1978 and Thomas in 1979, conducted cephalometric evaluations of the hard and soft facial profiles of the American Black woman whereas Conner and Moshiri (1985) layed down orthognathic surgical norms for American Black patients.

Jacobsen (1978) employed cephalometric radiographs in a study of the cranio-facial skeletal pattern of the South African Negroid. He compared the prognathism and ramus height of 55 Negroid and 55 Caucasoid subjects.

More within the field of reconstruction Caldwell (1986) refers to the Masters Thesis of a researcher also named Caldwell (1981) wherein the latter discusses the features of the whole face as they relate to the skull; and Macho (1986, 1989) posed some helpful guides for reconstructing the nose. Lebedinskaya et al. (1988) examined 3000 subjects representing 12 ethnic groups in the Soviet Union. They found that a number of stable correlations existed between certain facial features and the underlying skull.

Two radiographic contributions to facial reconstruction are worthy of detailed description. Walker and Kowalski (1971) and again Walk[illegible] (1972, 1976) described the use of the lateral cephalometric radiograph to produce computer-

generated hard and soft tissue profile. The outlines of individual bones of the skull were traced from the radiograph. Each bone or element was allocated a fixed number of points along its outline. The points were mapped in a clockwise direction and always in the same sequence. They were of two types: conventional anthropometric landmarks and selected points lying midway between. The latter were calculated by dividing the outline between the landmarks into two, four or even eight sections depending on the distance between the landmarks. For each skull 177 points were recorded. These were digitised into the computer and converted to x and y Cartesian coordinates. The tracings of successive head films were then superimposed over each other and centred on the sella turcica. They were oriented to match a line from the base of the occipital bone to the centre of the palate. Information on lines, planes, projections and angles was arrived at through coordinate geometry and the data were statistically analysed where needed. Hundreds of people ranging from childhood to old age have been measured in this way. This provides a data bank for future study of soft tissue depths and average faces for the various ages and race groups are available. Statistical and predictive methods have been developed to find "the most probable" profile for a skull. It is quite evident that the work of Walker provides us with valuable information on hard and soft tissue outlines. However, the points that are used for creating the profile are not

positioned in a way that facilitates the understanding of individual features and the manipulation of their smaller shapes.

George in 1987, used lateral cephalometric radiography to measure the facial profiles of 54 American Caucasoid men and women ranging in age from 14 to 36 years. He traced their hard and soft profiles onto a sheet of graph paper and measured the distances between the standard anthropological cranial landmarks and the equivalent soft tissue points. Sets of mean values for the distances were drawn up for males and females. Cephalometric analyses were then carried out to determine the facial proportions and skull type. A set of mean soft tissue depths was fitted to the hard tissue outline of the new skull and all the points connected by lines. The stepped angular outline thus produced was given a curvature by freehand drawing, which George terms "humanising". This intervention, plus the need to "harmonise" the skull by adjusting the shape of the lines in accordance with age, race and sex expectancies permits artistic licence to influence the result of the technique. However, a geometric method is offered for the planning the nose, lips and chin. George feels sure that the lateral craniographic method provides an effective research tool for collecting data on tissue depths. He attends to tissue depths and shapes as local happenings only. As with the work of Ghafari (1987) on

Moorrees meshes, George had no need for a centre from which measurements can be registered.

Since the same principles apply to measuring coordinates in the three dimensional world as apply to those in the flat or two dimensional radiograph (except for the added z coordinate) only a brief survey of the literature will be presented under the next three headings.

Pseudo-three-dimensional radiography studies

Three dimensional coordinates can be derived from two-dimensional radiographs of the head and face (Baumrind and Miller, 1980; Baumrind et al., 1983). In comparison with computed tomography, the method is simpler and involves low radiation doses. Brown and Abbot (1989) use radiographic equations based on geometry of a biplanar system to predict the location of a reference point on one film from its location on the other. Three-dimensional coordinates of the reference points are calculated and stored for subsequent retrieval when they can be used for metric analysis or for the display of simple wire-frame models of the skull. Grayson et al. (1988) also employed existing cephalostat-based data sets to derive certain analyses of three-dimensional form.

Trocmé et al. (1990) feel the biplanar cephalometric stereoradiography (BCSR) technique proved to be an accurate method for measurements in three dimensions. Supporting this confidence and working with Grayson et al. (1988) and Cutting et al. (1986), Bookstein et al. (1991) also conclude that the three dimensional cephalogram, or biplane reconstruction as they call it, is sufficiently accurate for routine clinical and surgical application. The three-dimensional method supports all the usual biometrics of landmark locations and takes advantage of a normative data base that is suitable for semi-automatic analysis of syndromic data. However, as with the method described by Cheverud (1983) using finite element scaling, the main drawback of all these systems is their inability to represent curved surfaces in three dimensions. Attempts to improve on the above methods have been made by the added use of stereophotogrammetry (Burke, 1983), Moiré fringes (Kanazawa and Kamiishi, 1978), the combined use of models, photographs and radiographs (Fanibunda, 1983) and the use of hundreds of grid points projected onto the face by Motoyoshi et al. (1992).

Three-dimensional radiography studies

A change in concept occured when measurements in three dimensions were introduced into head and face reconstruc-

tion (Marsh and Vannier, 1983; Vannier et al., 1984). Cutting et al. (1986) and Moss et al. (1988) used computer images for their surgical planning.

Arridge et al. (1985) created their three-dimensional reconstructions by using a fanned laser beam and a television camera for data acquisition. The outlines of the facial and skeletal surfaces were stored as spatial coordinates and were placed in registration with each other to produce a rotatable and dissectable three-dimensional simulation of the head.

Moaddab et al. (1985) produced three-dimensional shaded images of the temporo-mandibular joints from the sagittal CT scans of five cadaver heads and Salyer et al. (1986) reconstructed faces for pediatric patients. Schlusselberg (1988) used computer simulated three-dimensional images for cutaways and for the isolation and movement of three-dimensional objects in the planning and design of surgical prostheses. Additional benefits are reduced storage requirements, the rapid display of simple surfaces and a far more realistic appearance of the smooth reflective surfaces. Matteson (1989) compared measurements taken from a real skull with those taken on a computer simulated three-dimensional image and measurements of a three-planar radiographic reconstruction of the same skull and found the measurements taken from CT to be the better of

the two radiographic methods. Accuracy of measurements will improve as radiographic enhancement gains ground (Kalisman and Kalisman, 1986; Brinkman, 1988) and data redundancy reduction will allow more economic storage of data (Marsh et al., 1986). More recently the process has been taken a step further when computer-generated three-dimensional images were translated into three-dimensional forms (CAD/CAM), some examples of which are noted in the writings of Haskell et al. (1986), Lampbrecht and Brix (1988) and Guyuron et al. (1989).

f. Magnetic resonance imaging methods of measurement

The work done on MRI in collecting data on the head and face is already voluminous. Since the same principles of measurement in three dimensions apply to CT-gathered data and MRI images, the literature on MRI is not reviewed in this thesis except perhaps to mention that Lam et al. (1989) found the orofacial soft tissues of 26 subjects scanned with MRI to be clearly imaged. They saw distinct disadvantages in long exposure times, the danger of metal objects and the presence of pulse-makers. In addition the internal bone detail was lost. Fortunately this latter problem does not matter in facial reconstruction as only the outer table of the bone needs to be clearly visible. As an example of the use of MRI in measuring facial soft tissue the reader is referred to Helmer et al. (1986b).

Validity of facial reconstruction

Even if the only contribution of some was criticism, at least the spotlight was brought to bear on a subject that was controversial at the time. Czekanowski (1907) and von Eggeling (1909) were good sources of comment during their time. There will always be sceptics like Suk (1935) and Brues (1958) who were not convinced that the technique of facial reconstruction was reliable enough for the serious subject of establishing identity. Montagu (1947) in his comments on the work of that period went so far as to say that since the character of hair, eyes, nose, ears, eyebrows and skin creases were impossible to reconstruct, it was desirable that facial reconstruction be "dropped" as it could do "real harm". Riedel (1957) was of the opinion that the skeletal and soft tissue profiles were closely related. Burstone (1958) on the contrary was concerned that because there is such variation in the soft tissues covering the skeletal face, this relationship could not exist. As knowledge and ability improved, those with farsightedness like Krogman (1962), Stewart (1979), Rathbun (1984) began to discover merit in the subject. Charney and Wilber (1980) at least grant reconstruction a modicum of value when they claim it as "a last ditch attempt... when all else has failed".

Until recently the efforts of forensic facial reconstruction had never been subjected to any form of testing or evaluation. The first attempt at anything like a scientific testing was by Snow et al. (1970). The results they obtained were heartening enough to rekindle interest in approving the value of facial reconstruction.

In 1986, Aulsebrook and van Rensburg conducted an appraisal and comparison of two different facial reconstruction techniques. The face of a cadaver was photographed and the facial soft tissues were removed from the skull by an assistant. At no stage during the remodelling process was the reconstructionist (Aulsebrook) allowed to see the face or the photographs. Two different methods of facial recontruction were used. In the first (a morphometric method) the tissue depth tables of Rhine and Moore (1982) were consulted as sole guide to the remodelling process. In the second (a morphoscopic method) a sense of the sculptor's talent was encouraged, following the style of Gerasimow (1971). Here the only clues to the amount of tissue to replace were the bony morphoscopic characteristics on the surface of the skull. The resulting facial reconstructions were photographed. They were then masked in such a way as to reveal either forehead, nose, lips or chin and re-photographed. In judging the photographs it became possible to say which of the two methods was more successful at gaining a likeness of individual parts of

the face. The photographs of the completely revealed and partially revealed faces were evaluated by 25 artists and 25 engineers. Their task was to determine which of the two reconstructions more closely resembled the face of the cadaver. The results indicated Gerasimow's technique to be the more effective.

In 1986 Neave conducted a test to compare the results of the independant work of 9 reconstructionists in modelling their versions of a face over duplicate casts of the same skull. Photographs of the reconstructions and the deceased were given to a police artist for comparison and scoring using the Identikit system. In commenting on another successful case Neave (1988) states that the success of a facial reconstruction depends as much on the circumstances of the investigation as on the accuracy of the technique.

Helmer et al.(1988b, 1989a, 1989b) conducted a double blind trial in which two examiners reconstructed the soft tissue on casts of 12 skulls. They worked independently of each other after having been given information on the age, sex and constitution of the person in question. Results indicated varying degrees of similarity ranging from "approximate" to "far-reaching" with one exception, that of a "little similarity".

Rhine (1984) reviewed the status of facial reproduction in the eyes of the court. Hollien (1990) has little doubt that scientific testimony will impress a jury. However, when all is said and done the function of forensic facial reconstruction in the process of human identification is a distinctly adjunctive one. Just as with identikit-type systems and superimposition techniques it acts only in support of other more quantitative methods of identification like dental charting, comparison of sinus tracings and palatal rugae. Galloway et al. (1990) explain that although the forensic anthropologist is an expert witness the techniques he uses are governed by rules established by the legal system rather than those commonly accepted by the scientific and academic communities. The forensic anthropologist needs to move between these two spheres. If carried out by an expert, facial reconstruction can certainly assist in confirming the identity of an individual or even in excluding a suspect. At the very least it can help in narrowing down the number of likely candidates in a list of missing persons.

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CHAPTER II

AIMS AND OBJECTIVES

It can now be appreciated that there are two fundamental approaches to measuring the amount and form of the soft tissues of the face. The first is concerned with recording the single soft tissue depth measurements at isolated sites on the face. This will be refered to as the "depth system". The second is concerned with recording the continuous outlines of bony and soft tissue profiles. This will called the "profile system". Four other terms should also be defined. The hard and soft tissue outlines seen on the cephalograms are the "hard profile" and the "soft profile" respectively. Clearly defined anatomical regions like the ear, chin, nose, forehead and cheek are recognised as "features", whilst a "sub-feature" is a smaller part of a feature such as an ala, nose tip, glabella or the bulge of a commissure (Figure 1).

This study has three primary aims and a number of objectives.

A. AIMS

In short, these are:

- to create a new depth system
- to create a new profile system
- to establish facial tissue norms

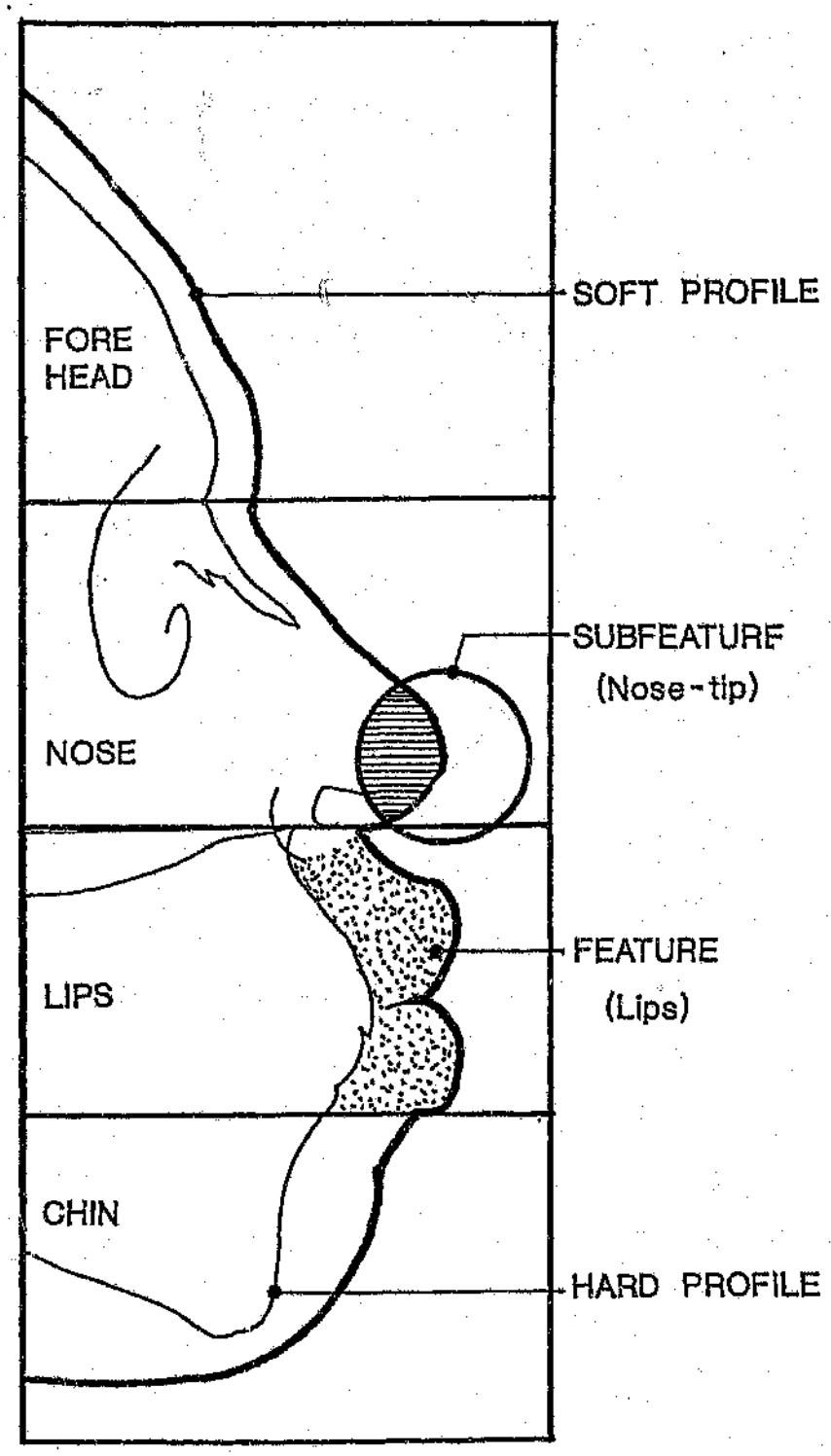


FIGURE 1 - Features and sub-features of the hard and soft profiles.

The face in profile can be horizontally divided into four distinct modules, each one representing a feature. Each feature in turn, is comprised of three sub-features.

1. A new depth system

It was decided to use the proven modalities of diagnostic ultrasound and cephalometric radiography, coupled into a dual measurement system, for determining the thickness of facial soft tissues.

Many of the landmarks used in the new depth system were the same as those layed down by previous workers, thus ensuring comparability of data. In addition, a number of extra landmarks were planned to expand the collection. In the main the ultrasonic landmarks were selected to lie at similar horizontal levels to the landmarks on the lateral and oblique radiographs. Whether measured directly on the face during the ultrasonic measurement phase or taken off radiographs, the landmarks were chosen to be at the tops of feature bulges and in the depths of depressions and grooves (Figure 2). This sets the maximum and the minimum extremes of tissue thickness for that locality. There was also a need for information on the size and shape of the more complexly sculptured features such as lips and nose.

a. The use of diagnostic ultrasound

Sound waves outside the range of human hearing (20 Hz to 20,000 Hz) are classed as ultrasound. Medical ultrasound

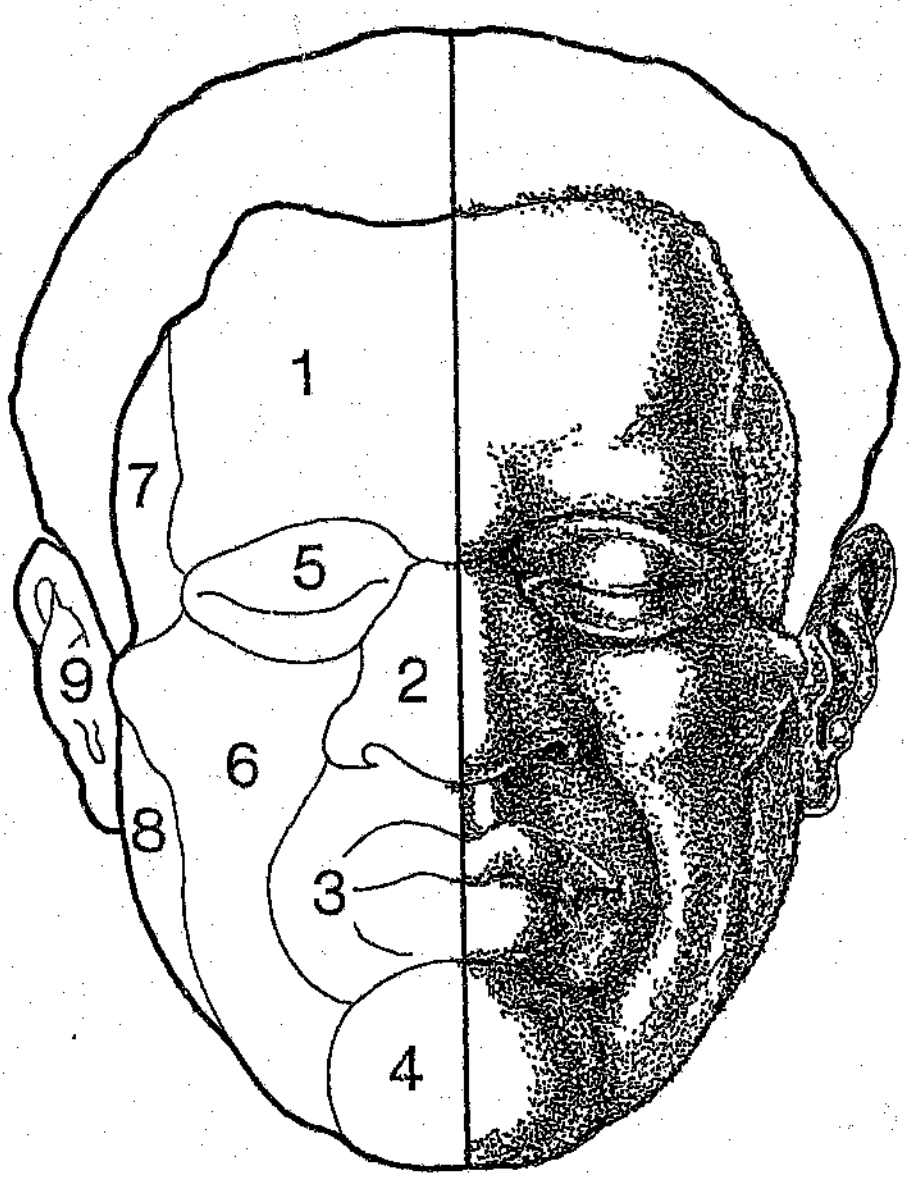


FIGURE 2 - Surface contours that determine landmark selection.

Certain anatomic bulges and grooves are common to all faces. In front view the features of the face can be clearly demarcated: (1) Forehead (2) Nose (3) Lips (4) Chin (5) Eyes (6) Cheek (upper hard cheek, a d lower soft cheek) (7) Temple (8) Jaw (9) Ear.

ranges from 1000 Hz to 10,000 Hz. The operational modes of ultrasound used in ultrasonography are A-mode, B-mode, M-mode, Real-time, and Doppler-mode. Hell (1989), using B-mode ultrasonics for examining soft tissues undergoing maxillofacial surgery, emphasised that although B-mode scanning produces good tomographic information it does so at the cost of detailed information produced by A-mode probing. This study makes use of the pulse-echo system of A-mode.

i. Accuracy of ultrasound

Stouffer (1963) found that ultrasound was comparable in accuracy to radiographic methods and that other mechanical methods like the ruler-probe were not as accurate as radiography and ultrasound. Alexander and Miller (1979) used an unfocussed transducer in a waterbath placed under vacuum to establish close contact with the skin of the forearm and then employed A-mode ultrasound with optimal reflections for measuring the thickness of the skin. The data were compared for accuracy against equivalent data taken from radiographic measurement of the same sites. A correlation coefficient of r=0.99 was obtained. Alexander and Miller concluded that ultrasonic methods of measurement compared favourably with radiographic methods.

ii. Biological effects of ultrasound

High doses of ultrasound can cause a local elevation of temperature due to molecular agitation, cavitation in the formation of tiny gas bubbles and free radicles, as well as viscous stresses within the tissues due to the interaction between the different viscosities of the adjacent tissues. The effects on the tissues are local changes in macromolecules and the disruption of membranes and cells. None of these effects have been noted when using diagnostic levels of ultrasound that fall within the intensity range of 1 to 10 mW/cm² (Buschong, 1984). The effect of cavitation only occurs with a 3 times greater dosage level than that employed in medical applications. In 1977 Communications of the American Institute of Ultrasound in Medicine issued a statement regarding mammalian in vivo ultrasonic effects: No demonstrably significant biological effects had been noted in mammalian tissues that had been exposed to intensities below 100 mW/cm². Most diagnostic instruments operate at a safe level of less than 15 percent of this figure. Jones and Frost (1984) feel that diagnostic ultrasound has the advantage of being non-invasive without any known deleterious biological effects. The use of the word non-invasive invites comment. Ultrasound does in fact invade the tissues in the true sense of the word. More correctly ultrasound should be claimed as being "low-risk" (Hodson et al., 1985).

b. The use of cephalometric radiography

Not as low-risk as ultrasound, cephalometric radiography is nevertheless an accepted modality for the measurement and analysis of linear dimensions and angles in the head and face.

i. Accuracy of radiography

According to Preston (1986), enlargement factors become important when the alteration in linear dimension is significant enough to affect the closeness of accuracy required for the study.

The accuracy of cephalometric radiography is related to collimation, focus-subject-film distances, contrast and resolution. One constant factor that affects the trueness of the result is image magnification. Thurow (1977) indicated that in radiography the image size is always larger than the object size. This is due to an inherent property of roentgen rays to radiate outwards from the anode. The rays are never parallel. Diverging from their source they magnify the image of the object through which they pass. The radiographic image must therefore be corrected for magnification.

ii. Biological effects of radiography

The biological effects of x-rays are reduced by the use of reliable and frequently tested equipment, narrowed collimation, a long cone, effective patient shielding, a high kVp and fast high-yield films (Taylor et al. 1988). In a study on the use of rare-earth screens Tyndall et al. (1988) concluded that the substantial reduction in exposure associated with these techniques warrants the use of rare-earth screens, beam-filters, flat-grain technology film, and soft tissue enhancement methods.

2. A new profile system

In the depth systems previously mentioned, the landmarks for measurements were too few in number and were located over established and familiar anthropological landmarks that were not at all descriptors of shape. Measurements were isolated and represented local information only. The amount and shape of soft tissues between landmarks were unknown. To a degree, reconstructionists were guided by familiarity with the anatomy of the area and by closely following the contour of the visible bone. Nevertheless a problem could arise if a presumption was made that the soft tissue between one depth marker and the next was evenly graded in thickness (Figure 3). In certain areas like the forehead and scalp this may well be so. However,

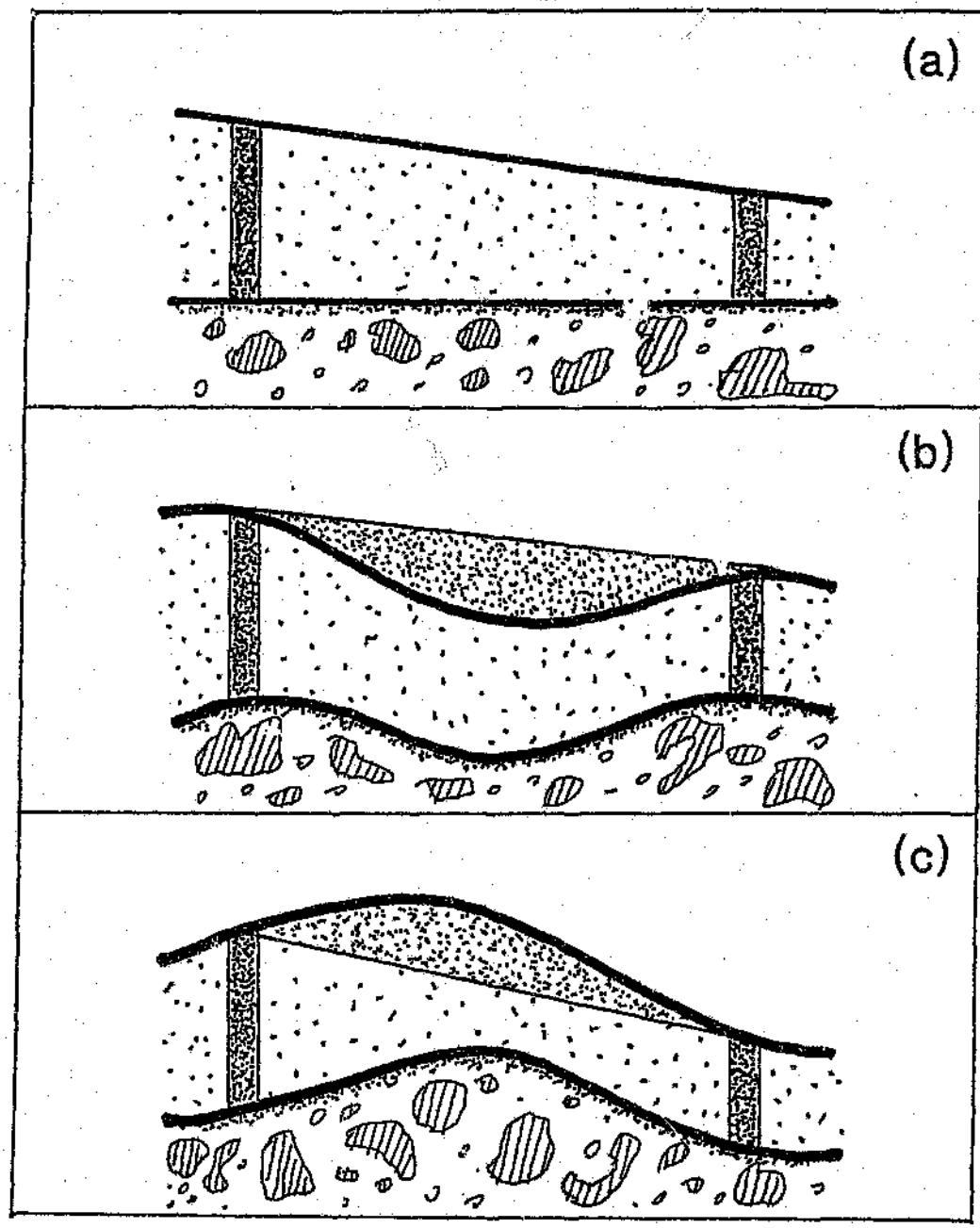


FIGURE 3 - Soft tissue variability between depth markers.

In (a) the clay has been built up in an evenly diminishing thickness from the depth marker on the left to that on the right. In (b) the real contour shown by the thick line has been increased by wrongly adhering to the method of making a straight line between markers. In (c), there is an error in the opposite direction.

in using this standard approach for remodelling tissues between sub-nasale and tooth tip for example the sculptor could land up producing a flattened upper lip. Being an unlikely shape for a lip he could in error justify the use of artistic license and adjust the lip contour to produce a more "natural look". For example George (1987) traced the outlines of a planned reconstruction onto a sheet of drawing paper and "humanised" it by softening the line. He mentions the subtle nuances of facial expression that identify a face and there is no doubt that subtleties do play a part in typing an individual. But it would be dangerously misleading if the wrong assumptions were made of shapes between points (Figure 4).

The problem of determining intervening soft tissue shape can never be resolved within the confines of the depth system. The depth system will always remain a collection of isolated data on depth with guesswork and assumption in the intervening areas.

Moyers and Bookstein (1979) inform us that landmarks by themselves do not define the curvature of a shape. They merely lie upon the shape. They also feel that any scheme involving landmarks but lacking information about curvature is inadequate in principle.

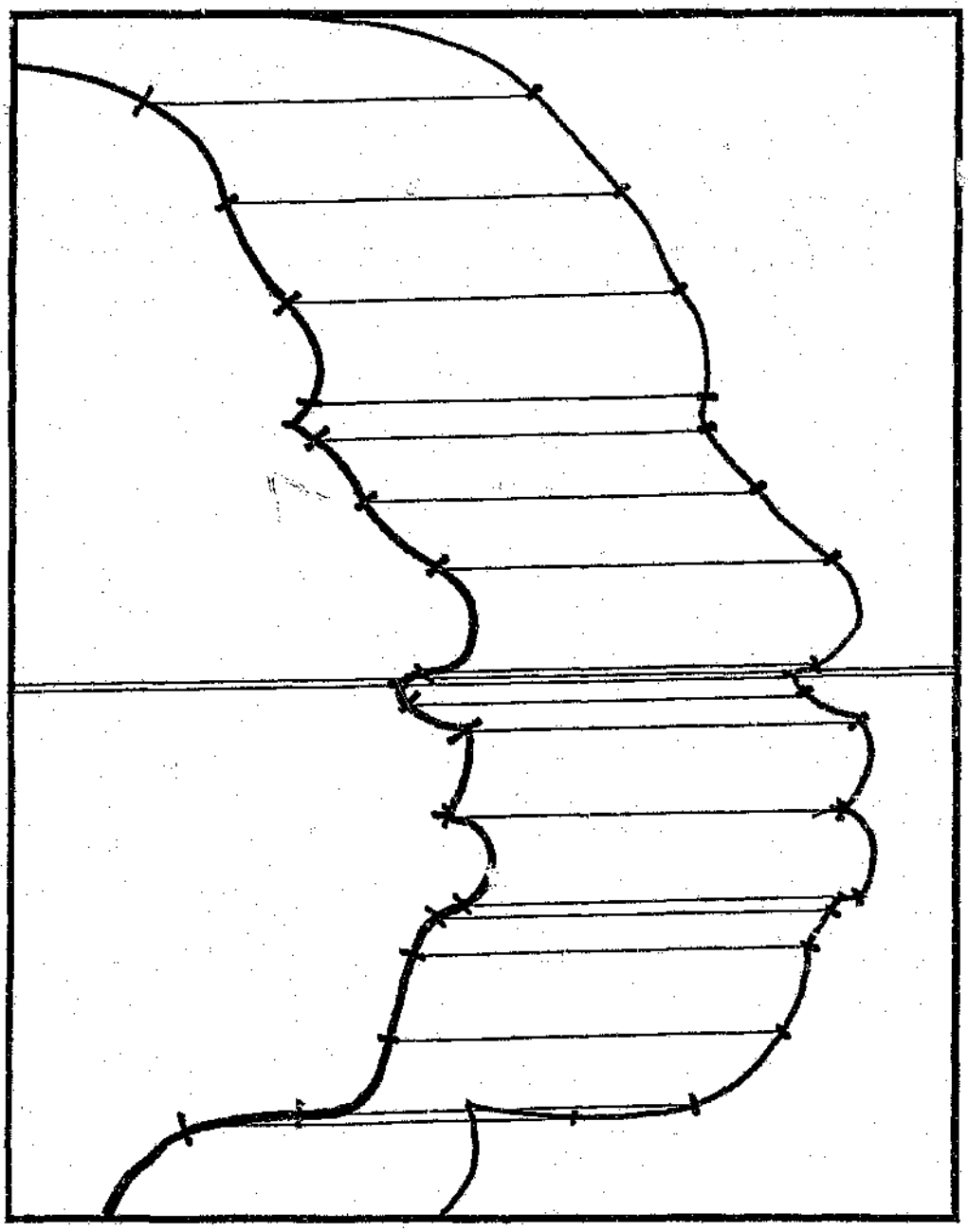


FIGURE 4 - Two different profiles running through the same points.

In the absence of control points two quite different face outlines can be drawn through the same set of points.

The capture of shape requires a quite different approach. Important to know is, not how thick the facial tissue is at an isolated landmark but, how the entire soft profile relates to the entire hard profile. At first it may seem that this study is a repetition of previous studies that have examined traced profiles of subjects. This is not the case.

Simply producing hard and soft profiles by linking as many coordinates as possible is not as useful to facial remodelling as might first be thought. An understanding of precisely what constitutes the highly characteristic appearance of a person is not accomplished by the mere tracing out of a profile.

The new profile system requires a different conceptualisation to those of the profile systems discussed in the literature survey. It invites a perception of the hard and soft profiles as being composed of distinct, discernable, smaller shapes that can be captured and stored as simple geometric objects.

As far back as 1942, Thompson noted that mathematical analysis of discreet measurements was not the way to understand or interpret form. He realised that we reach through mathematical analysis to mathematical synthesis. In doing so we are able to discover certain identities

that were obscured by our very methods of description, rather than revealed by them. Preferable to the perception of form in a statistical sense is a concept of the dynamic forces that give rise to that form. This involves seeing bulges and dents as intact and entire shapes, that is, the geometric objects mentioned above.

Koski (1973) agreed when he claimed that although studies employing points, lines, distances and angles may be good from a purely statistical point of view they are not well suited to reveal craniofacial biology.

The profile system proposed in this study will incorporate the basic principles of morphometrics. Bookstein (1982) neatly sums up the essential qualities of morphometrics when he defines it as the empirical fusion of geometry with biology and that its methods must take into account two distinct sources of information: geometric location and biologic homology. He feels those workers practising morphometrics for comparative purposes should be acquiring their information from the geometry of biologic shape. The writer agrees and is certain that it is in the field of biosystematics or numerical taxonomy that basic morphometrics can offer a contribution towards the advancement of a scientific approach to forensic facial reconstruction.

It must be emphasised that the present study is solely aimed at establishing a method of recording the hard and soft profiles of the face. It makes no claim whatsoever to having located a new growth centre. Nor does it make any attempt at replacing any of the current concepts on transformation grids and biological homologies, or any of the finite element analyses.

All information required for the profile system is to be found on the cephalometric radiographs. The system will be illustrated on the hard and soft profiles as seen on the lateral radiograph. The same procedure can be adapted to the oblique radiograph.

For a complete description of a shape we need to know:

- Its location in space with respect to the measuring system.
- Its orientation with respect to the three planes of space.
- Its size in measurable and finite quantities.
- Its shape in respect of its outline and contour.

This requires that we first select a frame of reference in which to position the head of the subject and which for this study shall be called a "head world".

Next we must choose a locative system that will allow us to record the position of any point within the head world by a pair of coordinates.

Finally we must decide how to select, record and store (archive) as well as retrieve the coordinate pairs that represent the locations of the significant points which describe the simple geometric shapes within the hard and soft profiles of the face.

a. Selection of a "head world".

Determining the proper position for the head in space has intrigued many, from artists like da Vinci (Gould, 1975) and Dürer (Strauss, 1972) to the pure scientists of the present. It is accepted that when viewed from the front, the head should be positioned with the inter-ocular axis parallel to the floor. Seen from a lateral viewpoint the horizontal positioning or the antero-posterior tilt seems to be dependent on what it is we are trying to prove.

Cephalometrists of the calibre of Krogman (1962), and Sassouni (1955) recognised the effect that orientation and registration of head position can have on an interpretation of cephalograms They feel that assessments of the profile can become significantly different depending

on the position of the head in the cephalostat. This outlook on the need for a frame of reference is supported by Moorrees and Kean (1958) in their evaluations of the face profile.

The Frankfort Standard Horizontal (FSH) plane has been accepted as the principle anatomical determinant of head orientation since 1882. Moyers and Bookstein (1979) point out that the Frankfort plane passes through the top of the porions and the bottom of the left orbitale, yet "top" and "bottom" are themselves defined in terms of the orientation of that one subject to earth.

One of the challengers to this standard head placement, is the "natural head position" (Moorrees and Kean, 1958; Solow and Tallgren, 1977; Sandham and Duvall (1985); Cooke and Wei, 1987; Huggare (1989); Lundström and Lundström, 1992; Solow and Siersbaek-Nielsen, 1992). Nielsen and Solow (1982) found the natural head position (NHP) to have sufficient reproducibility (a mean of 2.3 degrees off the true vertical). They claimed this was of clinical value in the study of head posture as relating to orthodontic treatment. Unfortunately the natural head position is not the same from person to person.

Another contestant to the FSH is the ala-tragus line as described by the Dutch anatomist Camper (1794), and

commented upon by Neger (1959). In 1985, van Niekerk et al. made the valid observation that the ala-tragus line is differently defined by different authorities.

In orientating the head prior to taking radiographs it was decided not to use the FSH or the NHP. Instead the ala-tragus line as modified by Spratley (1980) was chosen as the horizontal. This line runs from the centre of the ala to the centre of the tragus.

In orientating the cephalogram, the horizontal was taken as the line that represents Camper's plane (as defined by Salzmann in 1974). This is the line between the centre of the bony external auditory meatus (EAM) and the acanthion (AC). For the purposes of this study this line has been given the name "external auditory meatus-acanthion" line or EAMAC line.

Since the calibrated rings of the earposts will always be superimposed upon each other, their common centres will represent the ends of a transverse axis passing through the head, the middle of which is the centre of the polar coordinate system to be discussed below. The head is thus registered on the transmeatal axis and is orientated with the EAMAC line placed parallel to the horizontal plane. This horizontal plane sets the orientation of the other two planes, the coronal and median.

The choice of these two locators, EAM and AC, may seem controversial to some. Nevertheless there exists support for their selection.

Some may argue that the centre of the external auditory meatus is a landmark in space. The landmark is no more difficult to mark than the sellion (also lying in space) used in orthodontic studies.

Another criticism may be that the thickness of the cartilagenous lining of the bony external auditor. canal is not equal in amount throughout, and that the centre of the hard and soft meatusus are therefore not quite the same. Lestrel (1974) also used the EAM as a centre for his Fourier analyses of cranial vaults. He found that the difference in the EAM centres of the casts and the radiographs he studied was quite small whereas the difference between craniums was appreciable. In the light of this it was realised that providing the earposts were well seated within the patient's earholes this fractional difference could be discounted.

There could also be concern by some that since there is asymmetry between the locations of the two meatuses on the skull the median plane cannot always be the same as the anatomical mid-sagittal plane. This is of course

true. However this variation has had to be accepted in all cephalometric analyses.

The acanthion has been accepted in radiographic studies by workers such as Todd and Marks (1981). A strong point in favour of the acanthion and anterior nasal spine is that unlike the orbitale, one of the determinants of the Frankfort plane, both are midline structures and can be located with ease providing a radiographic profile filter is used to prevent burn out of the soft tissues and the thin bony tip. In this study the acanthion is preferred to the anterior nasal spine. The latter is an anatomical structure whereas the acanthion is a landmark on that structure. Salzmann (1974) supports this when he defines the anterior nasal spine as the median sharp bony process of the maxilla at the lower margin of the nasal opening, and the acanthion as the tip of the anterior nasal spine.

b. Selection of a coordinate system

Once the head world had been established, with a centre point from which measurements could be made, a coordinate system had to be selected for describing the profiles. At this stage in the development of the profile system all measurements were to be taken in two dimensions. However, the system can accept a third dimension at a later stage.

In selecting a coordinate system, the spherical shape of the head suggested that a radial polar coordinate system would be ideally suited for dealing with curved surface elements of the face and features. It would in fact be preferable to the more popular rectangular or Cartesian coordinate system. Todd and Marks (1981) elected to use optimal polar coordinates for their studies of the human head and Holloway (1981) computed mean spherical coordinates (in a three dimensional polar coordinate system) in his study of brain endocasts.

Registered with its center at the midpoint of the transmeatal axis and its zero line orientated on the EAMAC line a measuring system is now set up to locate any point on the two-dimensional radiographic profiles by using the polar coordinates of one angle and a distance (Figure 5).

c. Selection of points

In selecting the points that effectively describe the hard and soft profiles of the face as seen on the radiograph, reference was made to Bookstein's (1982) remarks on existing systems that record anatomic points. He feels that all the schemes he had commented upon had archived points with one or two points of redundancy. He further states that the sampling of lines on forms in two dimensions or circles touching twice would be of preference, as

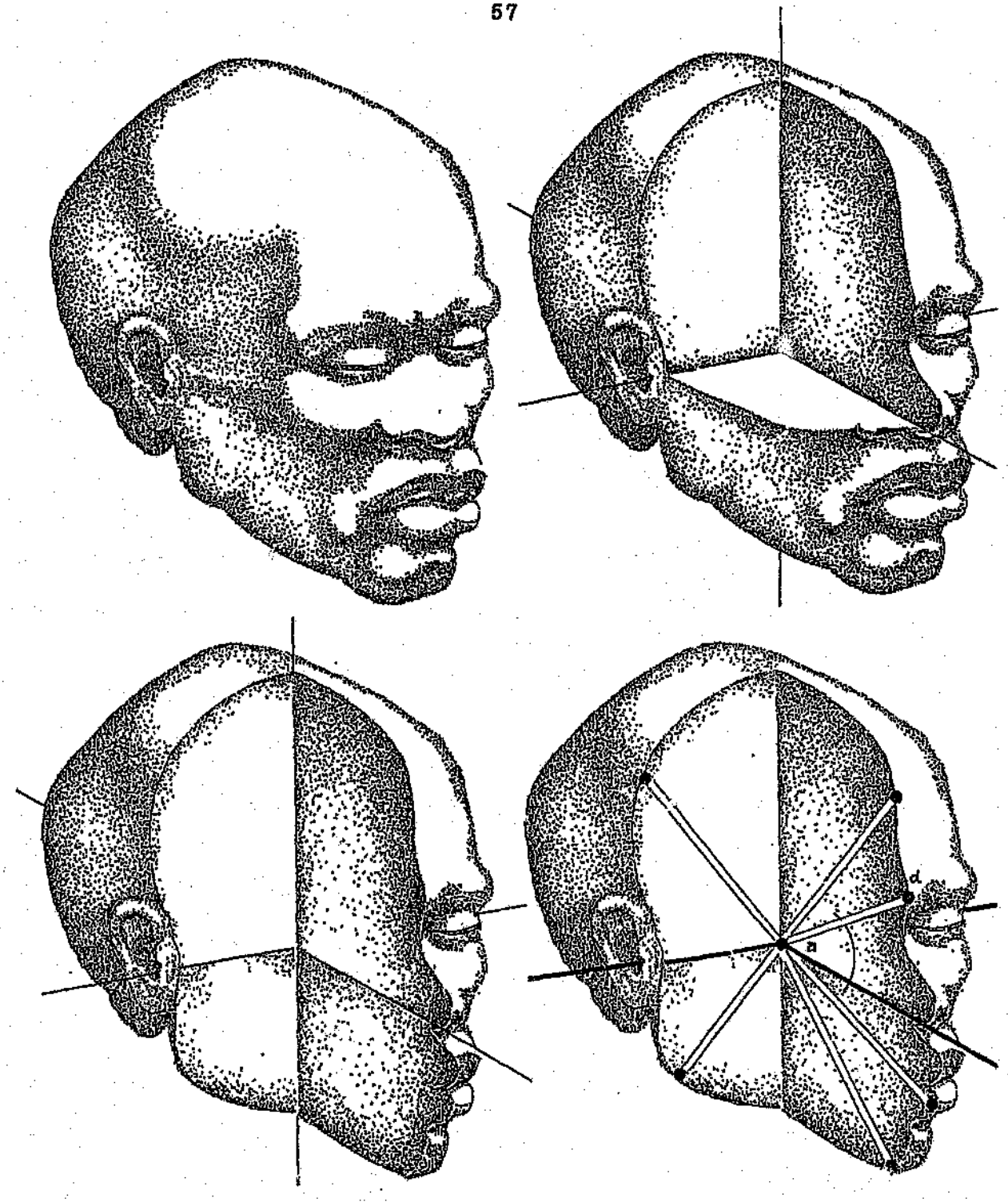


FIGURE 5 - "Headworld", showing polar vectors and EAMAC line.

This series of drawings shows how the head can be dealt with as a sphere. It can be sectioned to show the planes and axes for orientation. A polar coordinate system with its origin at the center of the head is used for recording the position of any point within the headworld.

these geometric objects often quantified the meaningful features of form much more directly. In looking for these geometric objects within hard and soft facial profiles attention must be paid to those subtle but nevertheless clearly discernable significant points along the profile where the line alters direction and character. The turning points mark the beginnings and endings of geometrically simple shapes: lines, angles and arcs of circles which are in themselves simple to record, economical to store and are mathematically tractable to compare and to transform (Figure 6).

3. Establishing facial tissue norms

It was intended to record two sets of norms for the group of subjects selected for the study. The first was an expanded table of facial soft tissue depths. The second was a set of standard hard and soft tissue profiles. It was realised that as the numbers of subjects studied in this way increase over time the norms would have to be altered accordingly.

The subjects used in this study were living adult male Zulus. The living subject was chosen because in the dead the effects of pressure and gravity produce changes in the distribution of facial tissue fluid. The resulting post-mortem distortion can occur soon after death (Snow

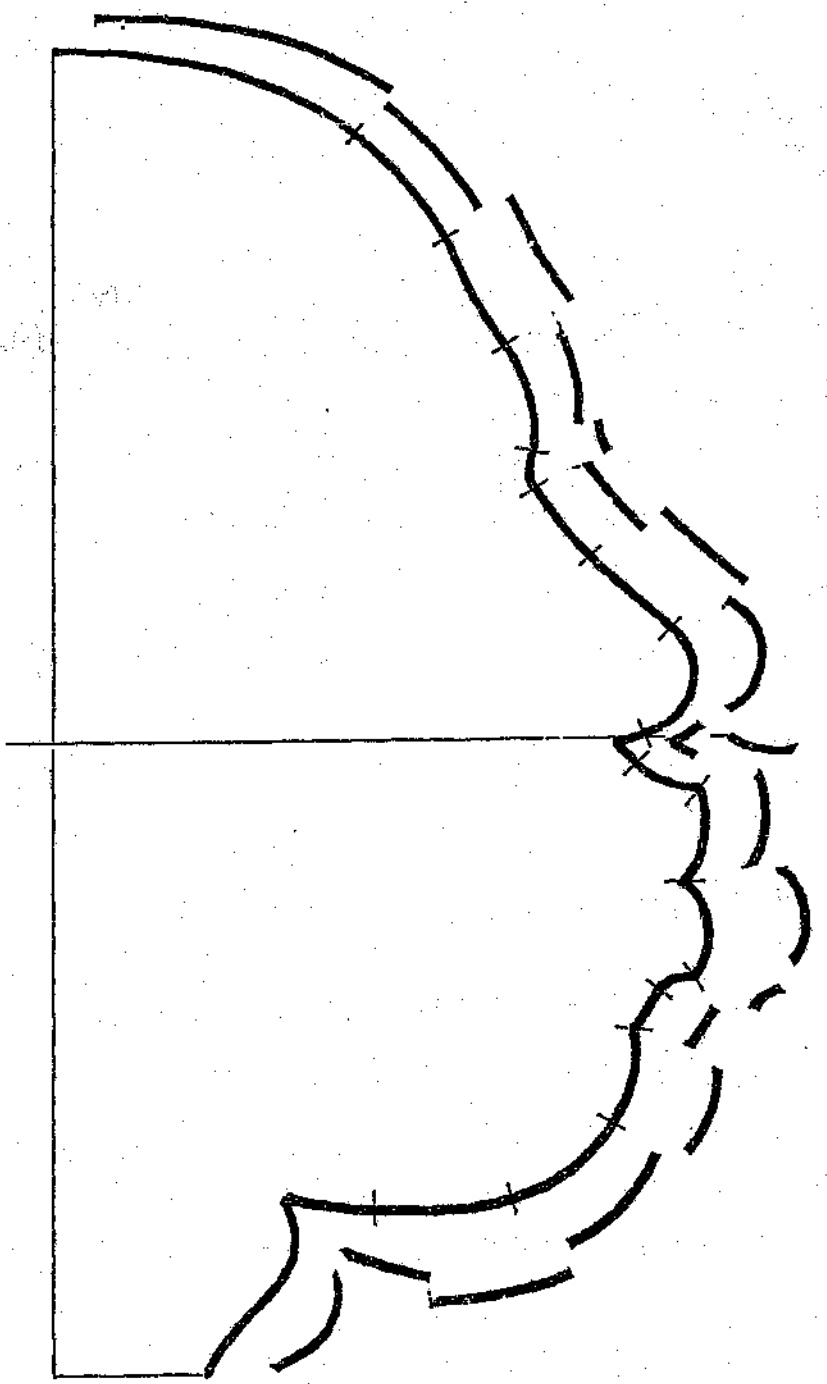


FIGURE 6 - Geometrical "objects" comprising the profile.

The outline of the face can quite readily be subdivided into smaller shapes. Though they may at times be straight (forehead and bridge of the nose) these line-segments are generally curved shapes, effectively represented by arcs of varying radius and length.

et al., 1970). There are other advantages to measuring living subjects. Firstly, in studying how features like the lips or the cheeks are related to the skull there is the requirement that they be relaxed and in their normal position as determined by the pull of gravity. The distorted and unyielding soft tissues of the supine dead are not true representations of the reactive full tissues of the erect living. Secondly, when required to identify a person from a facial reconstruction based on soft tissue depths from cadavers, the identifier must conjure up a projected mental image of how the person would most likely appear in death. The identifier would surely be more comfortable comparing the reconstruction to a memory of the face as it was during life.

The Zulu is a member of the closely-knit Nguni tribe of African Negroid. The large databanks of tissue depth measurements on Negroid faces that have been collected for forensic purposes are those on the American Negroid by Rhine and Campbell (1980), and Walker (1976). It is necessary that more applicable information be collected for the Southern African Negroid. It is also reasonable to assume that reconstructions of Zulu faces from locally derived tissue measurements would be more appropriate than reconstructions made from depth measurements taken of the American Negroid face. In time, the databank of Zulu faces should be enlarged to amplify the possibility

of finding characteristic and individual types. As far as can be determined by the writer, the Natal Nguni people have not yet been investigated in the light of forensic reconstruction.

If measurements are recorded in subjects having a variety of races, ages, weights and health the results would of course be representative of the human species in general. However, the equation for explaining Man's diversity of appearance, if indeed there is one, is already complex enough without further compounding it by accepting a broad diversity of subjects and states of health. If any system for predicting the likeness of an individual is to be effective it should first be looked for in creatures of genetically similar blueprint and the characteristic patterns of that group dissected out. In support of this concept Satravaha and Schlegel (1987) emphasize that we should evaluate all available data to find standards that are "valid for specific ethnic groups". In the case of mixed population groups where there is interbreeding of different strains the motley distribution of features can add to the confusion of the reconstructionist. These very often perplexing arrangements will be better understood if the structure of the smaller components (the features and sub-features) of each population group become more familiar to us. This base-line approach requires that we begin the study with a sample that has been selectively

controlled in regard to the age, race, sex and even the health of the subject. In this case, the subject was a healthy adult male Zulu.

B. OBJECTIVES

1. To compare data obtained from ultrasonic measurements on the face, against data of acceptable accuracy taken from radiographic measurements at the same landmarks, in order to check the reliability of the ultrasonic technique as a measuring tool.

2. To assess the potential value of combining these two techniques into a measuring system that can be used for future research of this type.

3. To determine standards of soft tissue thicknesses at established landmarks on the faces of live, healthy, adult Zulu males, hitherto not yet studied for this purpose.

4. To introduce a system of selecting points on the hard and soft profiles, traced from the lateral cephalometric radiograph, that best describes their shape through the use of simple geometrical arcs and line-segments.

5. To employ a system of relating hard and soft tissue points to each other and fixing them as sets of polar coordinates in space.

6. To develop a system of connecting the sets of hard and soft tissue coordinates by a system of arcs and lines to produce hard and soft face profiles.

7. To assemble from the collected data a table of average coordinates, from which standard hard and soft tissue profiles for the male Zulu face can be plotted.

8. To compare profiles of faces reconstructed from the above newly acquired data for the Zulu, with profiles constructed on the same skulls, from existing available measurements on American negroes.

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CHAPTER III

METHODS: METHODOLOGY

A. EXPERIMENTAL CONCEPT

Apart from age and colour, the unique facial identity of an individual is a combination of the size and shape of their features and the spatial relationship that exists between those features.

In addition, certain outlines of the face are simple and yet surprisingly descriptive of a person's likeness. For example if a subject is backlighted by positioning him in front of a well illuminated screen, a cameo silhouette is produced. As the subject's head is rotated about a vertical axis it displays a continuous, changing dark outline against the lighted background. Some outlines (profiles) are more characteristic of that person than others. The least typical of these is the profile of the head in the coronal plane. The most characteristic outlines of the face are the side view and the three-quarter view. These are the profiles seen on the lateral and oblique cephalometric radiographs. The lateral view reveals a major outline of the face often used in police identification. It is also commonly used for planning and assessment of the aesthetic results in surgery and orthodontic treatment.

Seen from the front, the edge that describes the lateral profile is a straight line. The oblique profile on the other hand is the wavy line that follows the undulating boundary between the front and the side planes planes of the head (Figure 7). This profile presents an outline so typical of a person that without it a portrait painter could fail to render a good likeness (Berry, 1977; Hamm, 1963; Raynes, 1979, 1981). A face seen from the front and modelled by side lighting displays a shadow the edges of which follow the course of this oblique profile. This gives rise to the term shadow modelling. Many a successful caricature has been created by the sole use of these two simple descriptive profiles (Figure 8).

In an effort to gain as much information as possible it would seem wise to probe the entire extent of the soft tissues lying between the two profiles, using ultrasound. In doing this, many soundings would return as distorted and even useless information. Ultrasonic soundings over eye-sockets, pyriform aperture and the complex caverns lying between the maxilla and ascending ramus would be simply absorbed by the deeper tissues. Pulses reflecting off irregular bony surfaces would be scattered and their echoes may never even be returned to the probe. This suggests that the sites for measurements should fulfil a set of requirements:

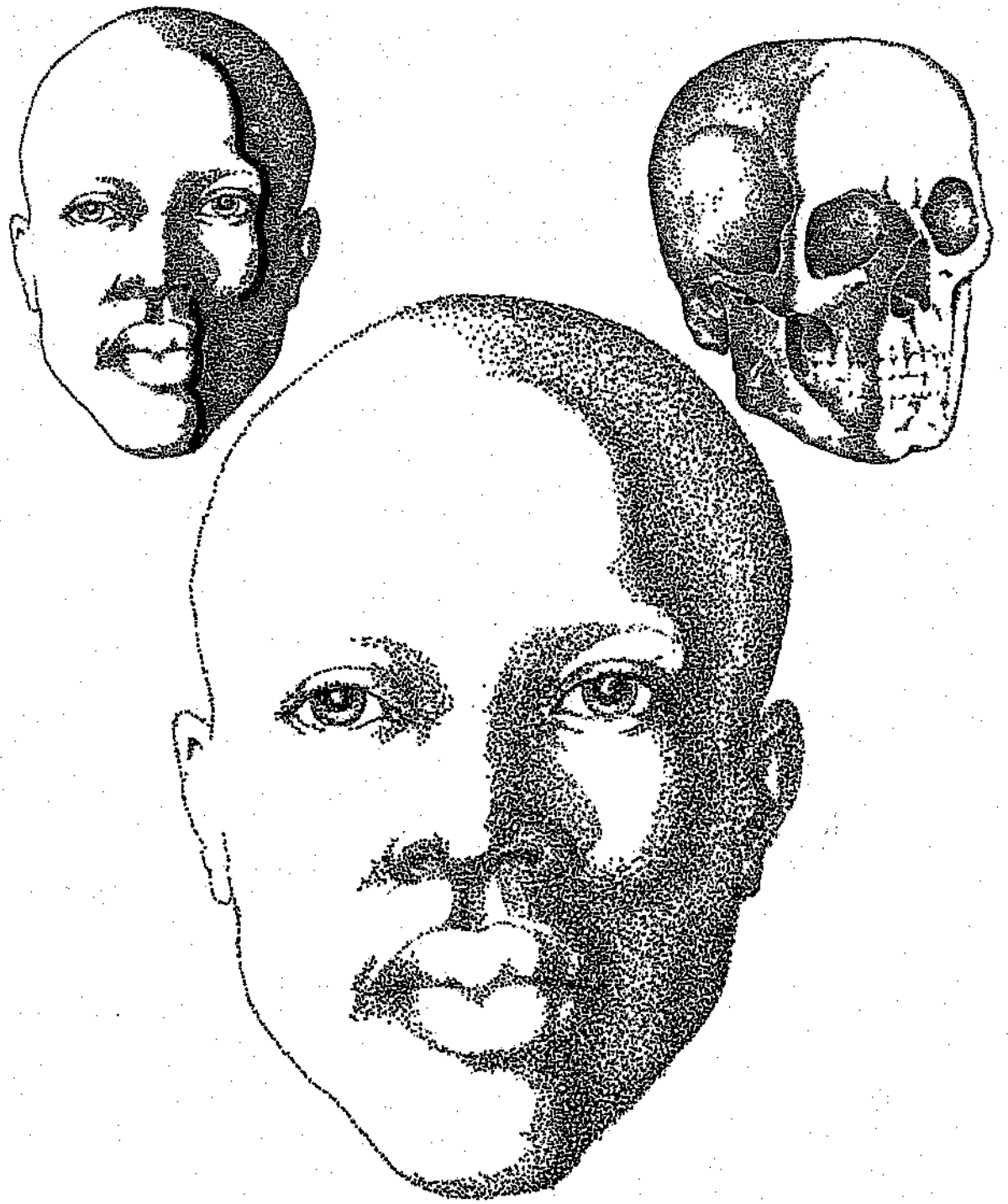


FIGURE 7 - Shadow lines on the face and skull.

Portrait artists are fully conversant with shadow lines cast onto the face by oblique lighting. The turning point of light as it is often called by artists can be seen on the faces and the skull above.

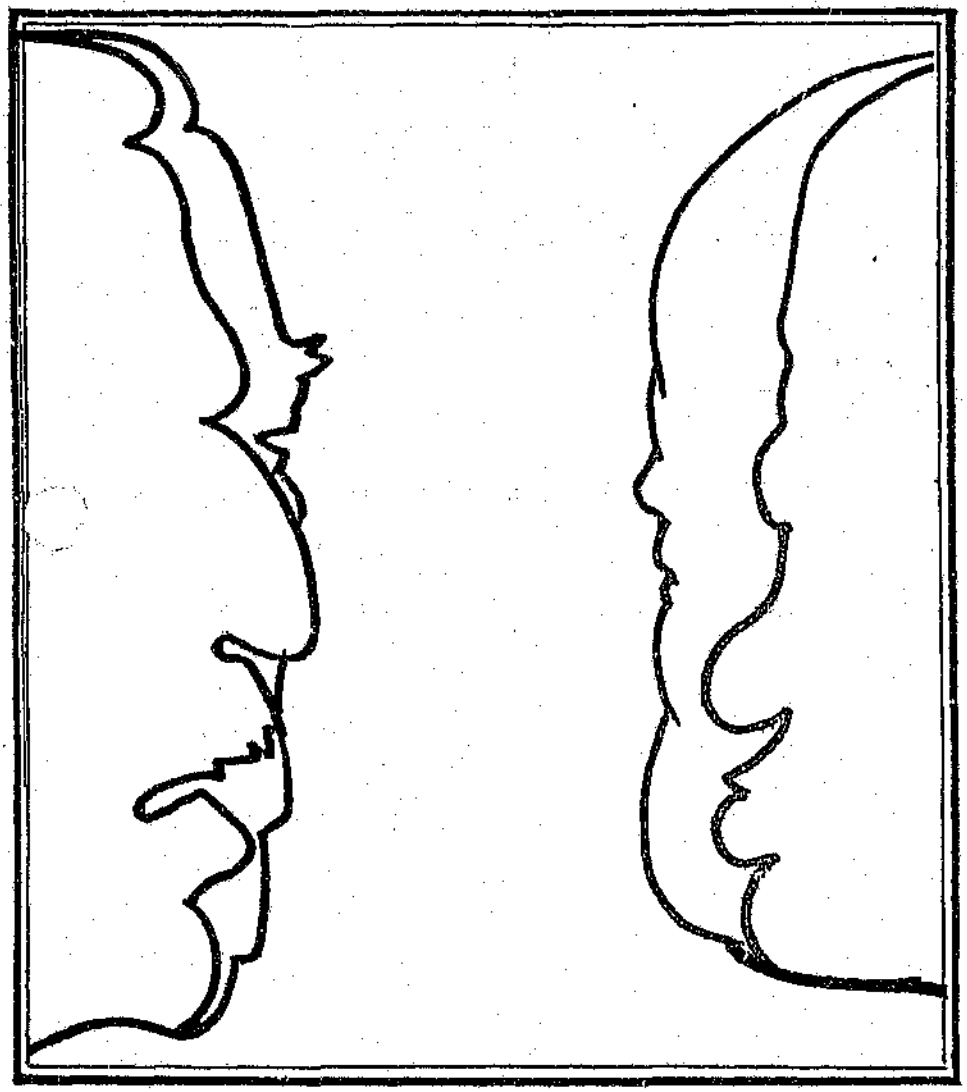


FIGURE 8 - The use of profiles to draw caricatures.

Using only these cardinal outlines, the lateral profile and the three quarter profile, a good artist can capture a likeness of his subject. A study of facial reconstruction should involve a examination of these characteristic profiles.

1. The landmarks should be positioned over flat bone wherever possible.
2. The same landmarks should be used for all subjects.
3. They should be in similar positions to those used by other researchers so that they may be compared.
4. Landmarks should be planned to lie at the summits of prominences such as the upper cheek, angle of the jaw, chin, or glabella; or in folds like naso-labial fold, labio-mental crease and soft nasion. They could also be situated on the maximum curvatures of lips and lower cheeks, provided there is a reflective bony or dental surface present beneath them. A list of the landmarks selected in accordance with these requirements is to be found in Chapter 5.

B. SELECTION OF SUBJECTS

Prior to commencing the study a written approval and a certificate of clearance was obtained from the Committee for Research on Human Subjects of the University of the Witwatersrand, Johannesburg.

The sample comprised fifty five Zulu males, ranging in age from 20 to 35 years and in good health. They were selected from patients attending the Oral and Dental Training Hospital, Durban. As far as could be ascertained, all were representative of an ethnically homogeneous

population group drawn to Durban from all over Natal. Subjects were chosen from the following: those requiring prosthetic replacement of an eye or an ear; assault and trauma cases in whom the areas to be measured were not affected; patients having sialolethiasis, sinusitis and other dental pathologies; and any other conditions where the problem could not distort the areas to be measured. Early exclusions were people having damaged or disfigured facial soft tissues, facial bone or both.

A Zulu staffnurse acted as an assistant and interpreter throughout the study. This assured the patient's complete understanding of questions and provided accurate answers. The extent of the research investigation was carefully explained to the patient and he was asked to sign an informed consent form. This was modelled on an example recommended by the above mentioned Committee for Research on Human Subjects.

The patient was first weighed on a medical balance scale with shoes and outer heavy clothing removed. The balance was checked using a known weight and was adjusted at each new weighing. The subject stood erect with feet together and the head in the natural head posture. In the absence of appropriate height-to-weight tables for Negroids those established by the Metropolitan Life Insurance Company were consulted.

The average individual rarely maintains a constant weight and it is therefore difficult to collect subjects with an ideal height-to-weight ratio. A small variation in weight is generally dispersed throughout the body and does not necessarily reflect in the face. The factors constituting likeness are more dependant on proportion than on finite measurements and are not destroyed by a small variation in weight. The height of a person has of course little or no bearing on soft tissue thickness. Taking this into account only those differing by less than 10 percent on either side of the stipulated average ratio were used as subjects.

A standard questionnaire on medical history and past and present health status was completed with the help of the interpreter. Information not covered by the questionnaire was noted on a separate sheet. The type of condition that would exclude the subject from the sample at this stage was a metabolic disturbance such as diabetes, or a debilitating condition like tuberculosis or bilharzia, as well as cortisone and other endocrine therapies.

A physical examination of the oral cavity, face and neck was carried out by the writer. Swellings, fractures, distortions, malformations or severe asymmetries in the area to be measured, not noticed at the time of the acceptance

of the patient, were now recorded. If too severe the case was rejected as a subject. Even the administration of a local anaesthetic for a dental treatment can distort the tissue through swelling and flaccidity and so can render the case unsuitable for measurement. Other reasons for exclusion were subjects having missing anterior teeth or those who were edentulous. These states produce an altered lip support and a disturbed vertical dimension respectively.

The blood pressure was recorded to exclude those with a possible cardio-vascular problem and a blood sample and urine sample were delivered to a pathology laboratory for testing. The serological tests carried out were platelet count, full blood count, a differential white blood cell count and an erythrocyte sedimentation rate. These were selected to reveal conditions like chronic infections or chronic bleeding that could cause a weight loss which may be small enough to allow the subject to be within the acceptable height-to-weight ratio set for the study, but nevertheless be unnatural to the patient's normal ratio. The urine was tested for pH, glucose and albumen to check for diabetes or possibly a renal disease that might cause weight loss through water loss.

Microscopic examination was only carried out if parasite infection was suspected. Any alterations in the norms for

the above tests did not necessarily result in the rejection of the subject unless further investigations showed sufficient weight change.

In this study the overall acceptance of the subject was left entirely to the discretion of the writer, and was based on the analysis of findings and the rigid parameters set by the criteria. In extended studies where the examination is conducted by different researchers it is suggested that a questionnaire be designed listing the conditions that can affect facial configuration and an accompanying explanation as to the significance of each. In this way the examiners will be consistent in their selection of subjects for study.

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CHAPTER IV

METHODS: CEPHALOMETRIC RADIOGRAPHY

A. EQUIPMENT

The cephalometric equipment used in this study was the Gendex GX-Ceph Counterbalanced Cephalometer System, made by the Gendex Corporation, Milwaukee, Wisconsin, USA. It has a vertically movable lockable horizontal arm supporting the tubehead, aligned to the head-positioner/cassette holder. The tubehead is provided with a collimater that rotates from a vertical to a horizontal position. allows matching of the collimater format with that of the cassette holder. Provision is made for close alignment of the ear-posts with each other. Nasion rest and correction scale are available if required.

The radiographic film used was Agfa-Gevaert Curix R.P.I X-Ray film (20.3 cm x 25.4 cm) housed in Curix MR400 cassettes with Hi-Plus intensifying screens. They were processed in a Velopex Extra-X Automatic X-Ray Processor made by Medivance, Harlesden, London, England, using a Photra-Cronex High Stability Developer Premix and Multi Process Fixer Premix. Other materials and instruments used were an artist's paintbrush, barium sulphate paste, a skin cleanser (Skin-Prep), a wall mounted mirror placed

opposite the cephalometer, a centimetre measuring rule with radiographically visible centimetre and millimetre graduations, a custom designed ala-tragus spirit level, and a skin marking pencil.

B. METHOD OF TAKING RADIOGRAPHS

Before being placed in the cephalostat a central vertical strip of the subject's face from below the chin up to the hairline about 2 cm wide, was carefully cleansed with a square of Skin-Prep gauze to remove any greasy deposits. A thin line of barium sulphate paste 2 mm wide was then painted down the middle of the face to show up the skin surface on the radiograph (Bunel and Sterling, 1989). If this is not done the operator can so easily measure from what is apparently the surface but what is in reality the projection of the soft tissues on either side of a dent in the midline. Examples are in the midline between both brow ridges where the supra-orbital soft tissues project beyond the midline crease at the level of the glabella; the midline of the philtrum where the heights of the two lateral philtral ridges give a spurious impression of the tissue depth in the midline; and a chin cleft or dimple which is always superimposed upon by the outline of the surrounding chin.

Two radiographs were exposed for this study: a standard lateral cephalometric radiograph as used in orthodontic analysis, and a cephalometric radiograph taken with the subject's head rotated horizontally through 45 degrees. Both films were able to contain within their boundaries (20.3 cm x 25.4 cm) the full area for measurement of the face (hairline to beneath the chin) when the radiograph was mounted upright in the holding frame.

In order to clearly delineate the soft tissue profile an aluminium wedge was positioned in front of the collimator to attenuate the X-rays. If this is not available a wedge of plasticine may be substituted. In their study on soft tissue enhancement Bunel and Sterling (1989) showed that when an enhanced cephalometric radiograph was compared to a non-enhanced one they both possessed the same level of diagnostic value. However the enhanced soft tissue image is clearer and identification of landmarks and measurements are easier. They also discussed the various methods of soft tissue enhancement.

The lateral cephalometric radiograph was the first to be exposed. The subject was positioned in the cephalostat, and the earposts were lowered into place and seated as deeply into the meatuses as comfort permitted. It is preferable not to use the nasion rest as it indents the soft tissue precisely where an important depth measurement is

to be made. The subject was asked to look directly ahead into the reflection of his eyes in the mirror before him.

It is important that the facial features are not altered by postural strain or discomfort. The lower jaw should be relaxed. If it is not, and the teeth are in occlusion, a strained unnatural clenched look is imparted to the lower third of the face. Short lips forced to close when they are normally parted become pursed and produce an undesirable puckering of the chin. These distortions are foreign to a normally relaxed face and represent soft tissue in action rather than at rest.

A levelling device was devised to relate the ala-tragus line to the horizontal plane. A perspex strip 16 cm long by 3 cm wide and 5 mm thick was heated and curved to 20 degrees at the three quarter mark (Figure 9a). A plastic spirit level was fused to the outer surface of the strip to lie parallel to its upper border. The centre of the tragus and centre of the ala on the right side of the face were marked with a skin-marking pencil. The levelling device was positioned with its upper border in line with both marks, and the head plus device tilted up and down until the bubble indicated they were level with the floor (Figure 9b).

To establish a reference for magnification the metal rule was suspended from the rim of the cephalostat and lowered

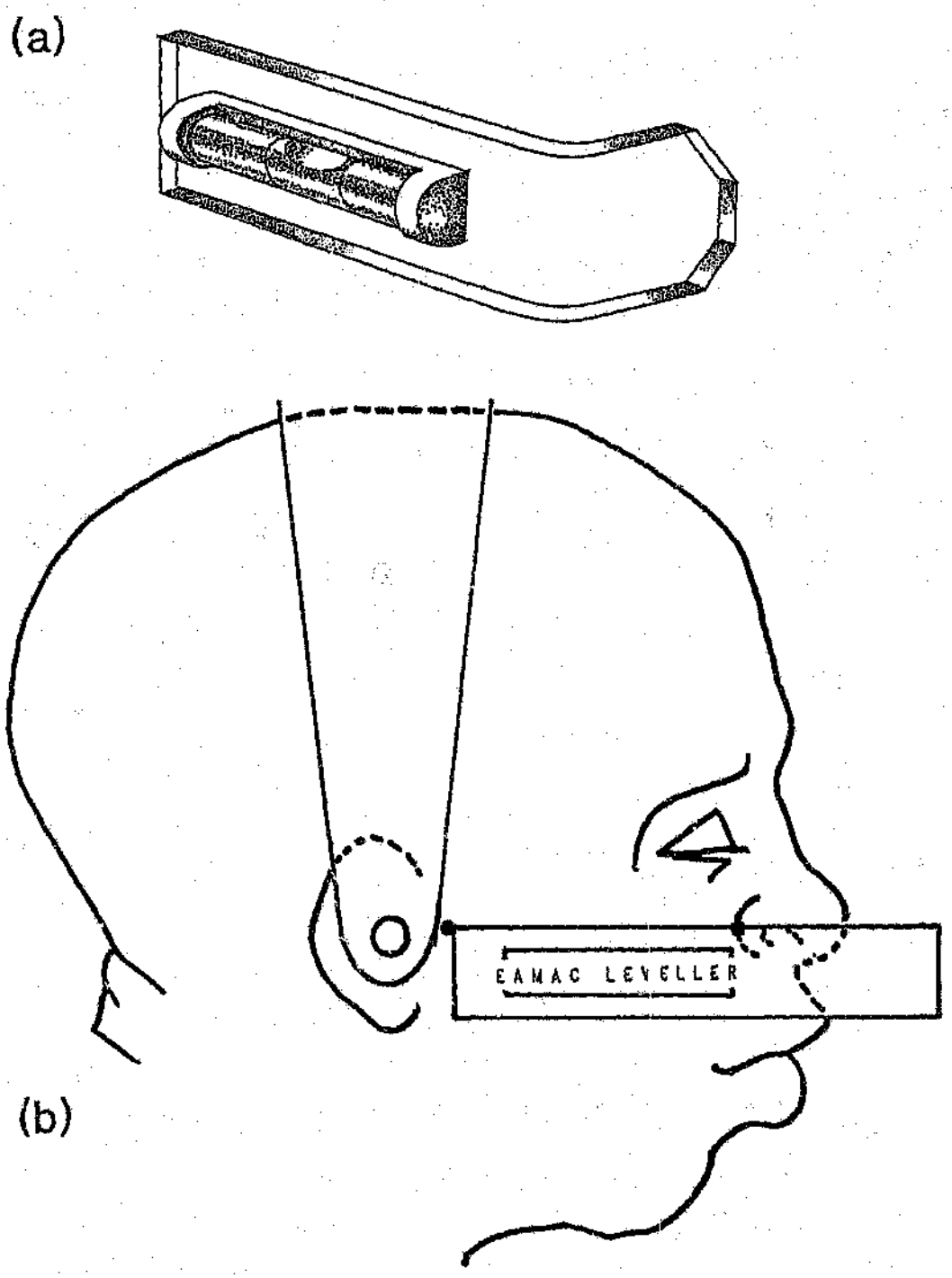


FIGURE 9 - The ala-tragus spirit level.

This specially designed and constructed spirit level (a) is used to ensure that the ala-tragus line of the subject is parallel to the floor. It is positioned as seen in (b) above.

in front of the forehead. It showed up on the radiograph and the magnification factor could be calculated from the enlarged millimeter markings. Being freely suspended, it also indicated the true vertical.

The cassette holder was positioned so that its film plane was 15 cm from the subjects's mid-sagittal plane and the film was exposed at between 75 and 85 Kv according to the bulk of the head. All radiographs were quality checked. No film was accepted unless it showed proper positioning, sufficient contrast and acceptable resolution with clear definition of hard and soft tissues. The subject was then allowed to wash his face to remove the barium paste as it was not required for the next radiograph.

For the oblique radiograph the head-holding device was locked in the 45 degree position. The subject was then positioned, requested to look at his mirror image and the ala-tragus line adjusted to be horizontal. The horizontal alignment of the head must be the same in both lateral and oblique views in order that measurements at common horizontal planes may be compared. The films were then exposed, quality-checked, given a file number and stored in envelopes.

C. ACCURACY AND ERROR CONTROL

The possible errors that can affect the accuracy of the measurements may be system induced or operator induced.

1. System error

Electronics technicians were asked to test the equipment and check that: the alignment of ear-rod copper rings was correct; the central beam was at right angles to the film plane; the cephalostat centering mechanism was adjusted so that ear-rods were equidistant from image plane; the magnification of the image was constant and the coverage of the tissue filter was adequate.

The magnification factor was calculated as previously mentioned by comparing the distances between the markings on the rule with their magnified images on film and was found to be 10 percent. As a further check the magnification factor was mathematically calculated.

Focus-to-subject distance (FSD) between tube and centre of the cephalostat (the image plane) is fixed at 150 cm. Subject-to-film distance (SFD) though adjustable was kept to a standard 15 cm. This produced an overall focus-to-film distance (FFD) of 165 cm and a magnification factor of 10 percent, arrived at by applying the formula:

$$\text{Magnification} = \frac{FFD}{FFD - SFD} \times 100 - 100$$

$$= \frac{165}{150} \times 100 - 100$$

$$= 10 \text{ percent}$$

At the analysis phase, individual magnified readings were adjusted by a correction factor derived from the formula:

$$\text{Correction Factor} = \frac{100 \text{ percent}}{100 \text{ percent} + \text{percentage magnification}}$$

In this instance the raw radiographic data were simply multiplied by 0.9091 in order to produce the corrected measurements.

Referring to Figure 10 it is evident that there are in fact two radiographic planes to be seen on the oblique radiograph. Since the planes are at different distances from the source of X-rays (maximum 3 cm), the structures at these two levels have different degrees of magnification. Tissue measurements made on plane (ii) in Figure 10 (the lower half of the face) should be adjusted by making use of a correction factor of 0.0155 less than that used

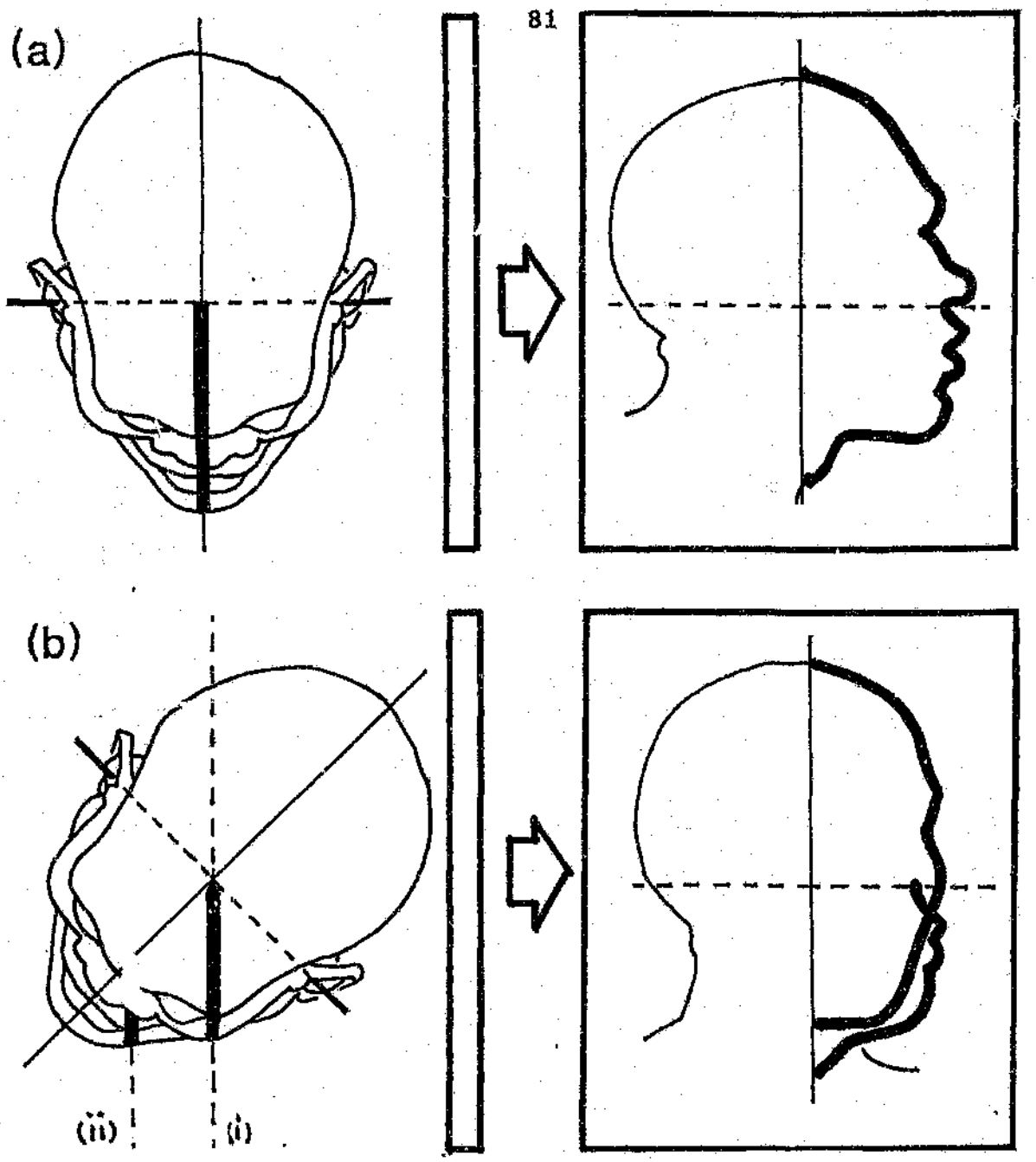


FIGURE 10 - Lateral (a) and oblique (b) radiographic planes.

A schematic diagram relating the positioning of the head for radiographs and the profiles seen on the radiographs.

for plane (i). If not accounted for, this difference in magnification will translate into an error of soft tissue measurement, varying from 0.05 mm to 0.24 mm depending on the tissue thickness. However, this is of such low magnitude that it has little or no significance during the practical phases of reconstruction.

2. Operator error

Out of the 55 lateral cephalometric radiographs, ten were selected by a computer programme that generated random numbers. These radiographs had their name tags covered by the assistant so that they could not be identified by the operator.

Accurate superimposed alignment of the radiographs and cels was essential. The modified radiograph viewing box (see technique mentioned below under "Recording radiographic measurements") was used. The radiographs, cels and paper sheets were punched out with a paper punch at the mid-left border. Both holes matched those of the peg-bar. The radiographs were put in envelopes and numbered one to 10. The computer was requested to select 10 numbers in 10 different batches. This ordering differed in each of the test runs and determined the sequence in which the envelopes would be taken from the pack and given to the operator. A test of accuracy of landmark

identification and a test of constancy of linear measurement were carried out.

a. Accuracy of landmark identification

The radiograph plus an overlying acetate cel were firmly seated onto the peg-bars and locked by the cover-caps. Ten radiographic landmarks were chosen from those used in the main study to best represent the different types of landmarks, for example a point at the maximum curvature on a vertical curve and on a horizontal curve, the deepest point in the dip of a bony contour, a spiny point, a flat surface, and a notch in the bone. All landmarks were recorded onto the protective cel with a fine pencil. The radiograph was then replaced by a sheet of stiff carding (approximately 2 mm thick) and a sheet of white paper was interposed between the cardboard and the cel. Taking care not to shift the cel, the paper (cushioned by cardboard backing) was pricked through the cel at the pencil dots. The paper record was removed, the tiny puncture points were marked with a fine fibre-tip pen and the record was handed to the assistant for numbering and storing.

b. Constancy of measurements

The same set of points that were selected for the above landmark study, were used in the test on the constancy of

linear measurement. The radiograph to be measured was again seated on the pegs, overlayed by a new acetate cel and locked into place with the cover caps. The selected landmarks were registered on the cel with a finely sharpened pencil. One mark at the bony landmark and one at the soft-tissue surface together formed a pair between which the depth measurement was taken. Care was taken to "average out" the radiographically fuzzy bony border, when it was present, by taking the mean value between inner and the outer extremes of its edges. On the lateral radiograph the soft-tissue landmark was more clearly discerned as lying at the junction of the barium sulphate paste and the skin surface. All readings were taken under constant lighting conditions and to an accuracy of 0.02 mm.

c. Analysis of operator error

Statistical data were processed by the Institute for Bio-statistics, of the Medical Research Council, on an IBM computer through the use of the BMDP Statistical Software package (copyright, University of California).

The error control tests in the present study were aimed at establishing the reproducibility of measurement by the observer, in other words, the precision with which the measurements were taken.

The 10 data points of 10 subjects on five different days totalled 500 observations, which were summarised by their coefficients of variation.

$$\text{Coefficient of variation} = \frac{\text{standard variation}}{\text{mean}} \times 100$$

Observations

1. For subject number one it was observed that the CV for a specific landmark ranged from 0.56 percent to 2.4 percent (Table 1).

2. Table 2 shows all 50 observations made over 10 landmarks on any one individual face, summarised in 10 coefficients of variation. The minimum and the maximum means for those 10 coefficients of variation were 1.4 percent and 2.2 percent respectively.

3. Plotting mean coefficients of variation against number of patients resulted in an overall CV of 1.6 percent.

These results indicate that the radiographic system of measurement as performed by the operator in this test represents a stable method of data collection.

TABLE 1 - Radiographic operator error

Operator error as reflected by the coefficients of variation for radiographic readings taken on subject No 1, at 10 landmarks, over 5 days.

Landmark	No.days	Mean	S.D.	C.V	Min.	Max.
A	5	7.76	0.13	1.69	7.55	7.90
B	5	7.09	0.07	0.92	7.05	7.20
C	5	8.86	0.09	1.05	8.78	9.00
D	5	4.46	0.08	1.72	4.40	4.58
E	5	13.79	0.22	1.63	13.52	14.00
F	5	14.43	0.08	0.56*	14.35	14.56
G	5	19.78	0.19	0.97	19.60	20.03
H	5	6.70	0.11	1.62	6.60	6.87
I	5	10.85	0.11	1.00	10.70	10.98
J	5	6.74	0.16	2.40**	6.56	6.9[illegible]

Note: * = low ** = high

TABLE 2 - Range for coefficients of variation

Coefficients of variation for radiographic observations at 10 landmarks.

Landmark	C.V. Minimum	C.V. Maximum
A.	0.9	5.1
B.	0.8	3.1
C.	0.6	2.6
D.	0.1	5.6
E.	0.7	1.6
F.	0.5	1.8
G.	0.5	9.2
H.	1.0	3.0
I.	0.9	1.7
J.	1.0	2.7

C.V. = Coefficient of Variation

D. LANDMARKS FOR THE DEPTH SYSTEM

Landmarks for soft tissue depth measurements were located on the lateral and the oblique radiographs. Radiographs were orientated with the EAMAC line as the horizontal axis and a perpendicular to this line at the external bony meatus as the vertical axis. The radiographic landmarks were coded LR.1 to LR.16 on the lateral radiographs and OR.1 to OR.20 on the oblique radiographs. They were also given descriptive names derived either from the name of a bony landmark or a surface feature.

Unless otherwise stated the soft tissue landmarks were established on the radiographs as follows: a tangent was drawn to the curve of outer surface of the bone at the bony landmark. A line was then drawn perpendicular to the tangent at the hard landmark and extended outwards to meet the face profile. The meeting point with the skin surface was registered as the equivalent soft landmark. To avoid having to mention the method each time it is referred to below as "by perpendicular". A point on "the deepest curvature" or "the maximum curvature" refers to a point on the maximum contour of that curve, whether it is concave or convex. It relates to the curve itself and is not selected in relation to a horizontal or a vertical

axis. For a visual appreciation of these landmarks the reader is referred to Figures 11 and 12.

1. Landmarks on the lateral cephalogram

LR.1 Supra-glabella

Hard: On the outer surface of the frontal bone, at the deepest curvature of the dip (or if there is no dip, then midway) between the maximum curvatures of glabella and frontal eminence.

Soft: by perpendicular.

LR.2 Glabella

Hard: A point on the maximum anterior convexities of both hard and soft-tissue glabellas.

Soft: by perpendicular.

LR.3 Nasion

The hard and the soft-tissue nasions are defined in the Glossary of Terms.

LR.4 Mid-nasal

Hard: A point lying midway between nasion and rhinion.

Soft: by perpendicular.

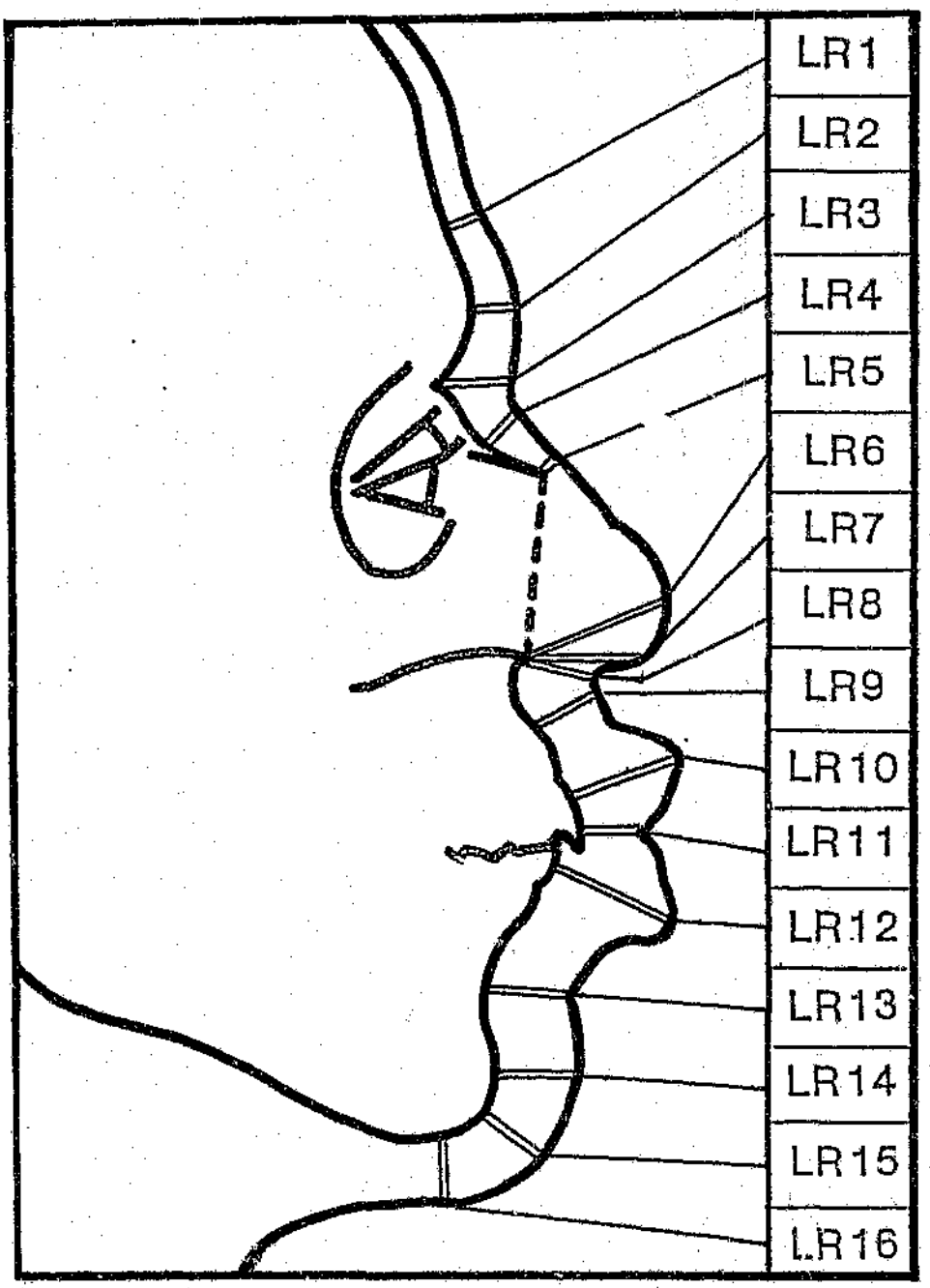


FIGURE 11 - Radiological landmarks: lateral cephalogram.

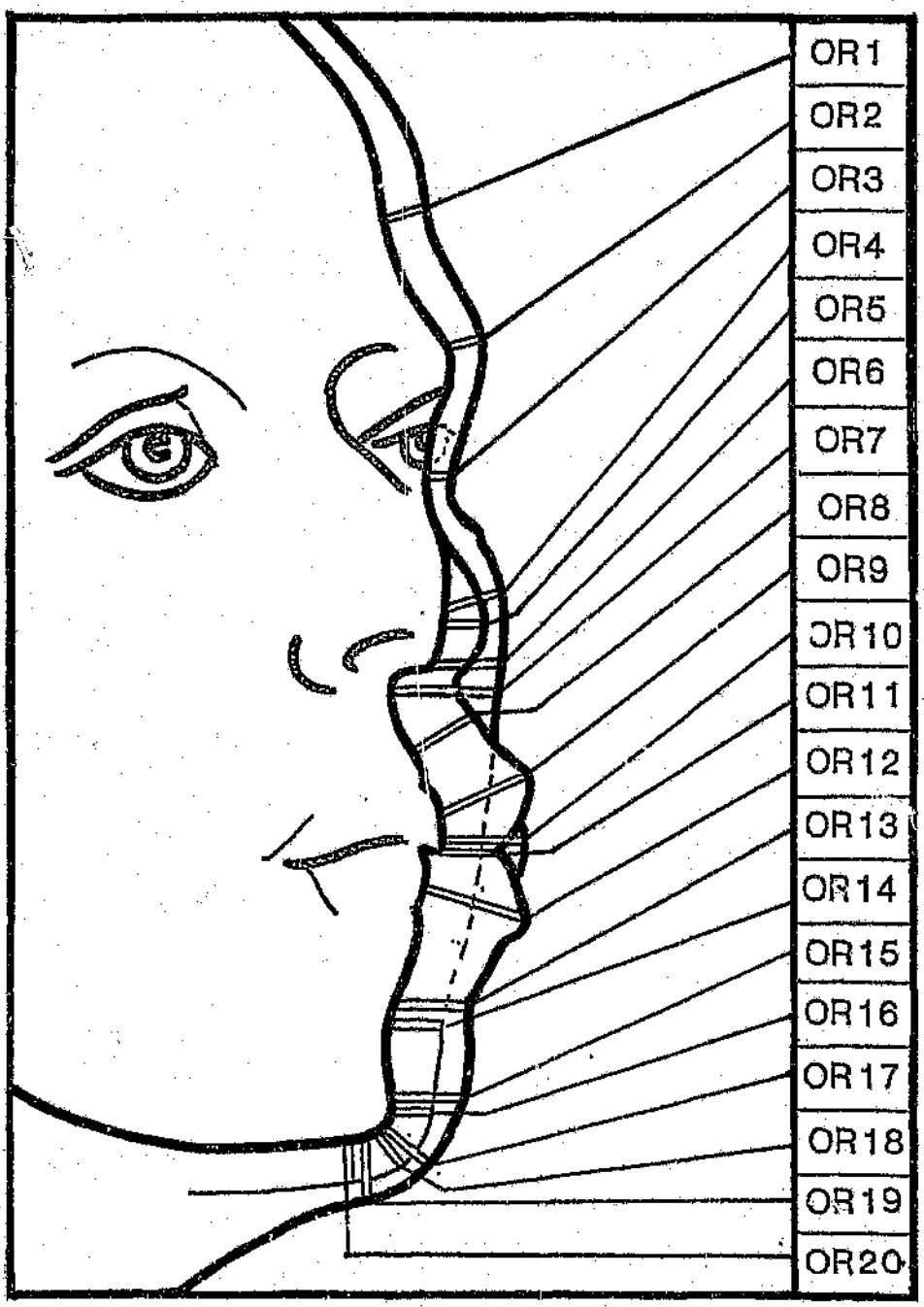


FIGURE 12 - Radiological landmarks: oblique cephalogram.

LR.5 Rhinion

Hard: The lowest point on the internasal suture.

Soft: by perpendicular.

LR.6 Anterior nose tip

Hard: The acanthion.

Soft: A point on the most anterior curve of the nose, often called pronasale.

LR.7 Inferior nose tip

Hard: The acanthion.

Soft: A point on the lowest curve of the nose tip.

LR.8 Mid-columella base

Hard: The acanthion.

Soft: The deepest point in the curvature lying at the base of the columella, often called subnasale.

LR.9 Mid-philtrum

Hard: The landmark is the orthodontic point called Point-A or subspinale.

Soft: by perpendicular, or if that is not feasible a point lying midway between "mid-columella base" (LR.8) and "mid-upper-lip margin" (LR.10).

LR.10 Mid-upper-lip margin

Hard: A point on the maximum labial curvature of

the crown of what appears on the radiograph to be the more anteriorly placed upper central incisor. If the surface is flat, then on the outer surface at the midpoint of the anatomical crown length.
Soft: On the maximum anterior curvature of the upper lip margin, often termed labrale superius.

LR.11 Mid-lipline

Hard: A point on the maximum lower curvature of the incisal edge of what appears on the radiograph to be the more anterior of the two upper central incisors, or if the edge is worn down then midway between the anterior and posterior edges of the wear facet of that tooth.
Soft: The point at the red-line junction of upper and lower lips, often called stomion.

LR.12 Mid-lower-lip margin

Hard: A point on the maximum labial curvature of the crown of what appears on the radiograph to be the more anteriorly placed lower central incisor. If the surface is flat, then on the outer surface at the midpoint of the anatomical crown length.
Soft: tissue point is on the maximum curvature of the lower lip margin, often called labrale inferius.

LR.13 Mid-labio-mental

Hard: Equivalent to Point-B or supramentale.

Soft: The deepest point in the labiomental crease.

LR.14 Anterior symphyseal

Hard: A point is on the maximum forward curvature of the mental prominence, called pogonion.

Soft: by perpendicular.

LR.15 Intermediate symphyseal

Hard: A point on the outer surface of the bone midway between anterior and inferior symphyseal points (see LR.14 and LR.16).

Soft: by perpendicular.

LR.16 Inferior symphyseal

Hard: A point at the lowest point on the curve of the bony chin, at the menton.

Soft: by perpendicular.

2. Landmarks on the oblique cephalogram

As previously explained the oblique soft tissue profile is not a straight line but a stepped and broken line. In Figure 7 it was seen as two discontinuous vertical shadow lines in both face and skull.

The reason for this is made clearer when consulting Figure 13(a) which illustrates a schematic top view of the curvatures of the frontal bone, maxilla and mandible. The arcs are not meant to be in anatomical relationship with each other but rather superimposed and registered on a common mid-point to show the relationship between their convex curvatures. The arrows indicate the part of each arc that is seen on a 45 degree radiograph. Each lies in a different plane (i and ii) as each arc has a different radius of curvature. This means measurements are recorded on slightly different but parallel 45 degree planes: the top half of the face is further from the radiograph tube than the lower half. This difference in magnifications was accounted for.

Looking at this on the cephalogram (Figure 13b) we see that in the upper set of profiles the bony outline (in the stipled area) runs down the forehead, alongside the bony eye socket, and around the border of the zygomatic bone until it disappears from view behind the protruding maxilla. Its soft counterpart follows the same path from the forehead and eyesocket until level with the bottom edge of the zygomatic bone.

In the lower set of profiles the bony outline starts again at the pyriform aperture and follows the outline of maxilla, teeth and side of the mandible to curve around

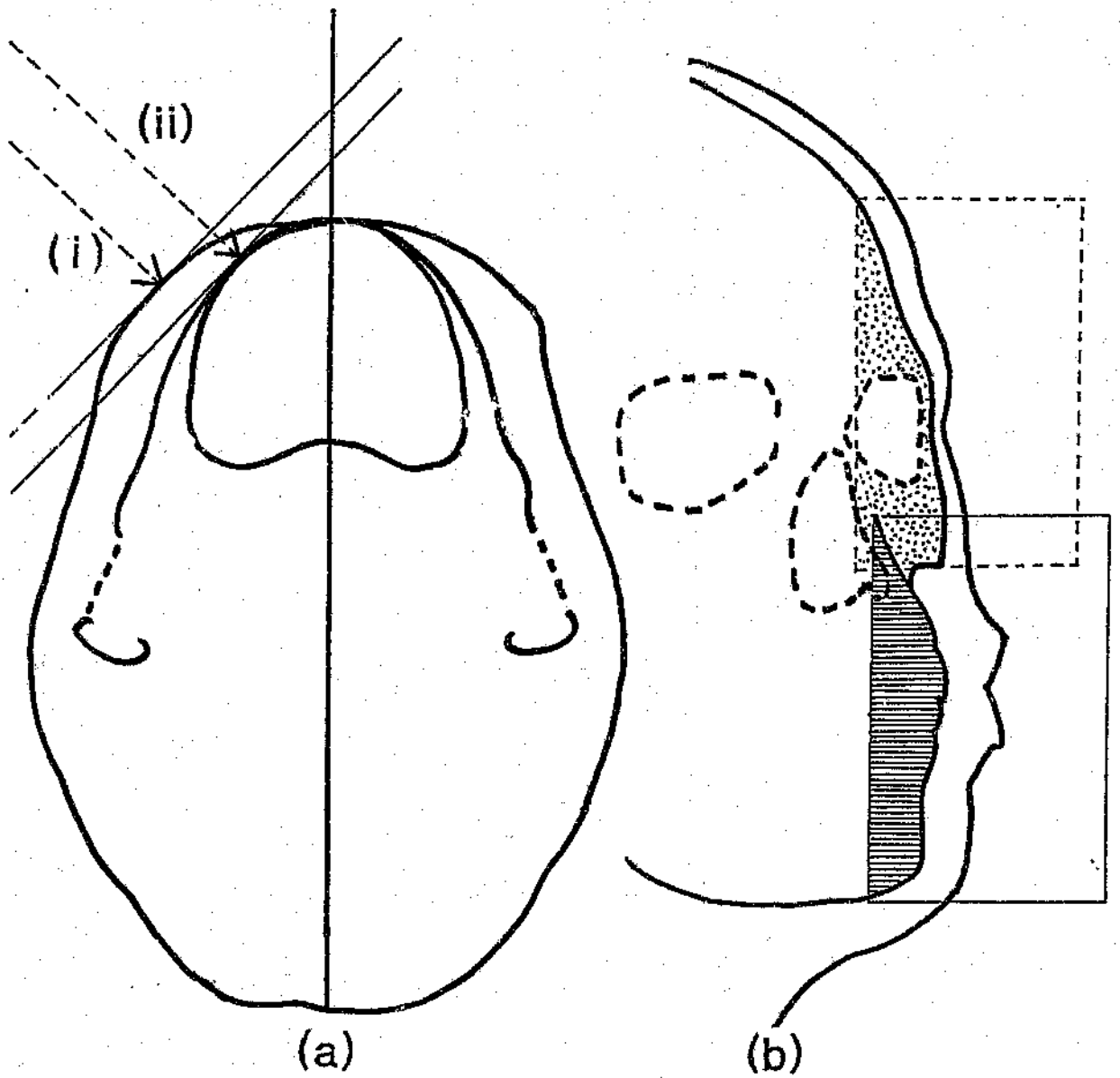


FIGURE 13 - Translocated Meridia of the face.

In (a) above, the curves representing the forehead, the maxilla and the mandible are superimposed for comparison. This results in the two different 45 degree profiles of the face seen in (b): one for the forehead (stippled), the other for the maxilla and mandible (hatched).

its lower border (the hatched area). The corresponding soft tissue profile follows the outline of the maxilla as the upper lip and the profile of the mandible as the lower lip. It then continues as the side of the soft chin.

However there is another lower soft profile to be seen on the oblique radiograph. In the same plane as the upper profile it is the outline of the side of the soft cheek continuing downwards behind the protruding lips and chin (the thick dashed line) to the side of the mandible. Except for that part of soft profile that is supported by the side of the body of the mandible, the rest appears not to be related to any visible underlying bone. In fact this part of the soft cheek is supported by the side of the maxilla and the ramus which cannot be seen on the oblique radiograph. However the depths of the soft tissue at those landmarks which can be seen (coded OR.16, OR.18 and OR.20) have been retained because of their value in making an oblique profile template (see Chapter 7 for the construction of the midline profile template).

It can now be appreciated why the barium paste line could not be drawn on the skin prior to taking the radiograph. The "turning point of light" is not a sharp edge but a wavy curved surface between the front and the side-facing planes of the face.

OR.1 Lateral frontal

Hard: A deepest point in the depression between the frontal eminence and the maximum curve of the supraorbital margin. If the bone is flat the point is on a horizontal level with the "supra-glabella" landmark (LR.1) as seen on the lateral radiograph.

Soft: by perpendicular.

OR.2 Lateral supra-orbital

Hard: A point on the maximum curvature of the supraorbital ridge.

Soft: by perpendicular.

OR.3 Lateral orbital

Hard: A point at the deepest curvature (when it is present) of the lateral orbital margin, or else midway between OR.2 and OR.4.

Soft: by perpendicular.

OR.4 Lateral zygomatic

Hard: A point on the maximum, most lateral curvature (as seen on the radiograph) of the zygomatic bone.

Soft: by perpendicular.

OR.5 Lateral alar

This is not a measurement of tissue depth but of just how far the outline of the nose tip projects beyond the oblique profile. It is used as a guide to estimate the position of the side of the nose tip.

Hard: A point located on the outermost maximum curvature of the zygomatic bone.

Soft: A point lying on the maximum curvature of the nasal soft tissue projection, whether that point be on the nose tip or the wing of the nose.

OR.6 Inferior border of zygomatic

Hard: The lowest point on the inferior curvature of the zygomatic bone as seen on the oblique radiograph.

Soft: The equivalent point is on the skin surface and at the same level as the bony point.

OR.7 Sub-zygomatic

Hard: A point at the deepest indentation between the zygomatic bone and maxilla as seen on the oblique radiograph.

Soft: its outer point is on the surface of the cheek on a level with the bony point.

OR.8 Sub-alar

Hard: A point on the outer curvature of the maxilla halfway between inner points of OR.7 and OR.9.

Soft: By perpendicular.

OR.9 Lateral upper-lip margin

Hard: A point on the maximum labial curvature of the crown of the upper canine.

Soft: A point on the maximum anterior curvature of the upper lip margin.

OR.10 Angle of mouth

Hard: A point on the maximum curvature of the rounded incisal tip of the canine or if abraded the midpoint between outer and inner wear facet edges.

Soft: The maximum outer curvature of the modiolus

OR.11 Lateral lipline

Hard: As in OR.10.

Soft: The red-line junction of upper and lower lips.

OR.12 Lateral lower-lip margin

Hard: A point on the maximum labial curvature of the crown of the mandibular canine.

Soft: A point on the maximum anterior curvature of the lower lip margin.

OR.13 Lateral labio-mental

Hard: A point lying at the deepest curvature of the mandible as seen on the oblique radiograph (on about the same level as the bony Point B of LR. 13, seen on lateral radiographs).

Soft: The deepest point in the labio-mental crease as seen on the outer soft profile.

OR.14 Lateral point B

Hard: The same as for OR.13 (an apparent hard landmark.

Soft: On the outer soft profile, at the same level as the bony point.

OR.15 Lateral mental

Hard: A point on the maximum lateral convexity of the mental protuberance as seen on the radiograph.

Soft: The landmark is at the same level, on the outer soft profile.

OR.16 Lateral mandibular

Hard: The same as for point OR.15.

Soft: On the outer soft profile at the same level as the bony point.

OR.17 Intermediate mental

Hard: A point on the maximum convexity of the body of the mandible, halfway between the bony points OR.15 and OR.17.

Soft: By perpendicular.

OR.18 Intermediate mandibular

Hard: The same as OR.17

Soft: By perpendicular.

OR.19 Inferior mental

Hard: A point on the lower border of the mandible, on a vertical line running at right angles to a line that passes horizontally through OR.15.

Soft: On the outer soft profile on the same vertical line as OR.18.

OR.20 Inferior mandibular

Hard: The same as for OR.19.

Soft: found vertically beneath this on the outer soft profile.

E. LANDMARKS FOR THE PROFILE SYSTEM

In the depth system, measurements were recorded between hard and soft landmarks. In the profile system the so-

called landmarks are the places along the hard and soft profile where the line alters its character. These places are called points and the line linking any two points is termed a line-segment. Important to remember is that a point is a locus in space whereas the coordinates that record its position are not in themselves points. They are the instructions (Moyers and Bookstein, 1979).

1. How to locate a point

In order to record the path of the profile line, we could simply register a series of evenly spaced points on that profile and link them together with short straight lines. Facial profiles have often been reproduced in this rectilinear fashion. The greater the number of points used the smoother the line appears. Most computerised systems can request that curves be drawn between points to produce a variety of differently shaped line-segments.

In Figure 14 the points A and B represent the end-points of a line-segment. Relative to each other they are in the same positions in each of the four drawings. Four curves of quite different shapes can be seen to pass between the two points, each constructed from different mathematical calculations. In (i), an arc of a circle interposes A and B. The curves between A and B in (ii) and (iii) are constructed by the use of polynomials of degree 2 and degree

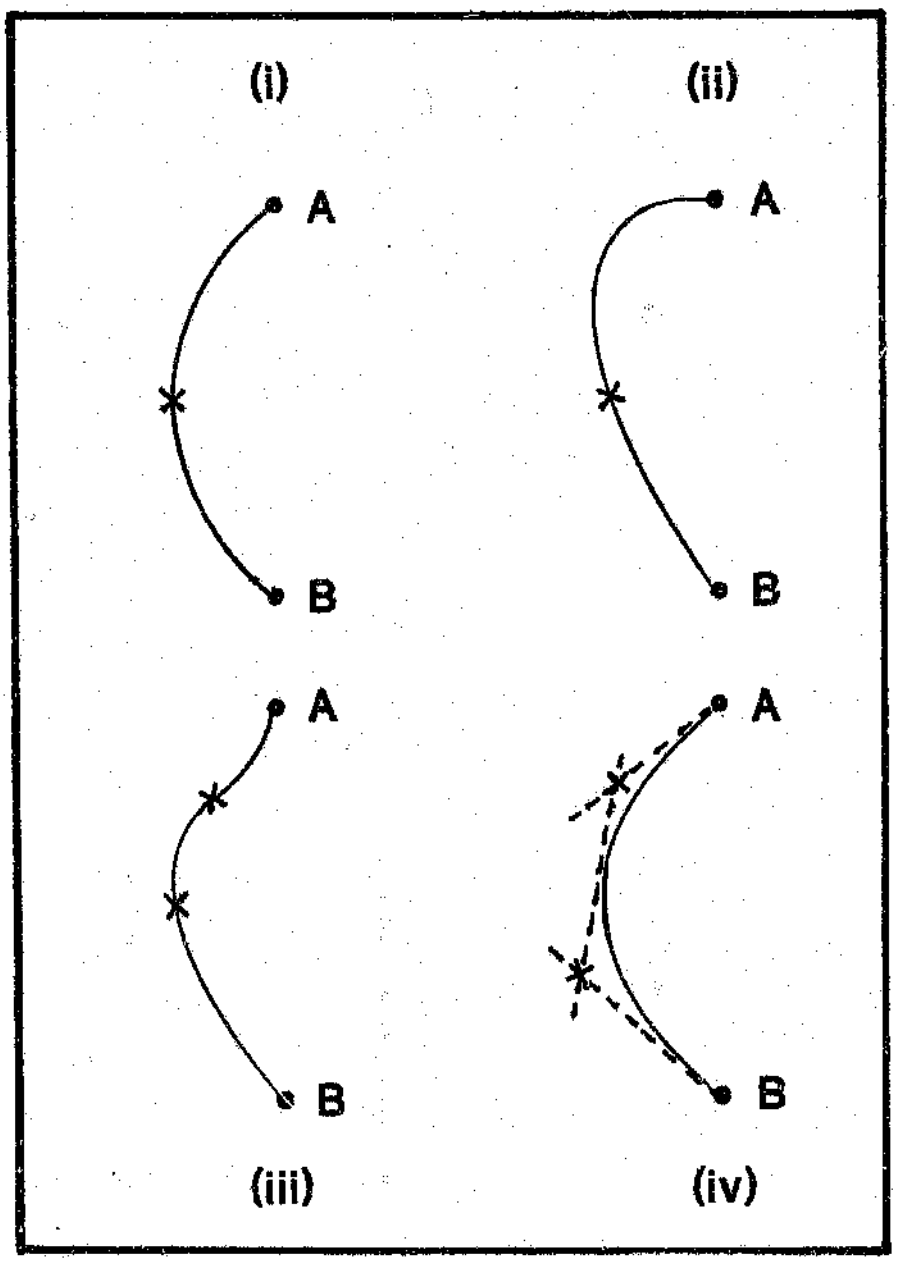


FIGURE 14 - Varieties of curves.

Various curves can be made to pass between two identically positioned points, (A and B): (i) an arc, (ii) a polynomial curve (degree 2), (iii) a polynomial curve (degree 3), and (iv) a parametric cubic fit curve.

3 respectively. In (iv) a parametric cubic spline curve links the two points.

Lestrel (1974) was of the opinion that the conventional metric approach to recording and describing shape by the use of linear measurements, proportions and indices, has its serious deficiencies. Like Inoue (1990) he advocated the use of Fourier analyses. Admittedly cubic B-splines and Bezier curves, used in engineering, can render very fine details. In forensic facial reconstruction however those barely discernable details are not that important for the recognition of identity. Savara (1972) sums this up well when he points out that if the object is merely to fit the best possible curves to the data then polynomials or a Fourier analysis will give the best results. However the object of simulation is to develop a mathematical model that not only fits the data but has meaningful parameters.

For our purposes we can be content with an easier, more manipulable system. In geometrical terms the simplest of the four curves shown in Figure 14 is the arc. All curved shapes can be constructed from arcs of circles, or as a series of connected and different sized arcs. Newman and Sproull (1981) concur that a shape that cannot be described by a single arc can often be described by several arcs joined together (Figure 15).

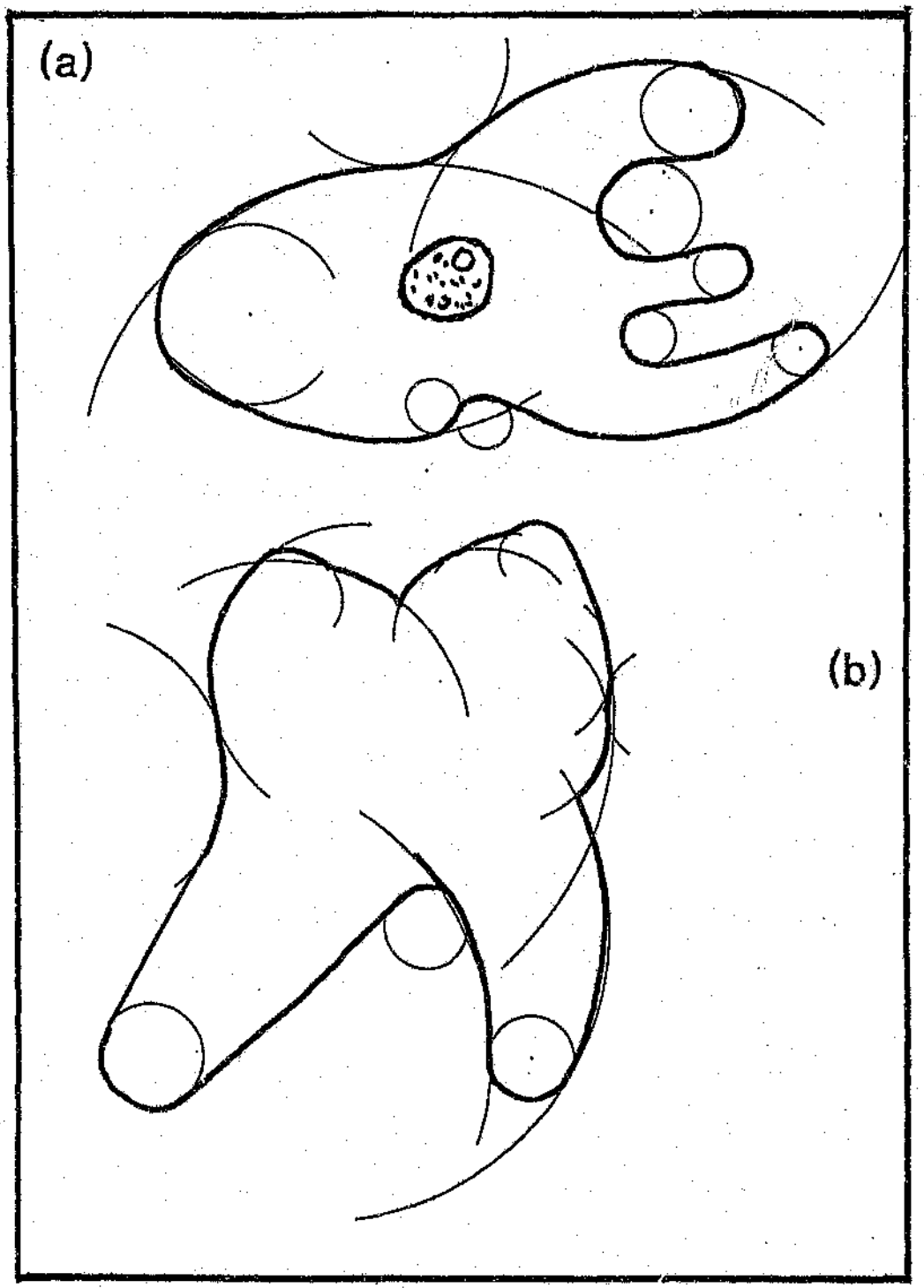


FIGURE 15 - Simplifying compound curves with simple arcs.

The relatively complex perimeter of an amoeba (a) and a tooth (b) can be simplistically described by the use of linked arcs of appropriate length and radius.

Points are of two types. The first type are those that mark the places along the profile where the line clearly changes its geometry. Though their locations must necessarily differ from person to person there are always the same number of points in each face where major changes in shape occur. In computer graphics nomenclature they are termed "joints". Figure 16 shows a compound line that has been divided into the simple shapes of an arc, an angle and a line. Each line-segment is a geometrical "object" (Bookstein, 1982), irrespective of whether it is a curve, an angle or a straight line. All objects have a starting point and an ending point (joints). If line-segments are joined together end to end into one continuous profile the end of one line-segment becomes the starting point for the next juxtaposed one.

The second type of point lies between joints and is known as a "control point". The shape of each of the curves in Figure 14 is determined by these control points. In (i) and (ii) there is one control point, whereas in (iii) and (iv) there are two each. Note also that a control point can be on or off the line it controls. It is defined as a point in space that has a decided influence in the shaping of that line.

The control point (sometimes called a node) for an arc is easily located. It is geometrically plotted as being the

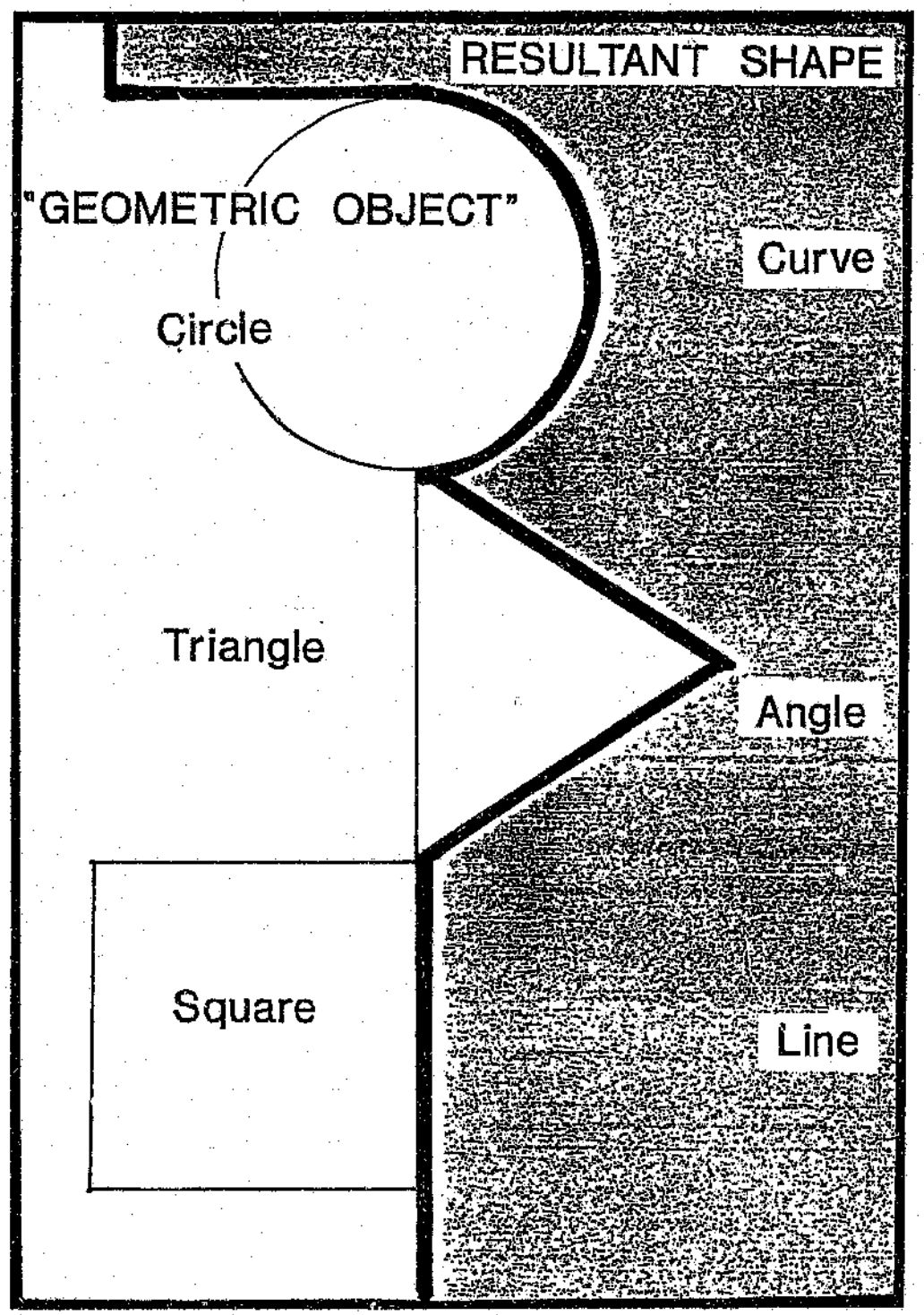


FIGURE 16 - Shape divided into curve, angle and line.

Parts of a geometric circle, triangle and square can be used in the form of an arc, angle and line respectively, to help draw complex shapes.

midpoint between two joints. Thus for each line-segment or object we have two joints and a node. Since every line-segment interpolates a trio of points the trio has been given the name "a triple" when refered to in the measuring stages.

2. Points on the soft profile

If the linear profile of the soft tissues is followed down the face from where the hairline starts (trichion) to just beneath the chin, its path will have traced the outline of four major features: forehead, nose, lips and chin. The soft profile can therefore be conveniently divided at the levels of soft nasion, subnasale, and the curl beneath the lower lip, into features or "feature modules" (Figure 17a).

The outline of each feature can be clearly subdivided into four distinct smaller simple geometric shapes: a curve, an angle or a straight line (Figure 17b). Since the last line-segment of the chin reaches down into the neck its triple has no final third point. For convenience its control point is its end point and the line-segment is therefore a straight line. In total both hard and soft profiles can be further divided into 16 small shapes or line-segments, the last being a straight short line.

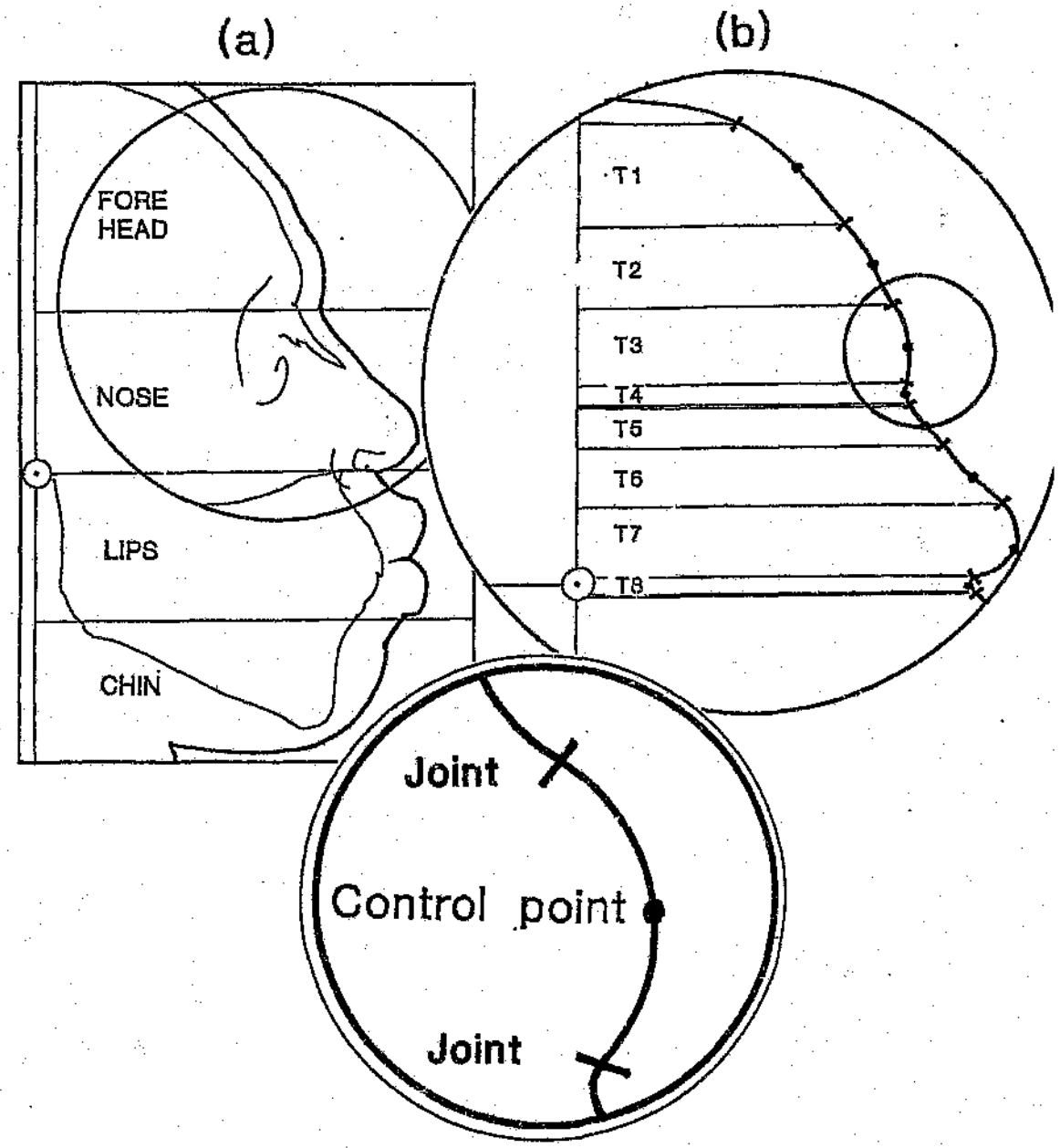


FIGURE 17 - Feature Modules and Shape Triples.

In (a), the face in profile can be conveniently divided into four "feature modules" (compare Figure 6). The hard and soft profile outlines in each module are then further divided to produce short line segments or shapes, as can be seen in (b). These are marked T1, T2, T3, etc. and are termed "triples", as their shapes are determined by three pairs of coordinates.

Although the joints separating line-segments are selected by eye, the control points that decide their shapes have to be precisely located on the profile. This is accomplished through the use of the two specially designed and handmade instruments, the "Arc Determinator" and the "Control Point Locator". These are illustrated in Figures 18 and 19, respectively.

a. Marking joints.

The Arc Determinator (AD) is a thin (1 mm) sheet of clear plastic on which is inscribed a series of circles of increasing radius, all registered on a common centre. The last few outer circles are incomplete and drawn as arcs. Once the profile on the cephalogram has been subdivided into geometric line-segments and the joints marked off, the nodes must be registered. The AD is placed over the tracing and aligned so that one of its curves exactly matches the arc being measured on the tracing beneath. This means that the arc of the line segment will have the same centre as the circle that matches it on the AD. A pencil dot is marked on the tracing through the centre hole in the AD. A pair of compasses are used to scribe a circle with its centre point on the pencil dot and its circumference superimposed on the curve of the line-segment. A joint is where the arcs or circles meet or cross each other. If two adjacent circles do not overlap

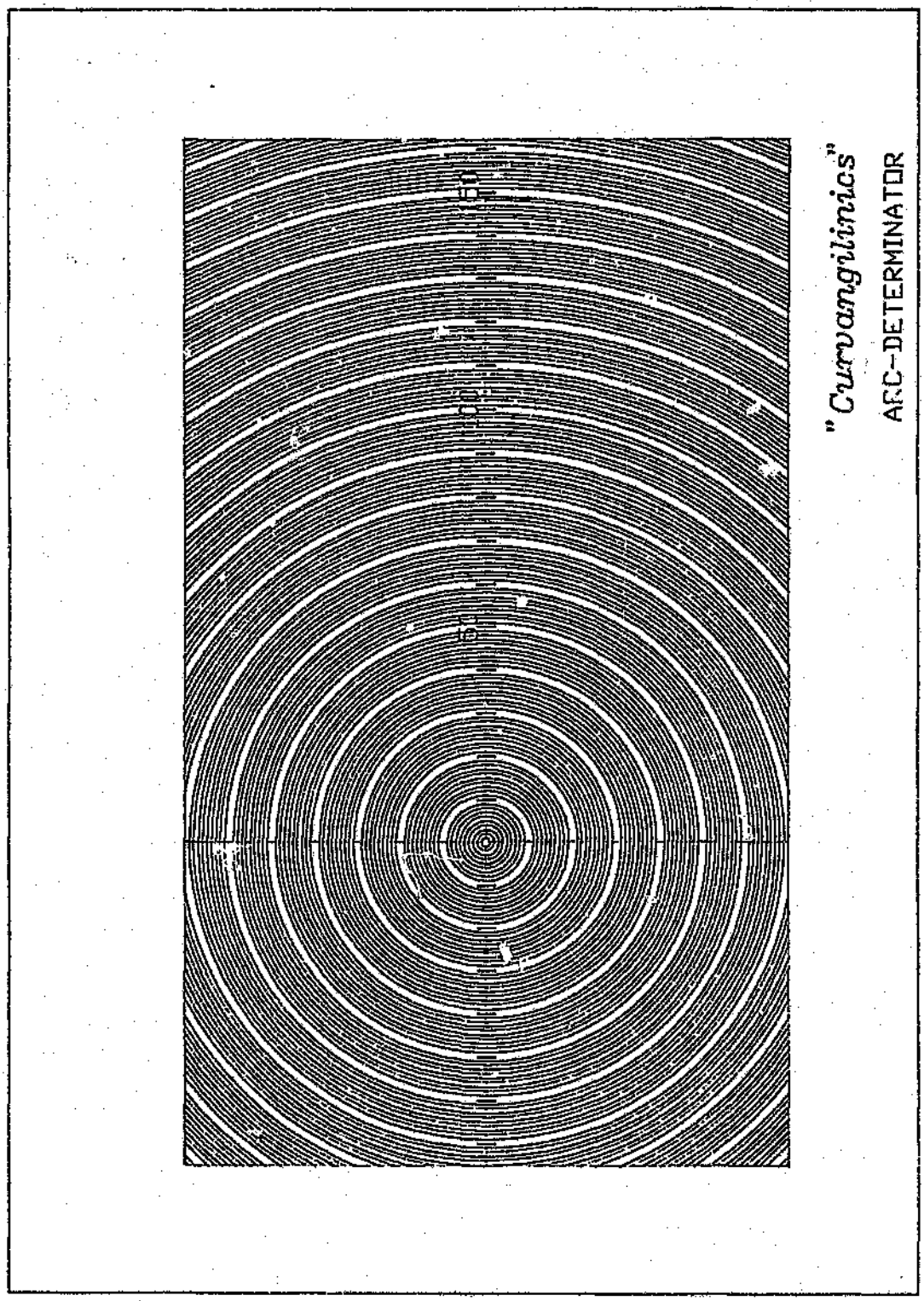


FIGURE 18 - The Arc-Determinator (AD).

Made out of 1 mm thick clear acetate, this overlay is placed over a curve on the traced cephalogram. The centre of the circle that corresponds to the curve, is then marked onto the tracing by a pencil point through the hole in the centre of the AD.

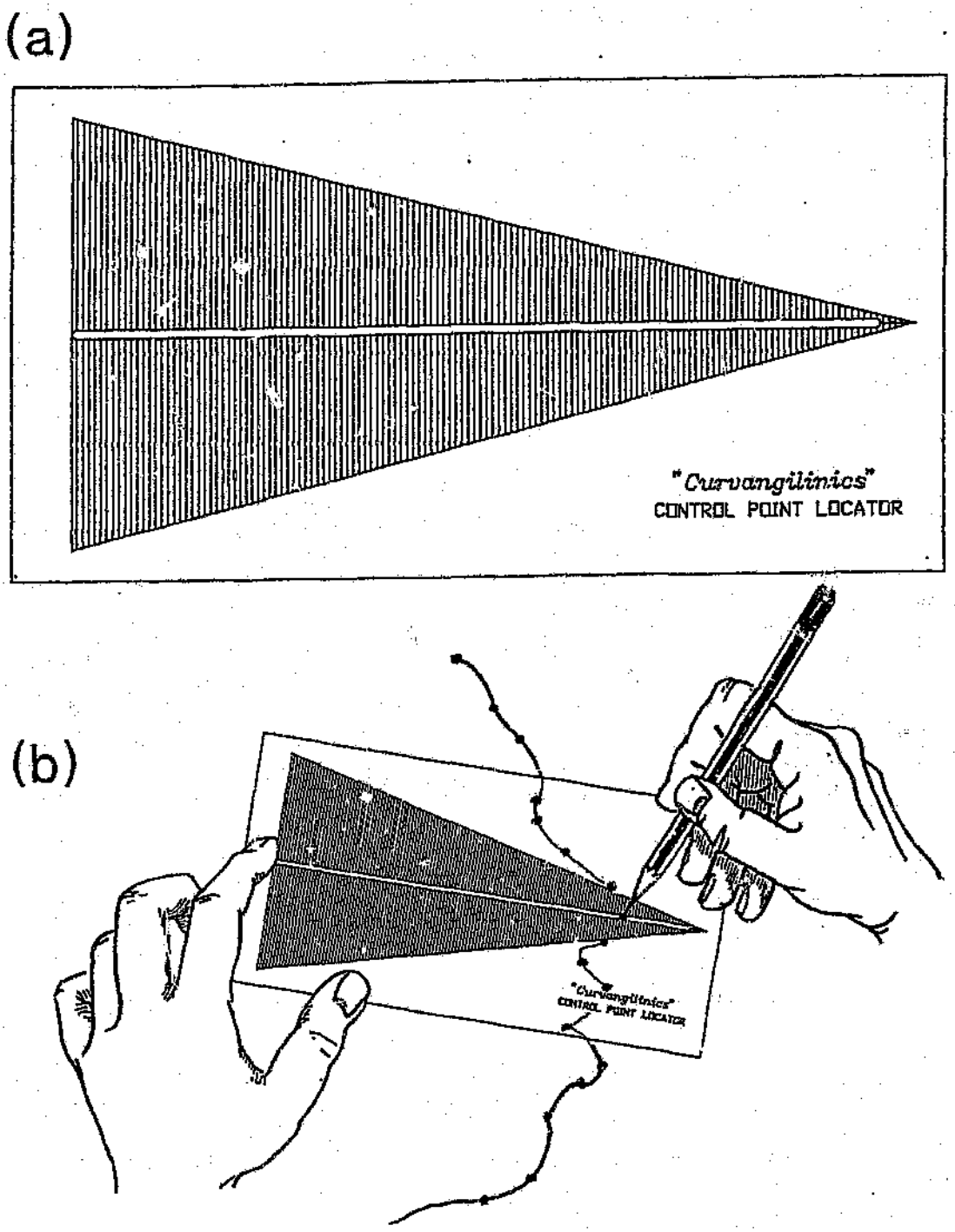


FIGURE 19 - The Control Point Locator (CPL).

The locator is used to establish the exact centre of curved line segment or arc, by aligning the "in" and "out" points (the joints) of the arc along one of the hatched lines on the CPL. The centre-point of the arc is then marked through the slot. This point becomes the "control point" of the line segment and decides its degree of curvature.

then the point at which the circle leaves the profile curve is marked as the joint (see Figure 20). If the profile arc is flatter than any of the arcs on the AD then the line-segment is taken to be a straight line.

b. Marking control points.

The Control Point Locator (CPL) is another sheet of thin plastic, 7 cm x 11 cm x 1 mm. Its surface has engraved on it a tall triangle. Running across the triangle from the base to the apex, is a mounting series of parallel lines 1 mm apart. A bevelled vertical slot 1 mm wide extends the full height of the triangle running up the middle. It is wide enough to admit a finely sharpened pencil point. Figure 19(a) illustrates the CPL. Figure 19(b) shows how it is adapted to a line-segment. The CPL is layed over the cephalogram and pointed in the direction of the line-segment. The tip of the triangle is slid between the two joints until a parallel line on its surface reaches from one joint to the other. The control point is marked on the underlying arc (or straight line) through the open slot of the CPL.

3. Points on the hard profile

The method of selecting points is much the same on the hard tissue profile. The corresponding hard feature mod-

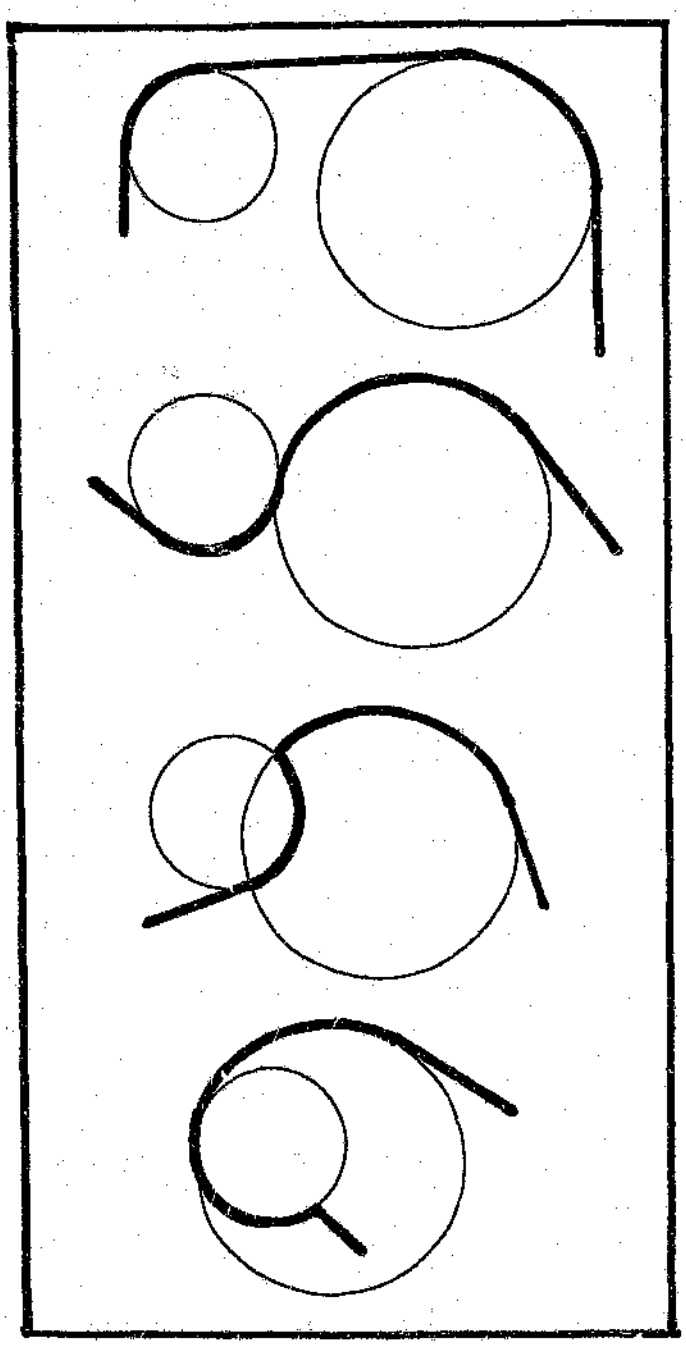


FIGURE 20 - Relationship between circles that form curves.

As the circles that act as the basis for the curved profile line approach and even overlap each other, the complex curved line that they generate, alters in character.

ules are the frontal bone, nasal bones plus nasal cartilage, maxilla plus both upper and lower teeth and bony chin of the mandible. The hard profile can again be conveniently divided into four at the bony landmarks of nasion, acanthion, and point-B. In the same way the hard profile can be separated into the same number of triples as the soft profile except for one difference. Because there are no hard points at the level of nasal aperture the acanthion becomes a common hard point to the 3 soft tissue points (Figure 21). The coordinate sets or soft and hard profiles are now equally matched and can be properly related to each other in space.

4. Coding the Triples

Unlike landmarks of the depth system those in the profile system were not given descriptive names. Instead they were coded by letters and numbers. The hard and soft codes have similar letters and numbers except that the hard codes are prefixed with the letter 'H' and the soft with 'S'. The total number of sixteen triples are coded from the top down as T1 to T15. The entry point (joint) of each line-segment is labelled 'a', the control point 'b' and the exit point (also a joint) is 'c'. Note that 'c' of one triple has exactly the same coordinate values as 'a' of the next triple. This avoids unnecessary duplication of coordinates in storage.

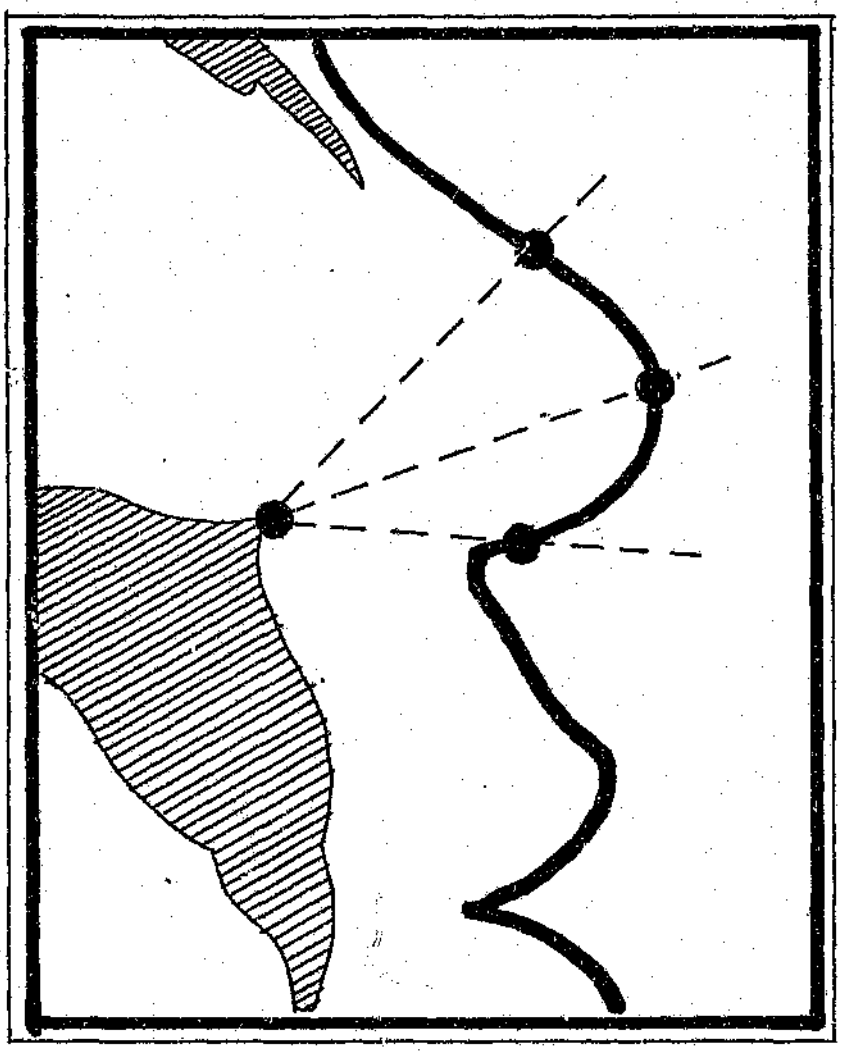


FIGURE 21 - Acanthion and its three soft tissue points.

Each soft tissue triple has a corresponding hard tissue triple except in the case of the nose tip triple. Here the three soft points all relate to the acanthion, which in turn represents the three hard points as one point.

F. RECORDING RADIOGRAPHIC MEASUREMENTS

For the depth system both the lateral and the oblique radiographs were required for taking measurements whereas in the profile system only the lateral radiograph was needed. However, the methods of mounting, viewing and tracing the radiographs were the same for both systems.

The instruments used were a sharp pencil capable of drawing a line of at most 0.2 mm thick a clean engineer's dial calliper with fine jaws and graded to 0.2 mm (made by Mitutuyo Manufacturing Company Limited, Japan) and a thin sewing needle mounted in a dental broach holder.

A standard radiographic viewing box, (with 36 cm by 44 cm opalescent viewing screen) had attached to its left side a panel to which was affixed cartoon animator's pegbars together with covercaps. The pegs are conically shaped so as to permit friction seating of the punched film. They have near zero tolerance and therefore prevent lateral slide. This assured the precise superimposed alignment of the radiographs with overlying acetate cels. The viewing apparatus is illustrated in Figure 22.

With a precision paper punch two holes were punched in the radiographs and cels at mid-left border. Both holes

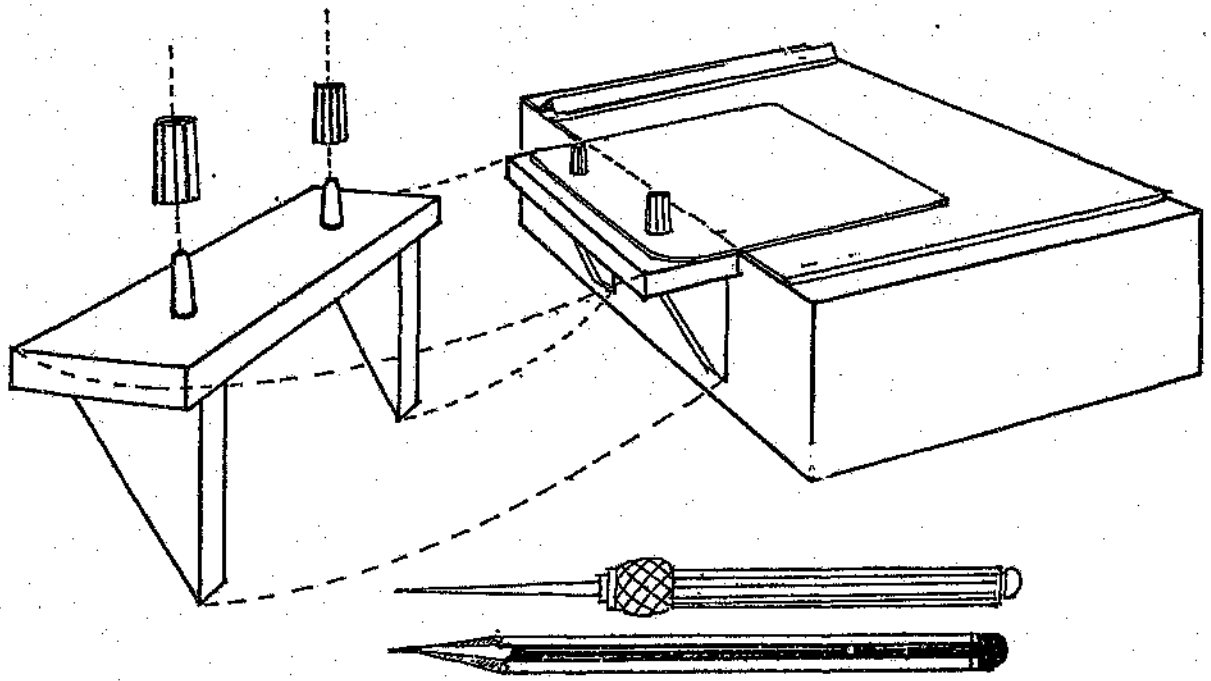


FIGURE 22 - The viewing and tracing of radiographs.

Fitted alongside a conventional radiograph viewing box is a platform, holding a cartoonist's "peg-bar" with locking caps. These allow the punched radiographs, overlay cels and tracings to be precisely related to each other at all times.

matched those of the pegbar in distance and in base diameter. Any lines used to plot the location of a point were drawn on the overlying acetate cel and not on the radiograph. The pencil dots were lightly marked on the cels and acted as pointers for finding the points on the underlying radiograph. Direct measurements were made off the radiographs itself. The thinness of the cellulose acetate cel (0.02 mm) precluded it from imparting refractive distortion to the radiographic image and acted as sketch pad as well as protective covering for the film against scratches from the calliper.

1. Measurements for the depth system

On the lateral radiograph the measurement of soft-tissue thicknesses between the hard and soft tissue landmarks is straightforward and was taken by Vernier callipers. Three of the soft tissue landmarks (the most protrusive point on tip of the nose (LR.6), a point on the lowermost curve of the nose tip (LR.7) and the crease at the base of the columella (LR.8) were all measured for depth from a common point, the acanthion (Figure 11). Loosely speaking LR.6 is found on a line in which the anterior nasal spine points. LR.7 is often found in line with with the EAMAC line and LR.9 is generally about the same angle below LR.8 as LR.7 is above it.

On the oblique radiograph all measurement of soft tissue thickness in upper and lower sets of hard and soft profiles were taken with Vernier callipers as were the lower set of measurements between the maxilla and mandible and soft lips and chin. It was found that more care had to be exercised in recording the soft tissues depths at landmarks OR.18, OR.18 and OR.20.

2. Measurements for the profile system

To record the joints and nodes marked off on the hard and soft tissue profiles in a polar coordinate system, two pieces of information about each point were required: an angular bearing taken from the centre of the headworld; and a measurement of the distance of the point from the centre. Both values were measured off the tracing using an ultra thin protractor and a ruler graduated in 0.5 mm divisions (Figure 23). A measuring device specifically designed for this purpose has recently been constructed to allow the above measurements to be carried out with greater ease (Figure 24).

The record sheet in Figure 25 makes provision for 128 entries: 32 pairs of hard and 32 pairs of soft tissue polar coordinates.

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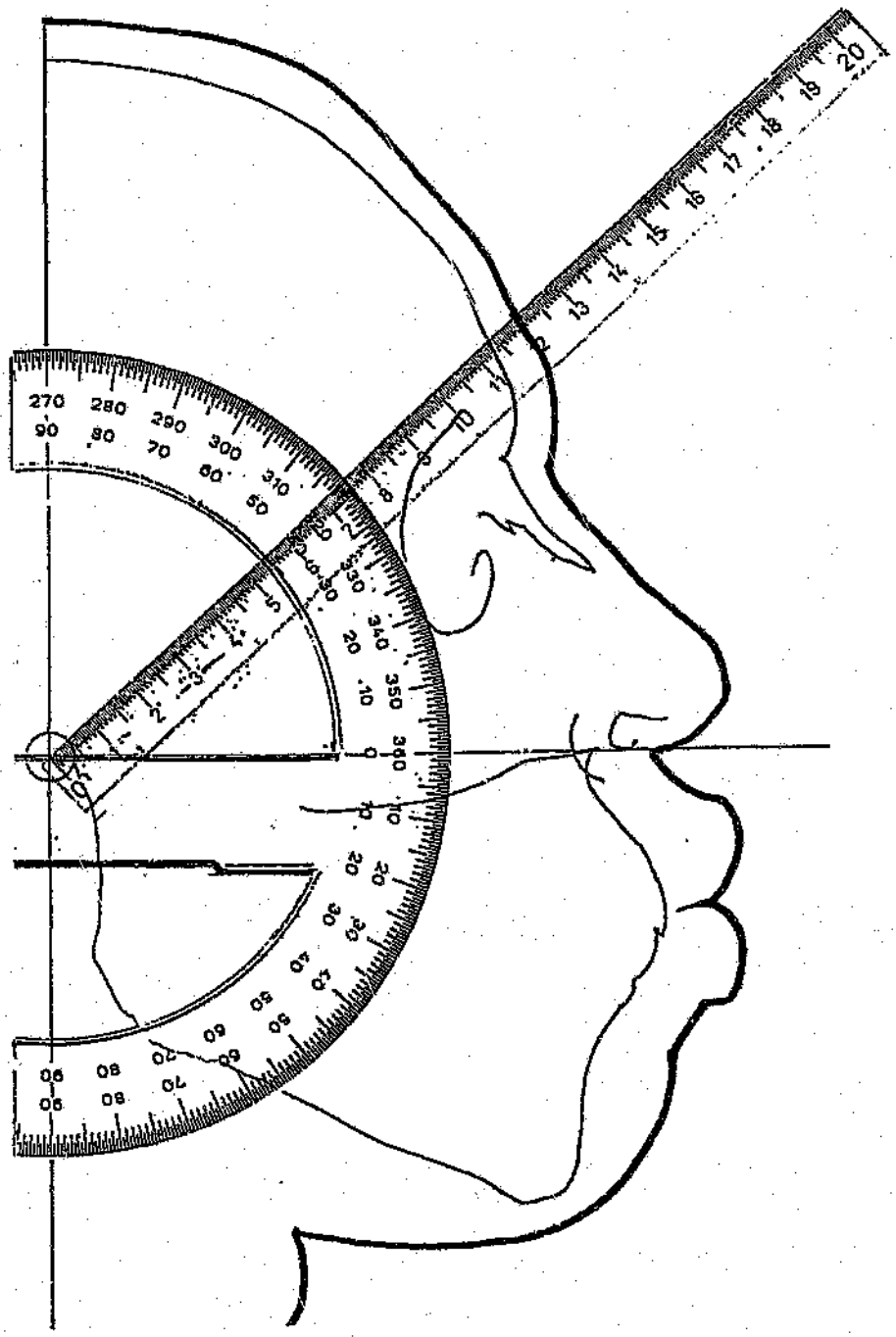


FIGURE 23 - The use of the protractor and ruler.

These are used for locating and measuring hard and soft points as polar coordinates. The centre of the ultra-thin protractor is placed over the centre of the external auditory meatus with its zero point on the EAMAC line. An equally thin rule is then used to determine and measure off the coordinates as angles and distances.

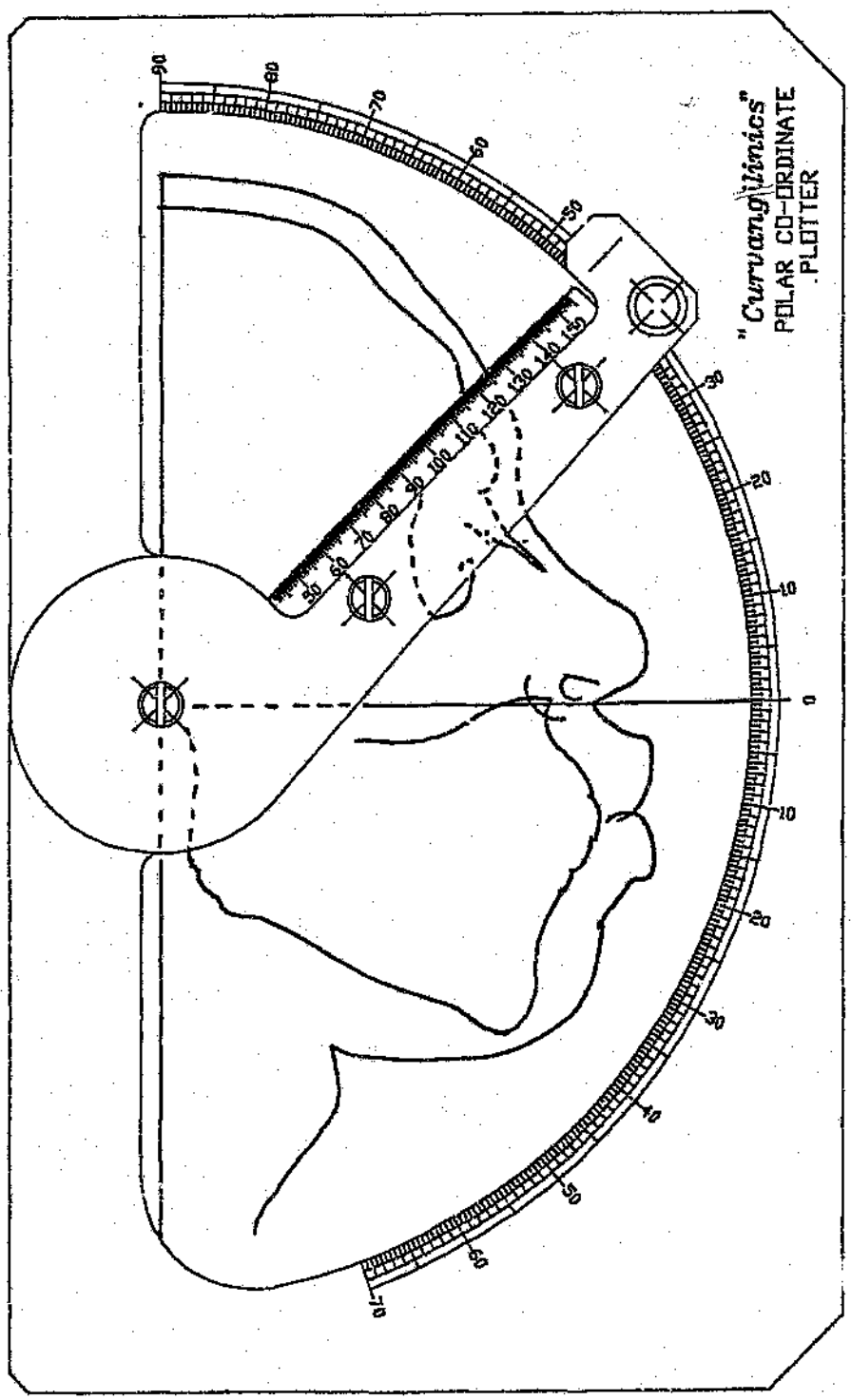


FIGURE 24 - The Polar Coordinate Plotter (PCP).

This is a specially-designed instrument. It is used in a similar manner to the more simple device seen in Figure 23.

HARD AND SOFT COORDINATES FOR THE PROFILE SYSTEM

(Dr W A Aulsebrook)

TRIPLE No:	HARD COORDINATES		SOFT COORDINATES	
	ANGLE	DISTANCE	ANGLE	DISTANCE
T1				
T2				
T3				
T4				
T5				
T6				
T7				
T8				
T9				
T10				
T11				
T12				
T13				
T14				
T15				
T16				

Case No: ..... Name: ..... Date: .....

FIGURE 25 - Record sheet for radiographic profile data.

CHAPTER V

METHODS: ULTRASONIC PROBING

A. EQUIPMENT

The diagnostic ultrasound equipment used was the Ocuscan-400 Real-Time Ultrasound Contact Scanner with a coupled 10 MHz fixed short-focus transducer, made by Cilco/Sonometrics, Huntington, West Virginia, USA.

The transducer or probe delivers an ultrasonic pulse that is generated from electrical energy by a piezoelectric synthetic crystal built into its head. The echoes are attenuated during their passage through the soft tissues by absorption, scatter and reflection. As the pulse reaches each level or interface between the various tissues a portion of the pulse is bounced back again towards its source and is recorded electronically as a measurable peak on a cathode ray tube or oscilloscope screen. The distance between blips (sometimes called spikes or peaks) is proportional to the distances between interfaces and is thus an indication of the depths of the various soft tissues overlying the bone at that point. Each tissue through which the ultrasound passes has its own density and compressibility, termed its acoustic impedance. At the time of calibrating the equipment it is necessary to

set the overall impedance to a mean value of all of the soft tissues likely to be encountered. This is equivalent to an acoustic velocity of between 1500 and 1580 m/sec. Echoes are returned at the acoustic interface between any two tissues. A good deal of practice is needed to detect the peak that represents the critical bone-soft-tissue interface.

Other materials used were: Medi-Trace, a contact jelly made by Graphic Controls Canada Ltd., Gananoque, Ontario (optional); liquid paraffin for lubrication and as an alternative contact medium for the probe; "Skin-Prep" to clean the face; skin marking pencil; tissues; protective covering for the subject.

B. PRELIMINARY ULTRASONIC INVESTIGATIONS

Before describing the landmarks and the method of taking ultrasonic soft tissue depth readings it is necessary to deviate a moment, in order to describe three ultrasonic tests that were carried out by the writer prior to embarking on ultrasonic measurements of the main study. There were certain questions that needed answering:

- How skilled was the operator in the use of ultrasound and how accurate and error-free was the system?

- How sure could the operator be of locating the exact bony ultrasonic landmark and how much depth variation is there around a landmark?

- How accurate is ultrasonic measurement compared to the known accuracy of radiographic measurement? This was one of the objectives listed in Chapter 1.

1. Accuracy and error control

In ultrasonic measuring there are four possible sources for error: system error, assistant error, operator error and landmark error. The last error will be discussed in the next section (section 2).

System error

The ultrasonic apparatus was checked by the agents at their workshops. The hand-held probe was replaced by the latest model and the system was pronounced by the company technician as accurate and in good working order.

Assistant error

There is always a possibility that the depth measurements called out by the operator for the assistant to record on the data sheets can be either heard wrongly or recorded incorrectly. Quite unbeknown to the assistant a test was carried out to estimate her recording accuracy. In the

first five and the last five cases the data called out by the operator were recorded by a hidden tape recorder. At the end of each session of measuring, the recording was played back and the values heard on the tape were checked against those recorded on the data sheet. Every case had been correctly recorded. The good results were attributed to the alertness and attention of the assistant and the clarity of verbal reporting by the operator.

Operator error

Correct use of the ultrasonic probe requires considerable practice. Hodson et al. (1985) suggest that a researcher using diagnostic ultrasound should acquire prior training in the use of ultrasound. Alternatively, he should employ the services of an experienced ultrasound technician.

In order to reduce inter-observer error the writer elected to do all the measurements himself after acquiring the necessary skill. Initial practice had been gained by measuring the thickness at various points of irregular slices of steak layed over ox-bone, first by ultrasound then with callipers. In another test a midsagittal section of a cadaver head was marked with an indelible pencil at selected points on the soft tissue cut edge. The depths were measured first by ultrasound then with a Vernier calliper. When the results correlated well the writer practised on living tissue (at first on his finger

then on his face) in order to develop the required sense of touch and pressure. Finally, the controlled test that is described below was conducted on the faces of live subjects.

2. Variation in depth readings around a landmark

The operator should be able to locate a landmark through his knowledge of anatomy together with a thorough visual and tactile examination of the face. There is such wide variation in human anatomy that if the operator should measure just slightly away from the anatomical point he is looking for, the measurement would then not be truly representative at that landmark. It was decided to investigate the variation in depths of tissues in the immediate vicinity of landmarks.

For the purposes of the test, the landmark itself was referred to as a "central data point" (CDP) and the four test points around the CDP were termed "regional data points" (RDPs).

The RDPs were marked on the face at a 5 mm distance from the CDP and were located superiorly, inferiorly, distally and medially to the CDP. A special template was made for this purpose (Figure 26). It consisted of a clear acrylic disc, cast as part of the end of the shaft. The disc was

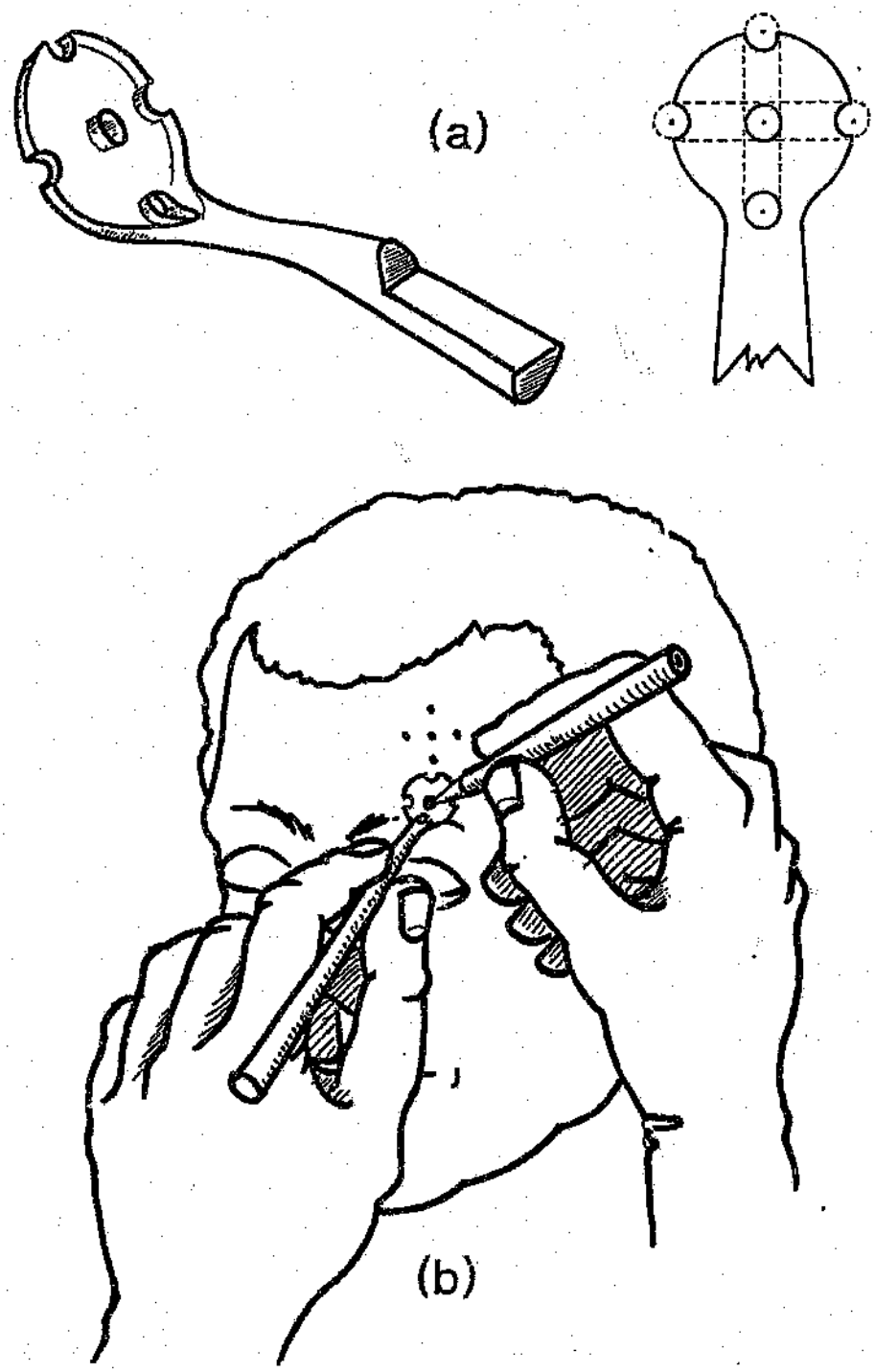


FIGURE 26 - Regional Data Point (RDP) disk and its use on the face.

The disk is applied to the skin of the face, with its central hole over the soft tissue landmark and its three notches and one hole in the 3, 6, 9 and 12 o'clock position (b). Marks are made through the holes onto the skin to register the central data point and the four regional data points.

pierced by a central hole 1 mm in diameter. Around the periphery were three 1 mm diameter semicircular notches and a 1 mm hole at the junction of the shaft and disc. The notches and holes were placed at right angles to each other.

The first 10 subjects of the sample were used for the test. The disc was positioned over the landmark and the CDP was marked through the central hole. The RDPs were then marked at the peripheral notches and hole. Depth readings at the CDP and the four RDPs were taken for all 18 prescribed landmarks on the 10 subjects.

From the data collected a "traversion map" was drawn up (Figure 27). It shows a face with circles placed at the 18 CDPs. Radiating from the centre of each circle are short lines that run up, down, left or right.

The CDP is the correct focus for measurements, but the advantage of using RDPs is that a guide can be drawn up that will indicate the direction and distance we may deviate from the CDP and yet still maintain an acceptable measurement for the study. The data were converted to mean values for all the RDPs and then calculated as a percentage deviation from the CDP value. Whether this was above the value of the CDP or below it did not matter.

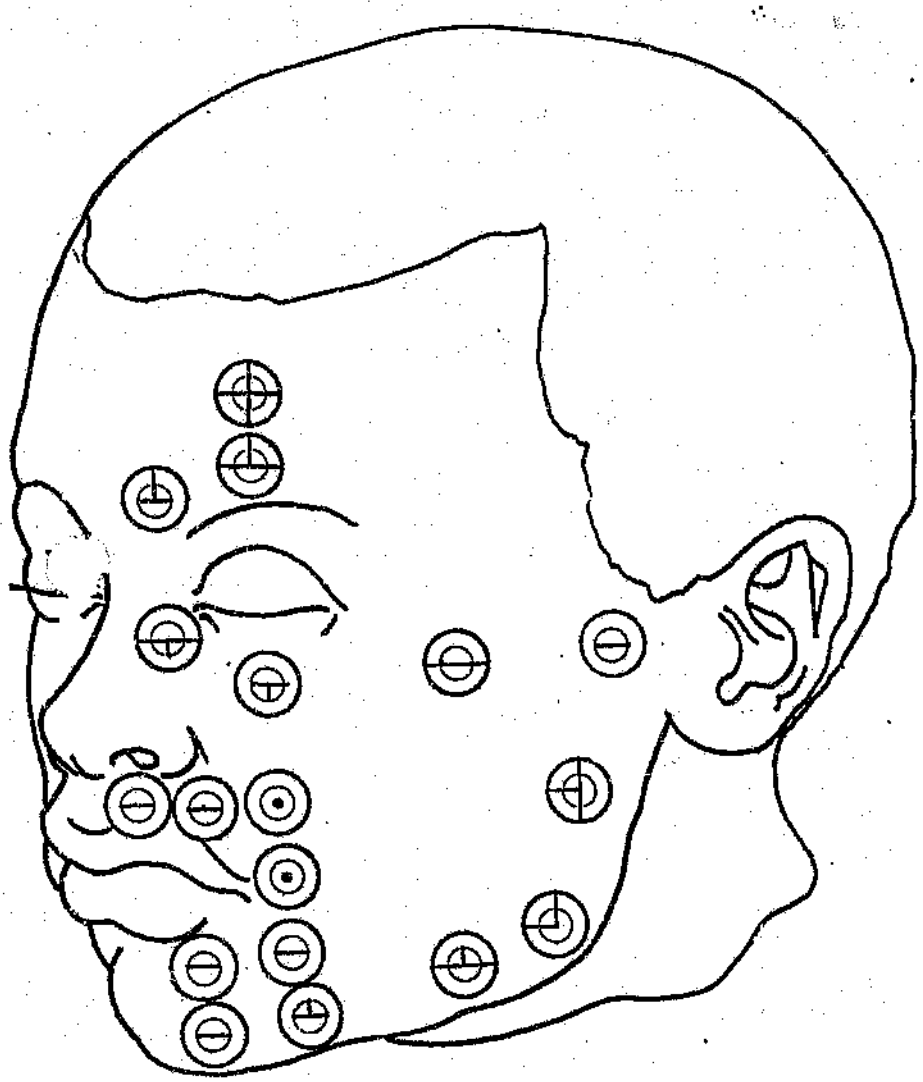


FIGURE 27 - Traversion Map

The circles surrounding the central data point have lines and dots in them that represent the directions and extent that the recorder may deviate in his measurements whilst still retaining a valid measurement.

It was decided that any deviation beyond 10 percent would be represented on the traversion map disc as the absence of a line and the placement of a dot, indicating that the measurement at this point was critical. Values between 10 percent and five percent deviation would be depicted by a short line running half the distance between the center of the disc and its circumference. Values less than five percent were shown by a line running the full radius of the disc. This implied a greater leeway for locating the CDP. The final result was a map of "stop - caution - go " indicators to guide the operator when the CDP reading was a little difficult to locate.

3. Comparing accuracy of ultrasound with radiography

In testing the accuracy of ultrasonic measurements as compared to radiographic measurements the readings must be taken at the same points on the face. It has already been mentioned that the pulse echo is best received when it is returned from a flat surface. Similar flat surfaces for the test measurements were found on the radiograph. Again, the first 10 subjects of the sample were used as test subjects. Measurement sites selected for the test were on the forehead in the midline, where both the skin surface and underlying bone are flat and where surfaces are nearly parallel to each other.

The CDP for the soft tissue nasion was found and marked. The method described by Montagu (1935) shows it to be on the level of the palpebral folds of the upper eyelid in the mid-sagittal plane. With this as a starting point three more midline points were measured out and marked on the forehead at 2 cm, 3 cm and 4 cm up from the nasion mark. Ultrasound depth readings were taken at these four positions.

On the cephalometric radiograph the soft tissue nasion was marked as being in line with the superimposed images of the palpebral creases. If this method was found to be unsatisfactory the soft nasion was taken as being at the site described in the Glossary of Terms. Points labelled A, B and C were then measured off upwards from the soft nasion in units of 11 mm (since the radiographic image had been magnified by 10 percent) and the depth of the soft tissue at each of the points was measured and recorded by the method described in section C below.

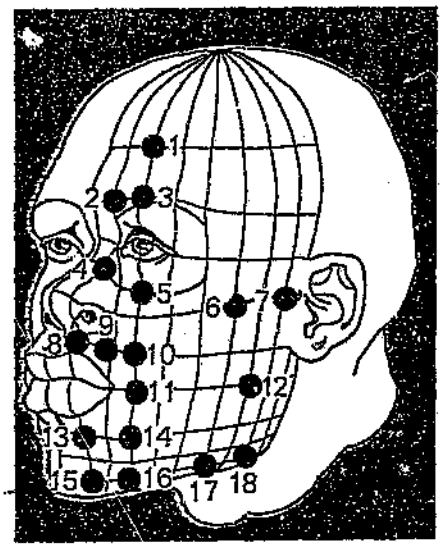
A copy of the record chart is seen in Figure 28. It shows a drawing of the face with numbered measuring sites, the names of the central data points and a series of blocks for recording the data. It is necessary to familiarise oneself with the description of the landmarks and to keep the traversion map (Figure 27) on hand when measuring. Three measurements were taken at each CDP and entered on

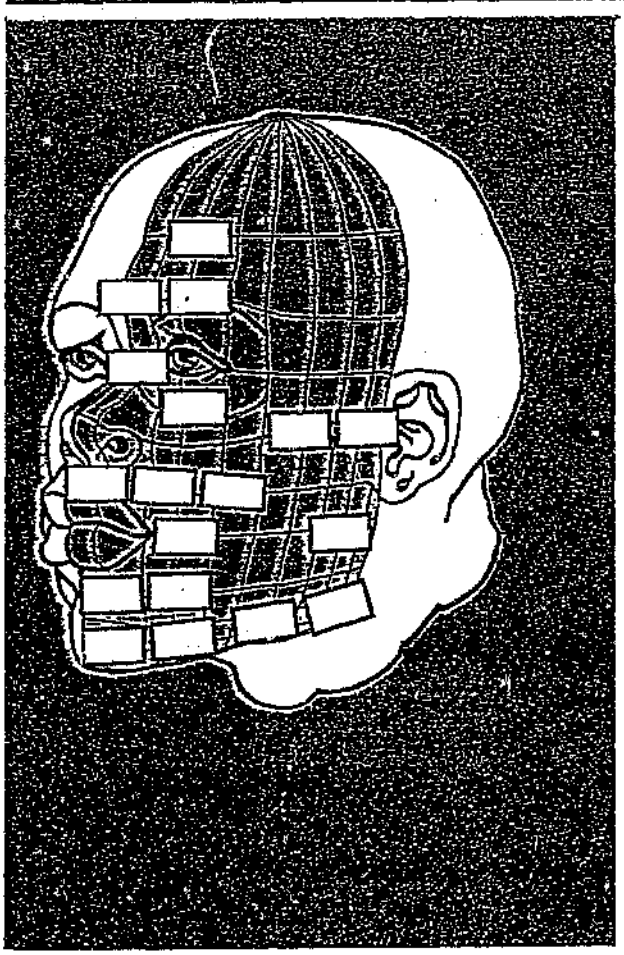
ULTRASONIC DEPTHS MEASUREMENTS

(Dr W A Aulsebrook)

Code: ..... Name: ..... Date: .....

US 1	FRONTAL
US 2	LATERAL GLABELLAR
US 3	SUPRA-ORBITAL
US 4	LATERAL NASAL
US 5	INFRA-ORBITAL
US 6	MID-ZYGOMA
US 7	ROOT OF ZYGOMA
US 8	PHILTRUM RIDGE
US 9	SUPRA-LABIAL
US 10	SUPRA-COMMISSURAL
US 11	COMMISSURAL
US 12	MID-MASSETERIC
US 13	SUB-LABIAL
US 14	SUB-COMMISSURAL
US 15	MENTAL TUBERCLE ANT.
US 16	MENTAL TUBERCLE LAT.
US 17	INSERT MASSETER ANT.
US 18	INSERT MASSETER POST.





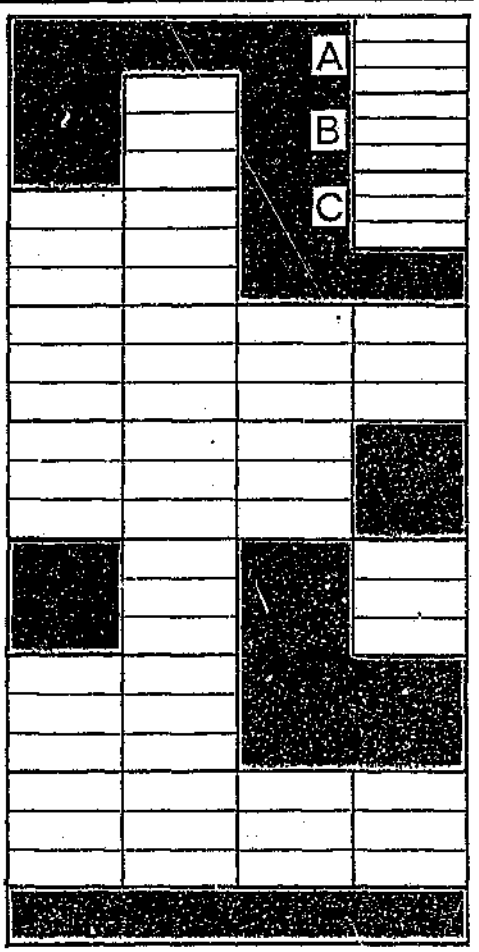


FIGURE 28 - Ultrasonic data record sheet.

At each of the landmarks three readings are registered. The largest is taken as the final reading. Blocks A, B and C are for recording the test readings.

the record sheet. Instead of taking the mean of the three readings the highest was chosen as the correct one. This measurement represented the lightest contact of the probe with the skin surface. If the skin contact with the probe is interrupted and there is still a seal between skin and probe, the thickness of the contact medium is shown by an additional peak on the oscilloscope. In this case slightly more pressure is applied to the probe so as to renew contact with the skin.

Out of the 17 data points normally measured on the face, 10 were selected as being representative of the different types of surface-to-bone combinations that could possibly be encountered by the operator. A volunteer was used as the test subject. Points were measured in random order, five times in a morning session, five times in the afternoon on five different days, five days apart. This resulted in 500 observations. Data were processed by the South African Institute for Biostatistics (Medical Research Council) on an IBM computer, using the BMDP Statistical Software package (Copyright, University of California).

Observations:

1. In Table 3 it can be seen that on the first morning for example, the coefficient of variation (CV) ranged between 0.3 percent and 1.8 percent.

TABLE 3 - Ultrasonic operator error

Showing coefficients of variation for Day 1 (Monday).

Day	Point	Readings(n)	Mean	S.D.	C.V	Min.	Max.
1 (am.)	1	5	4.97	0.05	1.04	4.90	5.01
	2	5	5.17	0.04	0.77	5.10	5.20
	3	5	5.31	0.07	1.38	5.20	5.40
	4	5	7.15	0.10	1.37	7.03	7.27
	5	5	3.33	0.05	1.60	3.29	3.42
	6	5	3.12	0.06	1.76**	3.04	3.18
	7	5	9.03	0.14	1.59	8.89	9.19
	8	5	12.39	0.10	0.78	12.28	12.50
	9	5	16.26	0.05	0.30*	16.19	16.32
	10	5	18.70	0.13	0.67	18.52	18.81
1 (pm.)	1	5	4.90	0.06	1.23	4.84	4.97
	2	5	5.04	0.04	0.80	4.98	5.09
	3	5	5.45	0.05	0.83	5.39	5.49
	4	5	7.25	0.15	2.10	7.04	7.39
	5	5	3.33	0.13	4.00	3.20	3.53
	6	5	3.17	0.10	3.10	3.05	3.29
	7	5	8.93	0.21	2.37	8.63	9.22
	8	5	12.53	0.07	0.53	12.45	12.60
	9	5	16.25	0.08	0.49	16.19	16.38
	10	5	18.96	0.42	2.21	18.65	19.69

Note: * = low ** = high

2. Over five days, the lowest CV was 0.1 percent and the highest was 6 percent.
3. Plotting morning against afternoon readings, on the first day the mean CV over landmarks for the morning was 1.12 percent and for afternoon 1.76 percent shown in Figure 29.
4. This same trend was evident on the subsequent four days.
5. Collectively over the five days the morning mean CV was 1.35 percent and the afternoon, 1.48 percent (see Figure 30).

If morning readings were similar to afternoon readings, their observations would be evenly distributed around the 45 degree line in Figure 30. In this case this was not so. The afternoon readings were higher than those taken in the morning. It seems therefore preferable to take all ultrasonic readings in the latter half of the day. From the above results it is also quite evident that good correlation exists between the morning and the afternoon measurements taken on different days.

The ultrasonic method of measurement employed in this test thus represents a stable method of data collection.

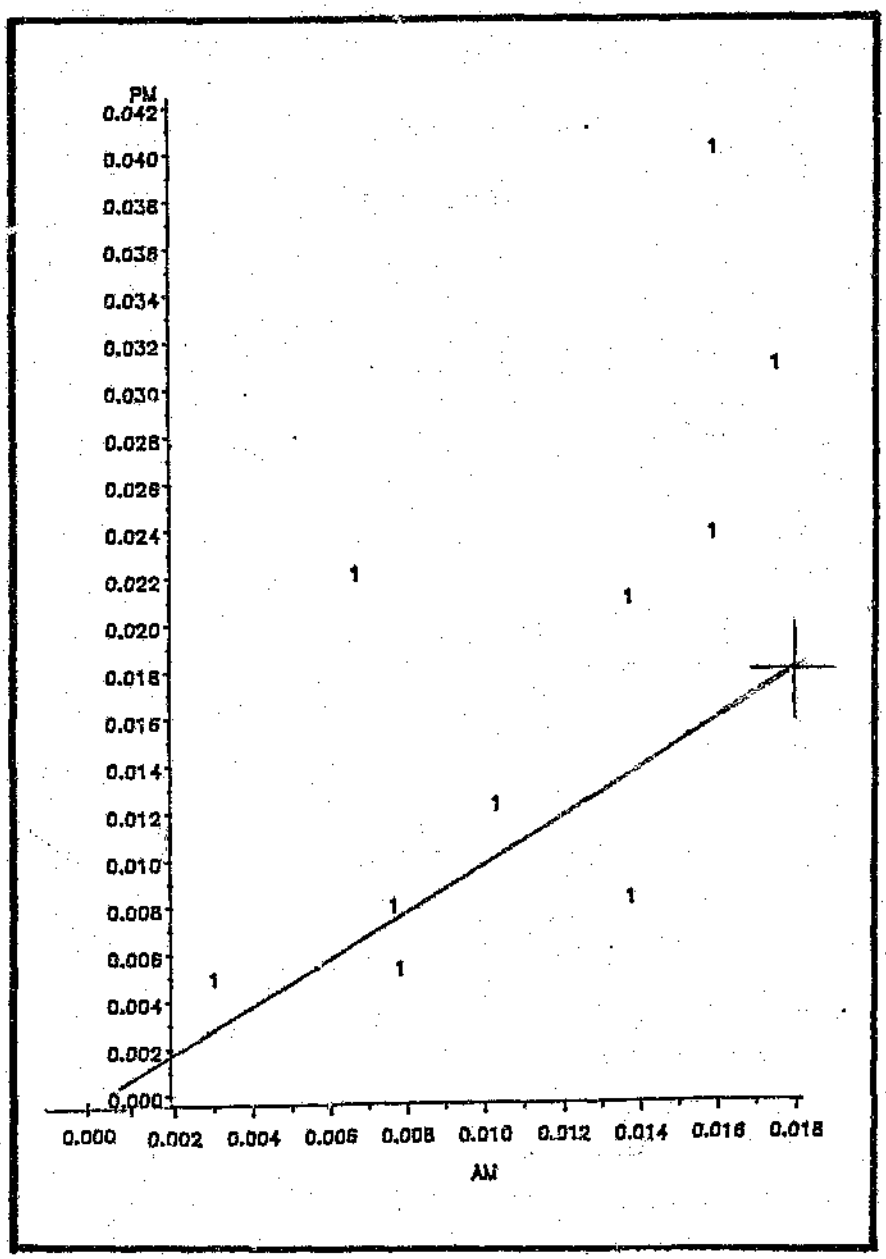


FIGURE 29 - Ultrasonic error.

Plot of morning against afternoon readings on the first day together with the line of perfect agreement, passing through the origin and having a slope equal to one.

	MEAN	S.D.
X:	0.01125	0.00484
Y:	0.01764	0.01186

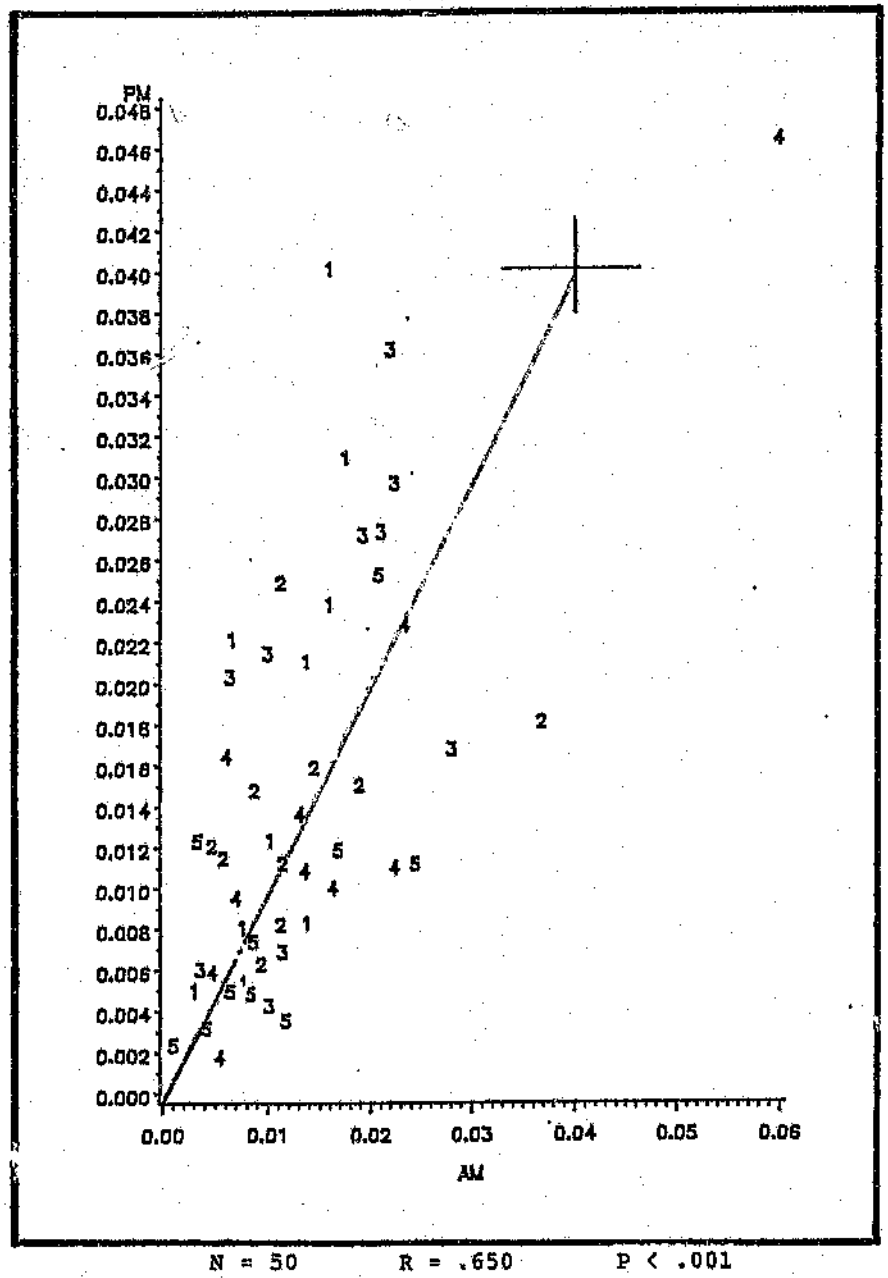


FIGURE 30 - Ultrasonic error.

Collectively over five days, the mean coefficients of variation were 1.35 percent for the morning and 1.48 percent for the afternoon.

	MEAN	S.D.
X:	0.01353	0.00996
Y:	0.01485	0.01021

C. LANDMARKS

Landmarks were coded with the prefix US (ultra-sound) and ranged from US.1 to US.18. Some of the landmarks were readily located by relating them to a surface feature of the face. Others could only be determined by first palpating the underlying bone and then marking the skin. All landmarks were named according to their surface location.

When mention is made of vertical or horizontal alignments they are in relation to Camper's Plane (with EAMAC line parallel to the floor). The landmarks are illustrated in Figure 31.

US.1 Frontal

A point on the forehead in a vertical line with the pupil of the eye and on the same horizontal level as radiographic points LR.1 and OR.1.

US.2 Lateral glabella

A point on the soft tissue supraorbital ridge on a vertical line with the inner canthus of the eye.

US.3 Supra-orbital

A point on the soft tissue supraorbital ridge in vertical alignment with the pupil of the eye.

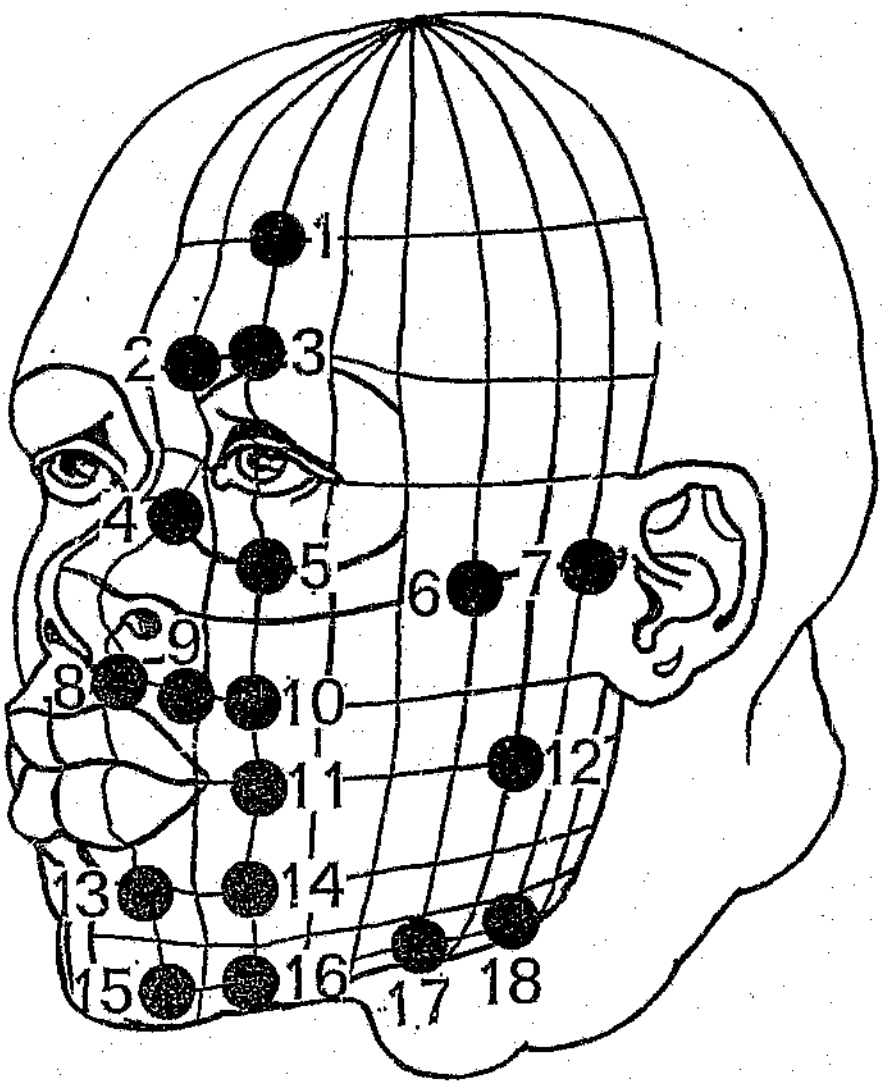


FIGURE 31 - Ultrasonic landmarks on the face.

Landmarks for ultrasonic depth measurement of the face, are located along vertical meridia, and horizontal parallels. Ultrasonic landmarks are always the same in every face, and are named according to surface anatomy (see figure 10).

US.4 Lateral nasal

A point on the side of the bridge of the nose at the same horizontal level as LR.4 and on a vertical line with the inner canthus of the eye.

US.5 Infra-orbital

This point is located after palpation of the lower bony orbital margin. It is on the flat plane lying just below the lower rim of the orbital socket and is in vertical aligment with the pupil of the eye.

US.6 Mid-zygomatic

A point overlying the bony zygion, on the maximum horizontal and vertical outer curvature of the zygomatic arch.

US.7 Root of zygoma

A point on the skin surface immediately above the mandibular condyle and superficial to the posterior root of the zygoma.

US.8 Philtrum ridge

A point on the lateral ridge of the philtrum midway between the base of the columella and upper lip margin.

US.9 Supra-labial

Over the maximum bulge of the canine eminence mid-way between the angle of the mouth and the root of the alar cartilage.

US.10 Supra-commissural

A point on a horizontal level with US.9 and on a vertical line with US.11. It is positioned over the root of the first premolar.

US.11 Commissural

A point on a horizontal level with the cheilion and immediately posterior to the commissural bulge It is frequently superficial to the crown of the first premolar.

US.12 Mid-masseteric

A point on the skin surface lying over the centre of an area bounded by the lower borders of the zygomatic arch and mandible, the anterior fibres of the masseter and the posterior border of the ascending ramus.

US.13 Sub-labial

A point within the labiomental creas in vertical alignment with US.9.

US.14 Sub-commissural

A point in a vertical line with US.10 lying on a horizontal level with US.13.

US.15 Mental tubercle, anterior

The most prominent point on the lateral bulge of the chin mound.

US.16 Mental tubercle, lateral

A point posterior to US.15 above, on the same horizontal level and in vertical alignment with US.10 and US.14.

US.17 Insertion of masseter, ant.(Antero-masseteric)

Determined by palpation, this point lies at the anterior edge of the insertion of the masseter muscle into the mandible.

US.18 Insertion of masseter, post.(Postero-masseteric)

Similarly found, this point lies at the lower and posterior edge of the insertion of masseter into the mandible, just anterior to the gonion.

D. RECORDING ULTRASONIC MEASUREMENTS

In order to set a standard, as well as for the benefit of future workers wishing to make use of this equipment, the

procedure for taking a ultrasonic reading is described in a fair amount of detail.

The subject is draped with a neck-to-knee plastic apron to protect his clothing. His face is wiped with spirits to remove oily deposits. These can prevent the landmarks from being registered on the face by the skin-pencil.

The subject is seated with his face level with the operator's hand. The foot control which "freezes" the screen is placed underfoot. Though there should be sufficient light falling on the subject's face the screen should be facing away from the light to prevent reflected glare.

The equipment is switched on and the adjustable measuring scale on the oscilloscope is centered, using the lateral shift control. To do this the graph peak signifying the probe-contact medium interface (which on contact with the skin will become equivalent to probe-skin interface) is positioned at zero position on the X-axis of the screen grid. The light intensity of the screen is adjusted and the two cursors are narrowed from horizontal dashes to small dots. Their intensity is set to be brighter than the graphic display. The measurement read-out time is adjusted to rapid and is checked on screen. Equipment, operator and patient are now ready for marking landmarks and recording data.

So that the continuity between the ultrasound probe and the bone surface is not broken, a contact medium (in this case purified liquid paraffin) is interposed between the tip of the probe and skin surface. The probe is cleaned with spirits and its tip lightly dipped into the liquid paraffin. The amount retained on the probe tip is enough to fill the cup-shaped depression at its end.

The probe is held against the skin, directly over the landmark. The angulation of the probe is important. The central beam should be directed at right angles to the bone and the probe must maintain contact with the skin without depressing it. Too little pressure will cause the thickness of the contact medium to be added to the measurement. If too much pressure is used the soft tissue is indented producing an incorrect reduced depth. Different pressure is applied at each measuring point. For example the cheek is easily displaced inwards even though the skin itself may not be compacted and a very light contact touch must be employed in this region. On the other hand the soft tissue over the forehead is dense and can withstand firmer pressure before distorting.

Figure 32 illustrates the varying angulations of probe to skin surface and the resulting angles of the echo. It is quite permissable to circumduct the probe (with the data

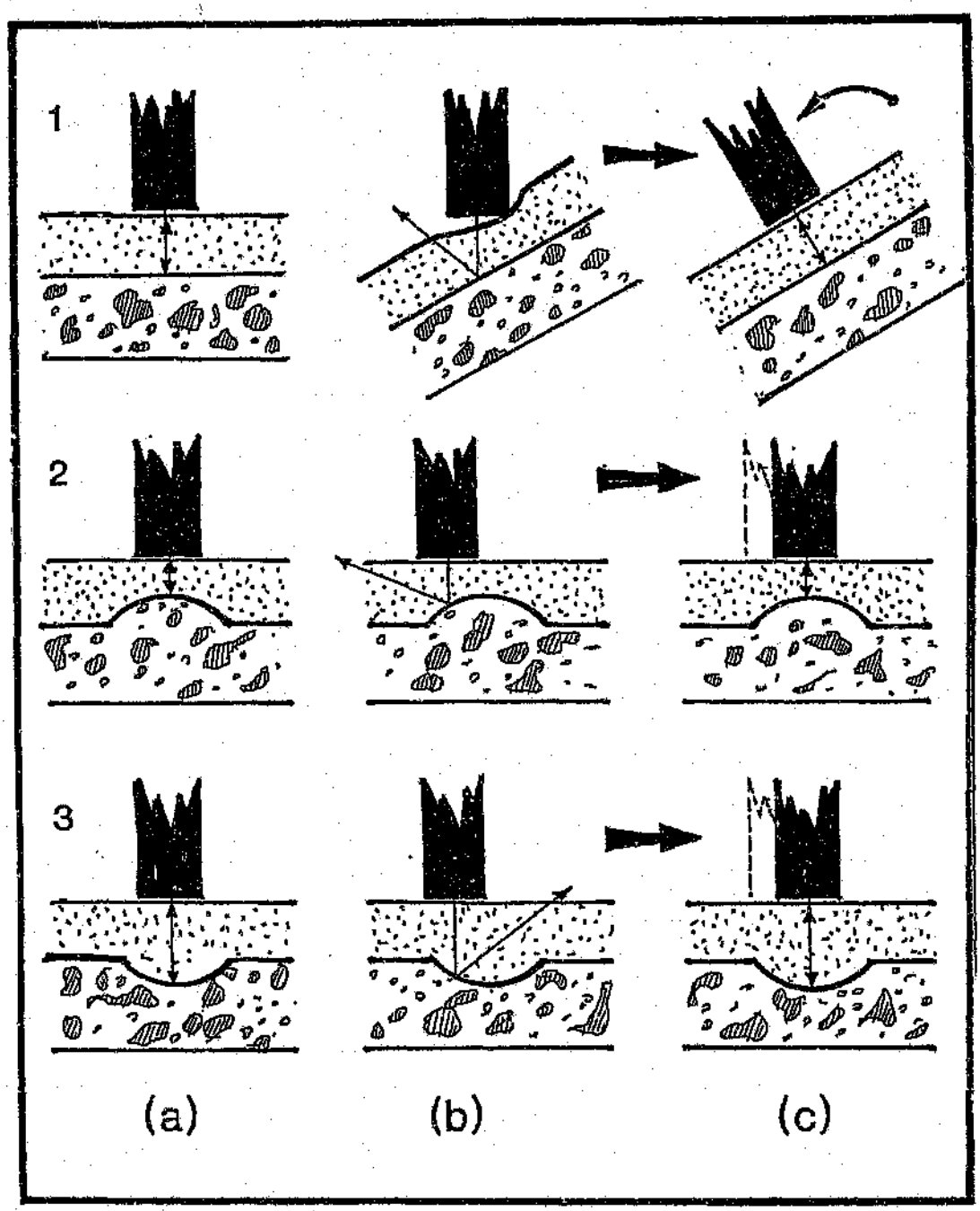


FIGURE 32 - Angulation of the ultrasonic probe to the skin.

Proper relationship of the probe tip to the skin is critical for securing relevant and accurate measurements. In cases 1, 2 and 3, the angulation and position of the probe is: correct in (a), incorrect in (b) and adjusted in (c).

point as centre) until an echo is received. However there should be no wandering off the target in order to find a more suitable spot unless it is within the "regional data area". Wandering can easily occur unintentionally as there is a need to watch the oscilloscope screen. For this reason it is wise to check the contact position of the probe before taking a reading.

When the probe is correctly positioned on the skin, the screen displays a line graph of the tissue interfaces through which the ultrasonic pulse passes. The bone to soft-tissue interface is represented by a strong peak. It is unwise to rely on a solitary reading. Only when a number of attempts indicate the bone interface peak to be in the same place on the screen, should a further three readings be taken of the point. Sometimes as in the case of the cheek it takes a while to find the right location. It is important on these occasions to resist the desire to see a peak where there is none, or to accept the "next best". Only when there is a definite and distinct spike denoting the soft tissue-bone interface should the foot control be depressed thereby "freezing" the image of the graph on screen. The value in millimetres is displayed to an accuracy of two decimal points.

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CHAPTER VI

RESULTS: DEPTH SYSTEM AND PROFILE SYSTEM

In keeping with the aims and objectives of this study, the results of the radiographic and ultrasonic measurements are examined under the following headings:

Depth System

1. Accuracy of ultrasound compared to radiography (objective #1).
2. A dual measuring system of radiography and ultrasound (objective #2).
3. Establishing standards for soft tissue depths (objective #3).
4. Comparing American (USA) standards of tissue depth with those of the present study.

Profile System

1. The standard profile (objectives #[illegible] #6 & #7).
2. The estimated profile.

Satisfying objective # 8 (results of the visual test) is covered in Chapter 7 on the application of the results.

A. THE DEPTH SYSTEM

1. Accuracy of ultrasound as compared to radiography

A test to determine the accuracy of ultrasound compared to the known accuracy of radiography was described in Chapter 5. Analysis of the data yielded the following results.

Observations

a. In Figure 33, ultrasonic measurements of point C (ULTRAC) are plotted against radiographic measurements of point C (RADIOC). The scattergram indicates that there is a strong linear relationship between the two methods of measurement. The ultrasonic measurements are slightly lower than the radiographic measurements (the 45 degree line, marked in Figure 33, indicates where y = x).

b. When expressing the ultrasonic readings as a percentage (PULTRAB) of radiographic readings corrected for enlargement (RADIOB), it can be seen from the scatter diagram in Figure 34 that a correction factor of 0.9560 should be introduced.

c. The mean correction factor of 0.9560 was derived by adding the correction factors of A, B and C and dividing by 3.

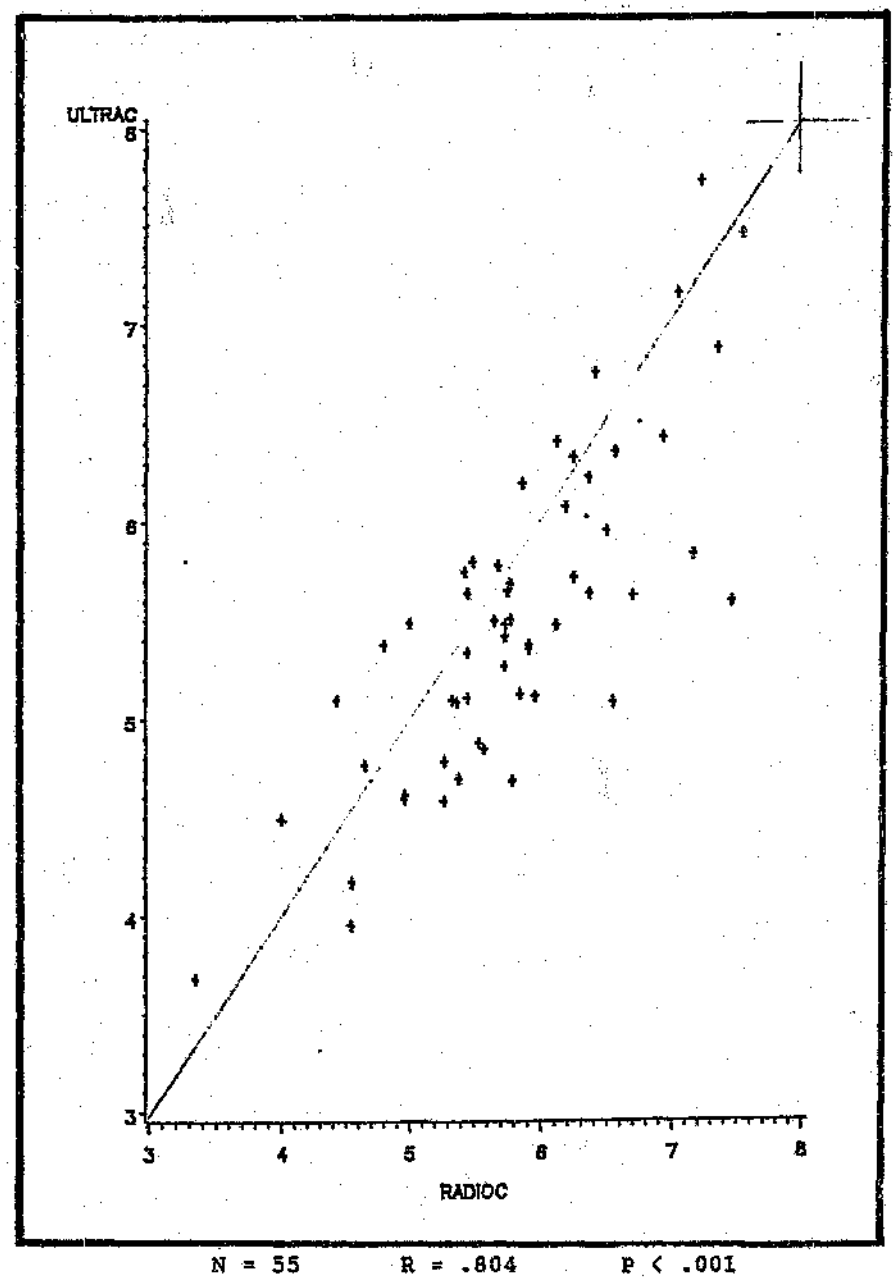


FIGURE 33 - Radiographics versus ultrasonics #1.

Scatter diagram shows a strong linear relationship between the radiographic and ultrasonic measurements.

	MEAN	S.D.
X:	5.7976	0.85872
Y:	5.4973	0.81009

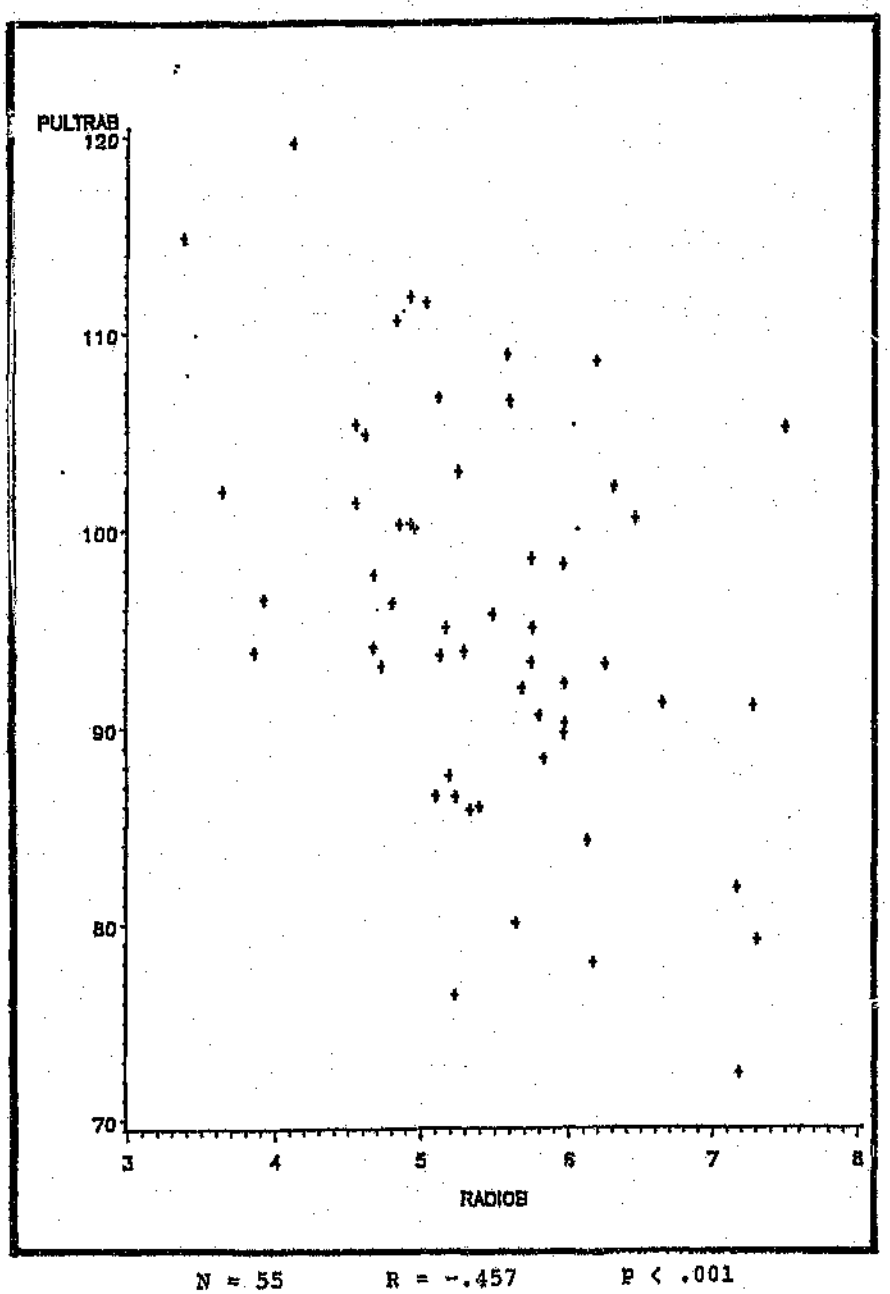


FIGURE 34 - Radiographics versus ultrasonics #2.

Scatter-diagram shows the ultrasonic readings as a percentage of the radiographic readings, indicating a need for the use of a correction factor (see text for details).

	MEAN	S.D.
PULTRAB	Y: 95.595	10.126

Discussion

It is thus evident that for both methods of measurement the readings require adjustment before they can be used as real measurements:

a. Raw radiographic data had been magnified by 10 percent and had consequently to be adjusted either by multiplying by a correction factor of 0.9091 or dividing by 1.1
b. Raw ultrasonic data also had to be adjusted accordingly by a correction factor of 0.9514

Provided these corrections are made to the raw data we are in a position to employ them to establish a set of mean values of the soft tissues in the human face.

2. A dual measuring system of radiography and ultrasound

The combination of the two systems of measurement into one composite mensuration system suggests no numerical or statistical analysis. Instead, an appraisal of the merits of the combined system is in order.

Discussion

Providing the necessary adjustments are made to the data acquired by both methods, the measurements can be read to an accuracy of two decimal places. Neither of the systems is difficult to use, providing the operator acquires the

necessary skills. Each modality has different advantages which can be exploited so as to gain optimal results. Ultrasound measures the depths of tissue on flat surfaces best and radiography on edges and crests. Working on live subjects, the safety of the low risk ultrasonic component of the system becomes a desirable feature. Not only does the dual system gather information at the same landmarks selected by other workers but it records additional data around the eyes and lips. The extra angular readings add the element of direction to the depth measurements. This allows the previously difficult-to-establish landmarks of nose tip and lips to be plotted in space.

For the present at least, data collected by the combined depth system is of value to those workers who are well versed in the use of the depth system of forensic facial reconstruction.

3. Establishing standards for soft tissue depths

From both the radiographic and ultrasonic measurements of facial soft tissue thicknesses of 55 subjects, a set of mean depth values was established for the 54 landmarks on the face. The results are reflected in Tables 4,5 and 6.

TABLE 4 - Mean depths, standard deviations minimums and maximums for this study

(Lateral radiographic measurements)

Code	Name of point	Mean	S.D.	Min.	Max.
LR 1	Supraglabella	5.21	0.92	3.36	7.13
LR 2	Glabella	5.76	0.88	3.35	7.62
LR 3	Nasion	7.03	1.11	4.16	9.36
LR 4	Mid-nasal	4.82	1.04	2.96	6.96
LR 5	Rhinion	3.08	0.58	1.91	4.80
LR 6	Ant. nose tip	25.40	6.34	20.27	30.25
LR 7	Inf. nose tip	18.13	1.93	15.31	24.10
LR 8	Mid-col. base	12.80	2.44	9.66	24.01
LR 9	Mid-philtrum	12.10	1.63	8.12	16.99
LR 10	Mid-U lip marg.	14.61	2.17	10.43	21.05
LR 11	Mid-lipline	7.04	2.24	2.60	13.67
LR 12	Mid-L lip marg.	16.38	1.96	11.16	20.49
LR 13	Mid labio-ment.	12.87	1.65	9.09	15.95
LR 14	Ant. symphys.	11.66	1.79	7.18	15.79
LR 15	Intermed.symph.	9.19	2.61	5.58	17.42
LR 16	Inf. symphys.	7.26	1.98	4.44	15.58

Key: LR = Lateral Radiograph (0 degree)

TABLE 5 - Mean depths, standard deviations, minimums and maximums for this study

(Oblique radiographic measurements)

Code	Name of point	Mean	S.D.	Min.	Max.
OR 1	Lateral frontal	5.37	1.01	3.41	8.00
OR 2	Lateral supraorbital	6.18	0.98	4.15	8.46
OR 3	Lateral orbital	3.71	0.76	2.40	6.41
OR 4	Lateral zygomatic	7.97	1.77	4.44	13.25
OR 5	Lateral alar	8.18	3.28	2.32	16.20
OR 6	Inf.border of zyg.	13.22	2.53	7.27	20.00
OR 7	Sub-zygomatic	18.74	3.07	8.33	26.72
OR 8	Sub-alar	10.22	1.18	6.62	12.62
OR 9	Lat. U. lip marg.	11.73	1.40	9.40	15.19
OR 10	Angle of mouth	11.76	1.85	7.94	16.46
OR 11	Lat. lip line	7.85	1.44	5.45	11.91
OR 12	Lat. L. lip marg.	13.06	1.88	9.09	17.68
OR 13	Lat. labiomental	12.08	1.59	8.43	15.73
OR 14	Lat. point B	7.49	1.68	2.95	12.37
OR 15	Lateral mental	10.42	1.63	7.27	15.18
OR 16	Lateral mandibular	5.43	0.85	3.95	8.56
OR 17	Intermed. mental	8.65	1.67	5.23	12.16
OR 18	Intermed. mandib.	4.40	0.88	2.73	6.82
OR 19	Inferior mental	7.36	1.43	4.42	12.21
OR 20	Inferior mandib.	3.95	1.19	2.23	10.43

Key: OR = Oblique Radiograph (45 degree)

TABLE 6 - Mean depths, standard deviations, minimums and maximums for this study.

(Ultrasonic measurements)

Code	Name of point	Mean	S.D.	Min.	Max.
US 1	Frontal	4.79	0.72	3.27	6.79
US 2	Lateral glabellar	5.53	0.88	3.89	8.43
US 3	Supra-orbital	6.05	0.87	4.48	8.49
US 4	Lateral nasal	4.80	0.99	2.86	7.36
US 5	Infra-orbital	6.56	1.88	3.45	12.42
US 6	Mid-zygoma	7.02	1.05	4.99	11.26
US 7	Root of zygoma	5.91	1.35	3.15	10.34
US 8	Philtrum ridge	9.79	1.68	4.15	13.46
US 9	Supra-labial	9.52	1.44	6.86	13.07
US 10	Supra-commissural	12.64	3.02	2.45	17.45
US 11	Commissural	13.07	1.86	7.57	16.33
US 12	Mid-masseteric	18.05	1.69	14.85	21.21
US 13	Sub-labial	10.30	1.42	5.90	13.67
US 14	Sub-commissural	11.54	1.66	8.05	15.29
US 15	Mental tubercle ant.	8.99	1.87	5.33	13.41
US 16	Mental tubercle lat.	8.61	1.50	5.44	12.72
US 17	Insert. masstr ant.	9.47	2.16	4.72	14.23
US 18	Insert. masstr post.	15.38	2.60	8.27	20.46

Key: US = Ultrasonic

Discussion

The mean soft tissue depths were measured to the second decimal place. This degree of fine measurement has been retained during the statistical phases of the study. However, when it comes to the practical stages of reconstruction the figures may be taken to the nearest 0.5 mm because of the relative crudeness of manual control in modelling.

4. Comparing American (USA) standards of tissue depth with those of the present study

A major difference between the South African (RSA) and American (USA) measurements gathered on the American Negroid face by Rhine and Campbell (1980) was that in the present study there are a number of extra measurements in both lateral and the oblique planes. It should be noted that there are no corresponding values for these extra landmarks in the study by Rhine and Campbell.

Table 7 compares data gathered in the median plane. There are additional measurements at the landmarks LR.4, LR.6, LR.7, LR.8, LR.11 and LR.15. Measurements at forehead, glabella and nasion in the two studies exhibit a "cross-over" or reversal of values. In one sample the thickness of forehead tissues is greater than in the other whereas the reverse is true of tissues over the glabella.

TABLE 7 - Comparing American standards of tissue depth with those of the present study

(Lateral radiographic measurements)

Code	Name of point	RSA mean (mm)	USA mean (mm)
LR 1	Supraglabella	5.21	4.75
LR 2	Glabella	5.76	6.25
LR 3	Nasion	7.03	6.00
LR 4	Mid nasal	4.82	-
LR 5	Rhinion	3.08	3.75
LR 6	Nose tip Front	25.40	-
LR 7	Nose tip Bottom	18.13	-
LR 8	Nose base	12.80	-
LR 9	Mid-philtrum	12.10	12.25
LR 10	Upper lip margin	14.61	14.00
LR 11	Lipline	7.04	-
LR 12	Lower lip margin	16.38	15.00
LR 13	Chin-lip fold	12.87	12.00
LR 14	Mental eminence	11.66	12.25
LR 15	Mid-chin	9.19	-
LR 16	Beneath chin	7.26	8.00

RSA = Republic of South Africa
USA = United States of America

Tables 8 compares data of the present study gathered at the 45 degree meridian with those USA landmarks that also happened to be placed in the same meridian. There was only one American landmark available for comparison (OR.2) with the 20 of the RSA study.

Table 9 compares the ultrasonic data of the present study with the remaining landmarks in the American study. Here there are six American landmarks for comparison with 18 in the RSA study.

In total, throughout the face, the present study measured 54 tissue depths per half-face, compared to the 21 in the American study (four of the USA landmarks are not comparable to any of those of the RSA study).

Discussion

The present study indicates certain differences between the tissue measurements of Zulu and the American Negroid. In evaluating these differences one should bear in mind the following:

- the study was conducted on live subjects, undistorted by either disease or death.
- it was a tightly-controlled study done on males within a 15 year age span at a prime physical time of their

TABLE 8 - Comparing American standards of tissue depth with those of the present study

(Oblique radiographic measurements)

Code	Name of point	RSA mean (mm)	USA mean (mm)
OR 1	Lateral frontal	5.37	-
OR 2	Lateral supraorbital	6.18	13.00
OR 3	Lateral orbital	3.71	-
OR 4	Lateral zygomatic	7.97	-
OR 5	Lateral alar	8.18	-
OR 6	Inf.border of zyg.	13.22	-
OR 7	Sub-zygomatic	18.74	-
OR 8	Sub-alar	10.22	-
OR 9	Lat. U. lip marg.	11.73	-
OR 10	Angle of mouth	11.76	-
OR 11	Lat. lip line	7.85	-
OR 12	Lat. L. lip marg.	13.06	-
OR 13	Lat. labiomental	7.49	-
OR 14	Lat. point B	12.08	-
OR 15	Lateral mental	10.42	-
OR 16	Lateral mandibular	5.43	-
OR 17	Intermed. mental	8.65	-
OR 18	Intermed. mandib.	4.40	-
OR 19	Inferior mental	7.36	-
OR 20	Inferior mandib.	3.95	-

Key: OR = Oblique Radiograph (45 degree)

TABLE 9 - Comparing American standards of tissue depth with those of the present study

Ultrasonic measurements

Code	Name of point	RSA mean (mm)	USA mean (mm)
US 1	Frontal	4.79	8.25
US 2	Lateral glabellar	5.53	-
US 3	Supra-orbital	6.05	4.75
US 4	Lateral nasal	4.80	-
US 5	Infra-orbital	6.56	7.50
US 6	Mid-zygomatic	7.02	8.75
US 7	Root of zygoma	5.91	11.75
US 8	Philtrum ridge	9.79	-
US 9	Supra-labial	9.52	-
US 10	Supra-commissural	12.64	-
US 11	Commissural	13.07	-
US 12	Mid-masseteric	18.05	-
US 13	Sub-labial	10.30	-
US 14	Sub-commissural	11.54	-
US 15	Mental tubercle ant.	8.99	-
US 16	Mental tubercle lat.	8.61	-
US 17	Insert. masstr ant.	9.47	-
US 18	Insert. masstr post.	15.38	14.25

Key: US = Ultrasonic

lives. All subjects were healthy, well fed and naturally muscular.

- the subjects all belonged to a homogenous population group. The Zulu nation has lived under constant environmental conditions for generations.

This indicates a controlled study with far less sample variation than the American study. Rhine and Campbell (1980) do not mention the age range of their 44 subjects but do state that no attempt was made to eliminate the thin or the amply endowed. Their intention was "rather, to sample from the broadest possible range".

When the data of this study are compared with the data of the American study there is no way of knowing whether the American differences in tissue thickness are due to the different sample of subject selected or whether they are produced by the sample variation, disease or death. If tissue depths are greater at one landmark it could well be that the American Negroid is fatter at that point. On the other hand a difference in thickness could also be due to post-mortem distortion. A more significant and possibly useful observation is the distinct crossing over of depths measurements at forehead, glabella and nasion in the two studies. At this stage of the study there is no evident reason to assume that these differences are characteristic of the sample types.

Generally, given that both types of information are of similar type, it is safe to assume that the more the amount of information collected the better the chances will be of a successful reconstruction. The collection of bilateral data in the American study increases the total amount of data available but tends to produce mean values with a bias towards one side having thicker soft tissues than the other. This is most certainly a valid statistical observation. However, if a bias had not been present in the face of the individual being reconstructed or if it was present but was on the other side of the face, the forced enlargement because of the statistical bias would be misleading.

In the absence of any data on the nose-tip in the Rhine and Campbell (1980) tables, it is not possible to compare findings in this region. What can be said is that a nose constructed from the RSA data would be based on the data acquired from a carefully-defined and local sample of subjects rather than made from a general "rule of thumb".

B. THE PROFILE SYSTEM

The data from 55 subjects was displayed in the form of sets of polar coordinate pairs for hard and soft tissue profiles. A completed record sheet is in Appendix A6.

The data was organised with two goals in mind: to produce a standard face for the adult male Zulu and to calculate an estimated soft profile for an unknown skull utilising regression lines created from the data.

1. The standard profile

The standard profile is a composite of the standards or norms established for measurements between the 34 hard and soft tissue points of all the subjects. For example for point T1(a) four values were calculated: the mean skull angle, the mean skull distance, the mean soft tissue angle and the mean soft tissue distance. In the same way measurements for all the 34 soft and 34 hard points were reduced to mean values, a list of which can be found in Table 10.

Discussion

The bland androgenic standard face profiles produced from the sets of mean values for hard and soft tissue profiles above act as a form of neutral generic face. It is doubtful if any face could exactly fit the parameters set by the standard profile. As the collection of data recorded by this method grows, the profiles of the standard face will of course change. The standard face profiles act as a common yardstick for measuring and comparing other male faces either within the same sample, the Zulu race in

TABLE 10 - Polar coordinates for the Standard Face

Triple No.		Hard coordinates Angle	Hard coordinates Distance (mm)	Soft coordinates Angle	Soft coordinates Distance (mm)
T1	a	61.5	134.0	60.5	139.0
	b	54.5	131.0	54.0	135.5
T2	a	47.5	124.5	47.0	130.0
	b	43.0	120.0	42.5	125.5
T3	a	38.5	116.5	38.0	122.5
	b	34.0	112.5	32.5	118.5
T4	a	30.5	106.0	28.0	113.0
	b	28.0	103.0	26.0	109.5
T5	a	25.0	103.0	23.5	109.0
	b	21.5	105.5	20.5	110.5
T6	a	18.0	108.5	17.5	113.0
	b	9.0	104.0	13.0	118.5
T7	a	0.0	103.5	9.0	125.0
	b	0.0	103.5	3.5	128.5
T8	a	0.0	103.5	-1.0	120.5
	b	-3.0	102.5	-2.0	116.5
T9	a	-5.0	104.5	-3.5	119.5
	b	-7.5	109.0	-5.5	123.0
T10	a	-10.0	112.5	-7.0	128.5
	b	-12.5	117.5	-11.0	131.0
T11	a	-16.0	119.5	-14.5	126.5
	b	-18.5	119.0	-16.0	134.0
T12	a	-21.5	118.0	-19.5	136.0
	b	-23.0	119.0	-20.5	133.0
T13	a	-24.0	118.5	-22.0	131.5
	b	-28.0	119.5	-24.5	132.5
T14	a	-31.0	123.0	-27.0	134.5
	b	-33.5	127.0	-31.0	138.5
T15	a	-36.5	129.0	-35.0	139.5
	b	-39.0	127.5	-39.5	136.5
T16	a	-41.0	123.0	-43.5	129.5
	b	-46.0	106.0	-51.5	116.0

general, or the males from the same age group of any other race. They are also employed in the visual test discussed in Chapter 8.

2. The estimated profile

The reconstructionist is presented with a found skull and requested to remodel a soft face to it. It would be helpful if he could measure certain coordinates on the skull and then consult a table that would list the equivalent soft tissue coordinates from which he could construct a soft facial profile for that skull.

In an effort to investigate this possibility a system was devised to construct what was termed an "estimated soft profile". Ideally, one would measure distance and angle of any of the significant hard points from the centre of the measurement system and then derive the soft tissue distance and angle by consulting a linear regression line. In constructing such a line the soft values were estimated from the hard. The skull distance and angle became the independant or X-variable in each case. The two variables to be related were the two distances and the two angles. There was no need to cross relate angle to distance.

Bi-variate scattergrams were plotted from these values, examples of which are to be found in Figures 35 and 36.

The following information appears below both graphs: N, the sample size; R, the correlation coefficient; the P value, which if less than 0.05 indicates that there is a significant linear relationship between the variables; the regression line formula, the mean values for X and Y and their standard deviations. The regression line is of the form:

$$Y = \text{constant} + \text{regression coefficient} \times X$$

where Y is the tissue angle or distance, and X is the skull angle or distance.

The graph shows the relationship between the two values thus enabling the soft tissue point to be estimated. If this procedure is carried out for all the hard tissue angles and distances, a complete set of equivalent soft points can be estimated from the hard. The points can then be linked to form a soft profile.

Discussion

We will remember that Bookstein (1982) felt that coordinate pairs are not themselves good variables and thus are not conducive to statistical analysis. However, instead of draping a mean face over a highly individual skull,

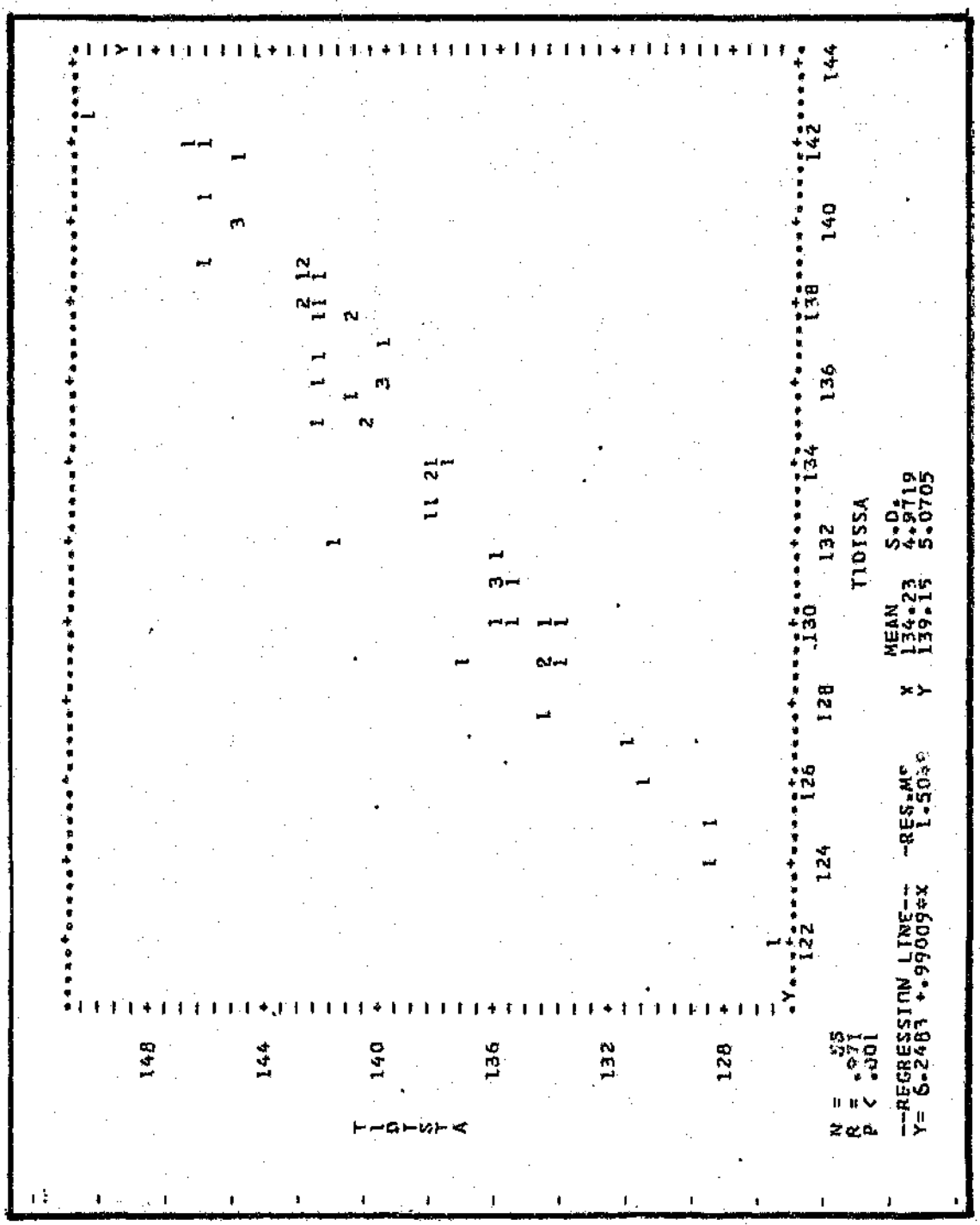


FIGURE 35 - Bi-variate scattergram #1.

Soft tissue distance (T1 DIST TA) of 1st point (T1) plotted against hard tissue distance (T1 DIST SA).

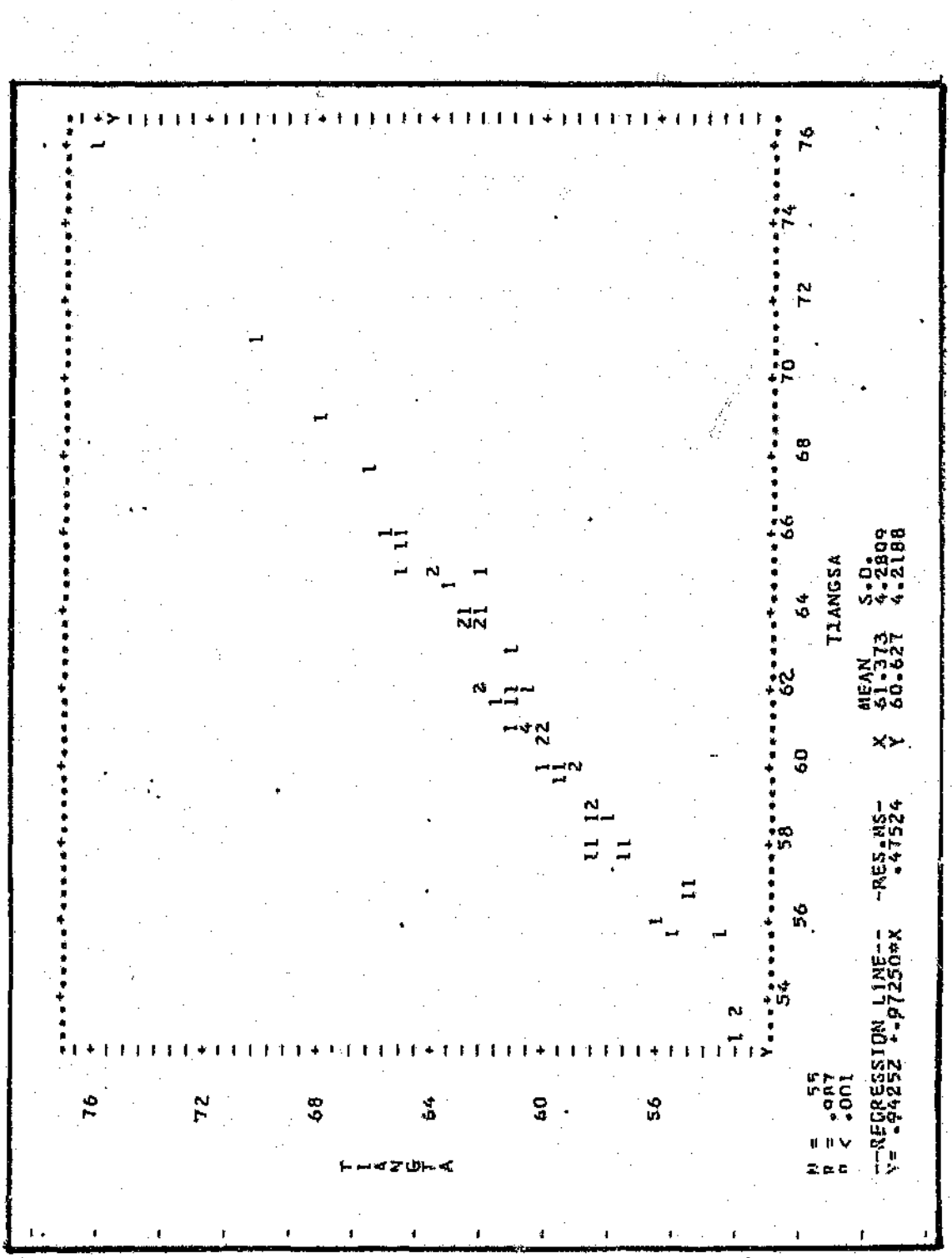


FIGURE 36 - Bi-variate scattergram #2.

Soft tissue angle (T1 ANG TA) of 1st point (T1) plotted against hard tissue angle (T1 ANG SA).

the idea of producing an estimated face profile is an attempt at finding a reliable relationship between the morphology of the soft tissues and their bony support. Its effectiveness as a reproducer of identity is examined in Chapter 8.

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CHAPTER VII

RESULTS: FACIAL RECONSTRUCTIONS

A. RECONSTRUCTION USING THE DEPTH SYSTEM

1. Reconstruction using RSA data (from this study)

In the past all reconstructions for the Southern African Negroid face have had to be based on the measurements of the American Negroid. A modified technique of forensic facial reconstruction using the increased data collected in the present study as seen in (Tables 4,5 and 6), and based on a method described by Gatliff (1984) will be briefly described. To assist in the visualisation of the technique the various stages are illustrated in Figure 37.

It is assumed that the found skull is that of a Southern African Negroid male aged between 20 and 35. The cleaned skull with its mandible fixed, is mounted on a sculpture stand. The eye sockets are fitted with acrylic artificial eyes (following the method laid down by Gatliff, 1984). A series of depth markers is cut from a balsa wood strip (2 mm x 2 mm cross section) to match the measurements in the table of tissue thicknesses. The markers are stuck onto the skull at the landmarks shown on the chart. Flattened strips of clay of 1 cm width with thickness ranging from

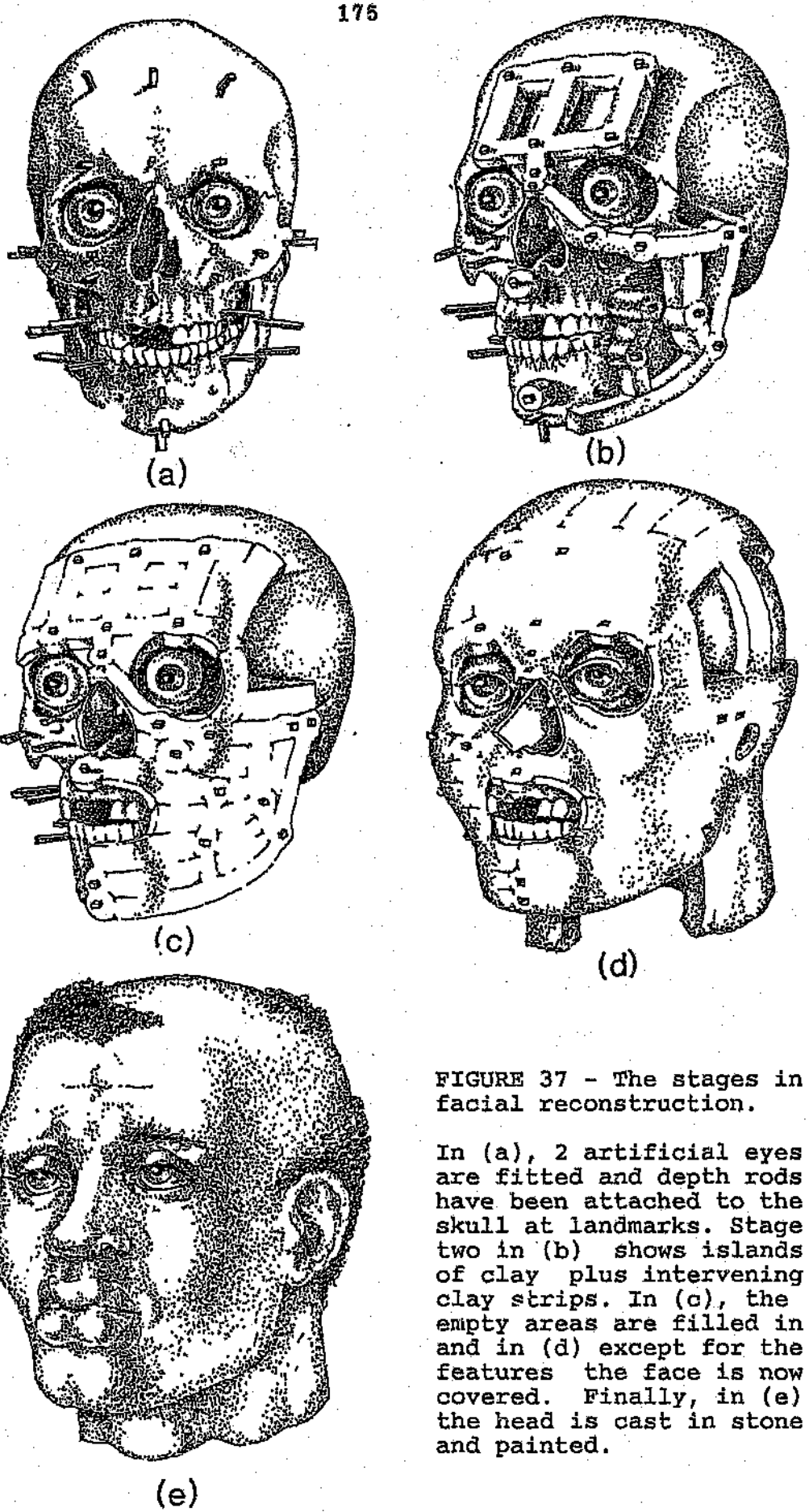


FIGURE 37 - The stages in facial reconstruction.

In (a), 2 artificial eyes are fitted and depth rods have been attached to the skull at landmarks. Stage two in (b) shows islands of clay plus intervening clay strips. In (c), the empty areas are filled in and in (d) except for the features the face is now covered. Finally, in (e) the head is cast in stone and painted.

the height of one depth indicator to the next are applied to the skull between the depth markers. Intervening empty areas are filled with clay and the surface of the face is smoothed off and texturised. Because in the past there was no information on tissue depth in certain areas like the lips and nose, the form of these features had to be modelled using the judgment of a sculptor, the advice of an anthropologist and the "rules of thumb" described by Gerasimow (1971) and Gatliff (1984).

A significant improvement can be made to the above method of facial reconstruction. A standard engineer's contour gauge is applied to the midline of the skull. The contour thus formed is traced onto a sheet of stout carding to produce a midline profile of the skull (Figure 38a). The carding is cut along the profile line dividing it into positive and negative profiles and the positive profile is discarded. Soft tissue depth measurements are marked off onto the negative cutout (Figure 38b) and the points linked to make a soft tissue profile. This is also cut out and this time the new negative profile is discarded. The remaining carding is a strip of varying width bounded on one edge by the skull outline and on the other by the soft tissue outlire (Figure 38c). The template is stuck to the skull where it acts as a guide to the placement of clay either side of the midline (Figure 38d). Once it has served its purpose it is removed and the gap is filled.

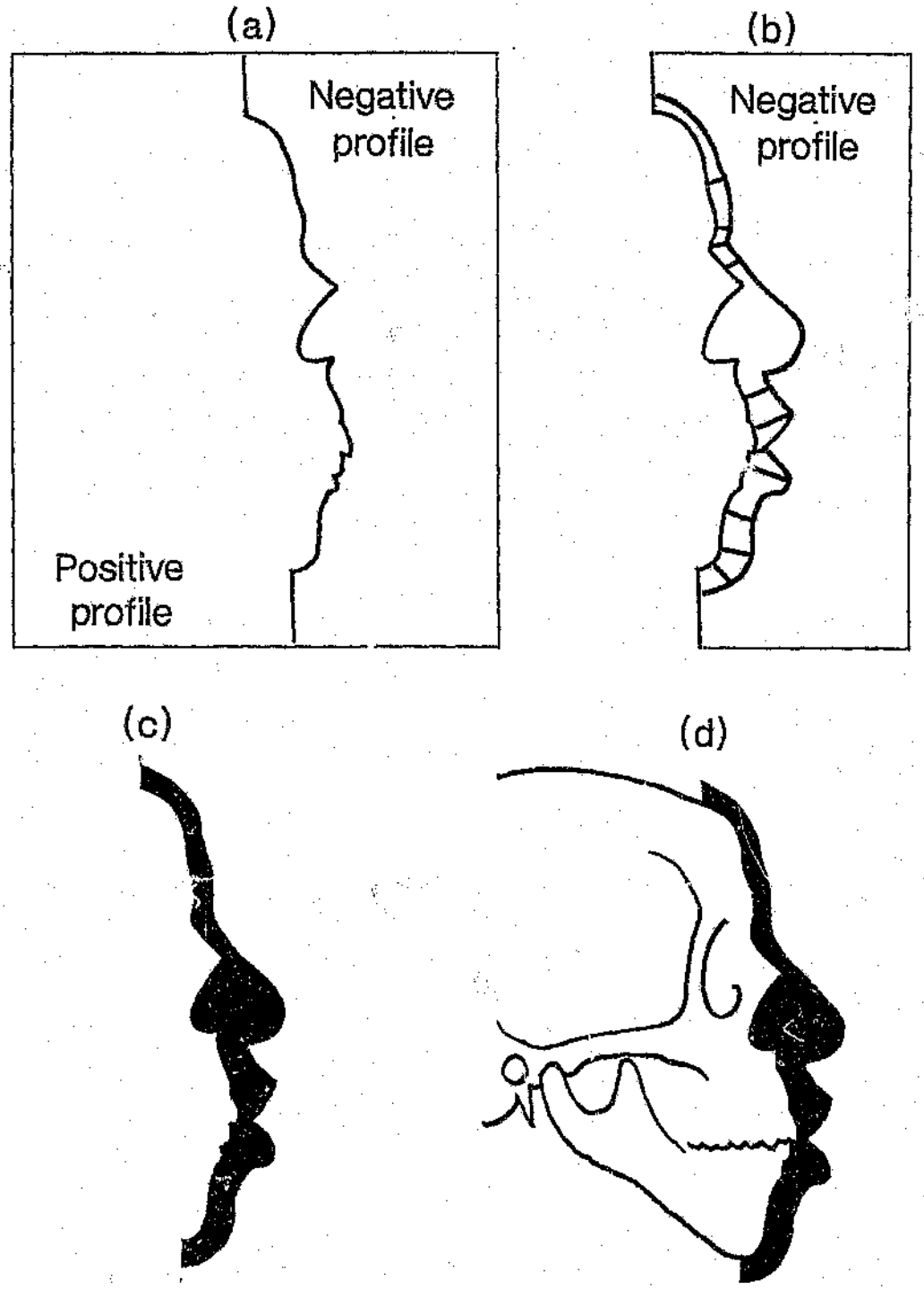


FIGURE 38 - Making the midline template

(a) the soft profile traced out on stiff carding.
(b) the negative profile plus depth measurements.
(c) the remaining soft tissue thickness template.
(d) the template attached to the skull's midline.

2. Reconstruction using USA data ("American profile").

In essence, the American Negroid soft tissue thickness measurements were applied to the South African Negroid skull.

The mean soft tissue depths of the USA Negroid soft tissues at the midsagittal plane were plotted onto the lateral profile of the RSA skull (drawn from the outlines produced by an engineer's profile gauge). The points were joined by lightly drawn straight lines and then converted to curves that were more in keeping with the expected shape of the soft profile. In the table of soft tissue depth measurements compiled by Rhine and Campbell (1980) there are no data for the thickness of the soft tissues of the nose. The nose had to be fabricated by depending on the judgement of the writer and the already mentioned rules of thumb. One of these for locating the position of the nose-tip was suggested by Gerasimow (1971). On the tracing a line was drawn tangential to the terminal third of the outline of the nasal bone and extended downwards and forwards. A second line was drawn upwards and forwards as the central axis to the anterior nasal spine. Where the two lines met was the estimated position for the tip of the nose. Another somewhat difficult point to estimate was the position of the lip margins. Although

there is a certain amount of information on the thickness of the lips in the tables there was no way of knowing the angle at which to build out the lip tissues. The complex undulating crease between upper and lower lips also had to be judged by eye.

B. RECONSTRUCTION USING THE PROFILE SYSTEM

1. Constructing standard profiles

The purpose here was to produce a pair of hard and soft profiles that would represent the average male Zulu skull and face. They were to be derived from the mean values of the hard and soft coordinates for all 55 faces. This was carried out in two stages:

a. Stage I

A clean sheet of A4 bond paper was taped to an architect drawing board and ruled with a horizontal line at mid-page. At 4 cm from the left edge of the paper a vertical axis was drawn to extend the full height of the paper. The intersection of vertical and horizontal lines was the centre of the measuring system and was labelled 'C', An ultra-thin (so as to reduce optical aberration) plastic geometry protractor graded in half degrees was positioned with its centre on C and its 0 degree line superimposed

on the horizontal line. It was taped to the paper. The half-degree divisions on the protractor read from 0 to 90 degrees upwards (a positive value) and 0 to 90 degrees downwards (a negative value). Maintaining the zero point over the centre of the protractor an equally thin ruler also graded to 0.5 mm was angled upwards and outwards to the right to measure off both the angle and distance of the first two hard coordinates. The point was marked and labelled. In this way all hard and soft points above and below the horizontal 0 degree axis were registered.

b. Stage II

The second stage of the transfer process was to connect the points to form two continuous profiles. The arc-determinator was positioned over the dotted outline and the three points of the first soft profile triple were located to lie on one of its many arcs. A pencil mark was made through the central hole onto the paper. With that as a centre an arc was inscribed that passed through all three points of the triple. When arcs are required that are outside the limit of the instrument they are for the purposes of facial reconstruction considered as flat and may be represented on the drawing as a straight line drawn with a ruler. By drawing all line-segments in this way the hard and soft profiles emerged as two continuous outlines (Figure 39). The spatiomorphic accuracy of this

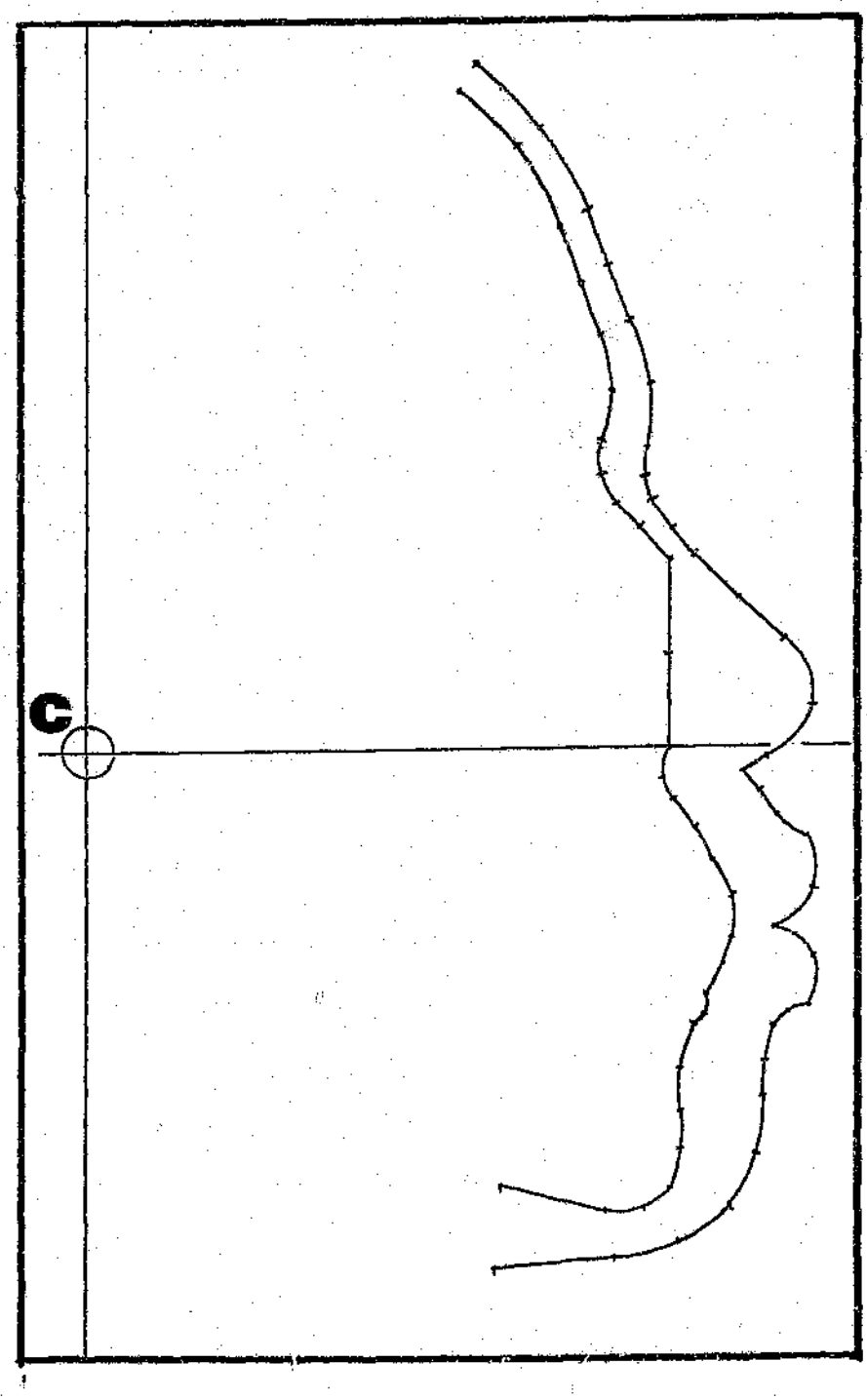


FIGURE 39 - The standard Zulu face (male Zulu).
Hard and soft tissue profiles.

system (within 0.5 of a degree, and 0.5 mm in distance) is perfectly adequate for the purposes of the present study.

? Constructing a mean profile

In reality, the forensic scientist is presented with a found skull of unknown identity. A face must be built for the skull. The data that are used to construct the standard face profile are now employed to create what is here termed the mean profile.

The unknown skull is placed in the cephalostat as if it were a patient. It is prevented from rolling backwards to seek its centre of gravity by locking the nasion rest in place. A radiograph is taken at an exposure setting that is appropriate for the density of the skull. The hard profile is traced off the cephalograph and the points along the profile are selected and marked in exactly the same way as with a test subject. For descriptive purposes this will be termed the tracing. At each bony point on the tracing a line is drawn across the paper, parallel to the EAMAC line. A photostat copy is made of the standard profile and a set of similar horizontal lines are drawn through its hard points. This will be called the photocopy. The tracing is now aligned over the photocopy to place the first hard point of the tracing over the first

hard point of the photocopy, at the same time ensuring that both the horizontal lines at these hard points are also exactly superimposed upon each other. The position of the first soft tissue point of the photocopy is now marked onto the tracing. This transposes the soft point from photocopy to tracing at the mean distance and the mean angle for that pair of standard points. All the soft points are plotted in the same way. The next stage, of linking the points is the same as described above in section B.1.

3. Constructing an estimated profile

The idea behind making an estimated face profile was that one could plot the hard tissue points and then from a set of regression lines (Table 11), predict the distance and the angular bearing of the soft tissue points. As with the standard face the main axes were drawn on paper and the centre of the polar coordinate measuring system was marked. The points for the hard profile of the unidentified skull were then plotted on paper in the same way as above. However, the procedure for marking the soft tissue points is somewhat different. A hypothetical example will serve to illustrate.

For the first hard point on the skull, T1:

- Let distance of the hard tissue point = 129 mm
- Let angulation of the hard tissue point = 62 degrees

TABLE 11 - Table of regression lines
(For estimating soft tissue distance and angle)
Note: Data marked (*) are used in the text as an example.

Point		Distance		Angle	
		Intercept	Slope	Intercept	Slope
T1	a	6.2483	0.99009	0.94252	0.97250*
	b	15.9430	0.91417	0.17261	0.98328
T2	a	8.2177	0.97813	3.25500	0.91581
	b	17.8500	0.89953	-0.39485	0.99544
T3	a	12.8800	0.94331	4.89250	0.85798
	b	19.8590	0.87774	-0.68822	0.94097
T4	a	24.5150	0.82615	2.95360	0.82111
	b	12.8750	0.93988	-0.26682	0.94020
T5	a	9.9608	0.96563	3.62990	0.79315
	b	7.7814	0.97713	-3.31550	1.12010
T6	a	12.3240	0.92887	-0.76276	1.02680
	b	24.9750	0.89971	4.44310	0.93140
T7	a	23.1720	0.98830	-	-
	b	23.0810	1.02210	-	-
T8	a	18.9890	0.98285	-	-
	b	25.5660	0.88725	-1.29600	0.20908
T9	a	22.0310	0.93240	-2.16760	0.26256
	b	26.4960	0.88444	1.01350	0.87933
T10	a	31.2990	0.86140	2.15520	0.90754
	b	33.7240	0.82608	1.37400	0.97206
T11	a	30.4590	0.80053	-1.18580	0.82365
	b	27.3320	0.89820	-3.19980	0.67532
T12	a	17.8730	1.00050	-4.21880	0.71401
	b	12.5460	1.00950	-3.88450	0.73258
T13	a	11.8160	1.01160	-3.89230	0.75022
	b	18.8120	0.95227	-4.75270	0.70681
T14	a	32.2380	0.82968	-8.97720	0.57723
	b	29.4900	0.86037	-4.80900	0.77971
T15	a	25.9120	0.88124	-6.33340	0.79647
	b	24.0320	0.88014	-5.54560	0.86871
T16	a	29.4780	0.81557	-4.00420	0.95698
	b	22.3610	0.88534	-6.29140	0.98471

What is needed for the position of the soft point is:

- The predicted distance of the soft tissue point
- The predicted angulation of the soft tissue point

Calculation

(1) The regression line describing the data represented in the scatter plot shown in Figure 35, was obtained by plotting the distances (for all 55 cases) of the first soft point (T1DISTA) against distances of the first hard point (T1DISSA). Below the graph, a soft point distance is represented by `Y' and a hard point distance by `X'. The former value can be derived from the regression line by knowing the hard point distance and then applying the formula:

$$Y = 6.2483 + 0.99009 \times X$$

(2)Therefore, in the example above:

$$\begin{aligned} \text{Soft distance} &= 6.2483 + (0.99009 \times \text{hard distance}) \\ &= 6.2483 + (0.99009 \times 129) \\ &= 133.97 \text{ mm} \end{aligned}$$

(3) Similarly in Figure 36, the soft tissue angle (Y) can be calculated by knowing the hard angle (X) and using the formula:

$$Y = 0.94252 + 0.97250 \times X$$

(4) Therefore, in the example above:

$$\begin{aligned} \text{Soft angle} &= 0.94252 + (0.97250 \times \text{hard angle}) \\ &= 0.94252 + (0.97250 \times 62) \\ &= 61.24 \text{ degrees} \end{aligned}$$

The estimated values for the distance and angle of the first soft point are transferred to paper by once again using the thin protractor and ruler. The coordinates for all 34 points of the soft tissue profile are similarly estimated from their own particular regression lines (taken from Table 11) and then transferred in similar fashion. In each of the profiles the triples are turned into shapes and the sequential shapes linked to form a continuous outline, again as described in Section B.1.

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CHAPTER VIII

RESULTS: VISUAL PERCEPTION TEST

To assess the values of the new profile system a visual test was devised to compare a real profile with profiles created by the new profile system and a profile made by the depth system.

A. CHOICE OF SYSTEMS FOR COMPARISON

In deciding which of the systems to use for comparison we need to ask ourselves three questions:

1. Which is preferable: continuous line information from the start or single depth information linked by lines?
2. Which are more reliable in creating the face profiles: geometrically constructed lines or hand-drawn lines?
3. Which are more appropriate in reconstructing a Zulu face: American Negroid measurements or Zulu measurements?

It will be remembered that the object of creating a new profile system was to display its advantages over the depth system and the reason for selecting the Zulu as a subject was to demonstrate that locally derived data were more applicable than data from another population group.

Bearing these factors in mind it was decided to compare the real facial profiles of five living subjects with facial profiles created for their skulls by three profile systems generated in Chapter 7: the American profile, the mean profile and the estimated profile.

The American profile was chosen because it was produced by a depth system using American Negroid data and it was hand drawn. These qualities are diametrically opposite to the probable answers to the three questions above. In addition it was considered important to decide which of the two profiles was better able to produce a resemblance of the real face: the mean profile or the estimated profile.

B. DESIGNING THE TEST

In essence, the test required that the three fabricated profiles be compared with the real profile of a face. The four profiles were to be presented as silhouettes to a group of viewers who would then be asked to indicate which of the three profiles most looked like the real profile. This same procedure was to be followed for five different faces.

In planning the test it was evident that the final proof of the success of a technique of this nature would lie in the visual assessments that are made by human beings. A

set of perception tests was designed that would require a "yes" or "no" type reaction and a simple form of recording the result. The test should allow for two different ways of looking at the profiles that were to be compared. The first involved an assessment of the whole profile. It is an overall usually instantly gained opinion which is often destroyed by deliberation. The second mode of evaluation is a more considered, analytical one. It is taken over time and logically processed. Although the analytical method may seem to be more thorough and therefore the method of preference there are sound reasons for including the overall method of assessment in the test.

It is well known that we are able to recognise someone at a distance. This is probably because the larger parts of the person's face are arranged in a characteristic configuration and no matter from which angle we may view the person they jog our memory. Thom (1975) tells us that though a given object can exist in different guises, we never fail to recognise it. Similarly, though with the opposite result, we could mistake a person for someone else if we happen to be short sighted, but only if the two people have the same general assembly of the large components. Another aspect to this type of recognition is that it is instantly processed. This unity of all the individual parts of the face into a whole is what occurs when someone exclaims "I recognised him at a glance". In

the word "glance" we understand two essential qualities that describe this method of assessing the total profile: overall and rapid. This primary opinion is a strong one and could also be the way a viewer may gain a first and often persuasive judgement of a reconstruction.

Since the object of the visual test was to evaluate an outline it may be felt by some that line drawings should have been used instead of a solid silhouette. Powell and Rayson (1962), Merrifield (1966) and many other workers have evaluated the face profile for its aesthetic value. In this study it was decided to utilise face silhouettes. Berg (1970) produced cameo profile cards for his patients as records of their facial contours. De Smidt and Dermaut (1984) used silhouettes minus the hair style and neck in 27 profile photographs presented for testing profile preferences. Barrer and Ghafari (1985) also preferred using silhouettes. They feel that the silhouette is better than a line drawing. It is easier to relate to and has more of a human shape since it is much like a shadow or a face outlined against the light. They concentrated on the face profile between the hairline and chin (as in the present study) and agreed that the use of a profile eliminates the need for information on skin and hair colour, hair style, make up, expression and even some of the effects of time. The only difference in the present study was that as with the study done by Lines et al. (1978) the

choice was for a white silhouette on black instead of a black one on white. Hershon and Giddon (1980) employed a useful modification in their tests. Subjects were asked to adjust four horizontally moveable face components (the forehead, nose, lips and chin) into what they felt was a simulation of their own profiles, after which they were required to construct an ideal profile. This modification was used to advantage in the second part of visual test in this study (see Chapter 8).

C. DRAWING THE PROFILES

Five adult male Zulus, all within the parameters set by the sample, were selected as subjects for the test. Tracings were made off their lateral cephalograms of hard and soft tissue profiles. These were photostatically reduced by 11 percent to account for magnification. Three photocopies of each hard profile and one of each soft profile were made. A method of making a set of four profiles for a single case will be described. The same procedure was adopted for all five cases.

1. Making the real profile

A photocopy of the real soft profile was cut out to form a silhouette, running from hairline to chin. This was stuck onto a black mounting card.

2. Making the American profile

On one of the hard profile photocopies a soft profile was drawn using the mean tissue thicknesses of the American Negroid (taken from Tables 7,8 and 9) using the method outlined in Chapter 7. The resulting soft profile was traced off onto white paper, cut out and mounted onto a black background.

3. Making the mean profile

The mean readings from the standard soft profile were used to create a mean profile (made by the method outlined in Chapter 7 and the readings from Table 10) for the second tracing of the skull. This was constructed on the second photocopy and also converted into a white silhouette mounted on a black background.

4. Making the estimated profile

Onto the third photocopy of the skull profile an estimated profile was made, calculated and drawn by the technique described in Chapter 7 and using the data from Table 11. It too was cut out from white paper and mounted on a black card.

5. Making the test booklet

Reduced photocopies were made of the four silhouettes on their black backgrounds. These were pasted onto a common A4 sheet of white paper in two horizontal rows (Figure 40). The top row of four profiles was unaltered. In the second row the four profiles were divided by horizontal lines into four feature modules of forehead, nose, lips and chin. All five test cases were handled in the same way. The five pages, one of each test case, were stapled together with a coversheet to form a booklet.

D. SELECTING THE TEST SUBJECTS

Much has been written on the type of test subject to use for visual perception tests. Nordby (1992) tells us that no two observers see the same thing, even though their eyesights are normal and they are aware of the same artifact. Burstone (1959) and Goldman (1959) asked artists to judge their results and Riedel (1957) and Peck and Peck (1970) used the general public. Sushner (1977) felt that the concept of beauty is subjective enough that Blacks should have facial standards of their own. Thomas (1979) decided to use both Black and White subjects to assess the aesthetics of their profiles. Foster (1973) found no significant difference between the scores of the various groups of people who participated in the investigations.

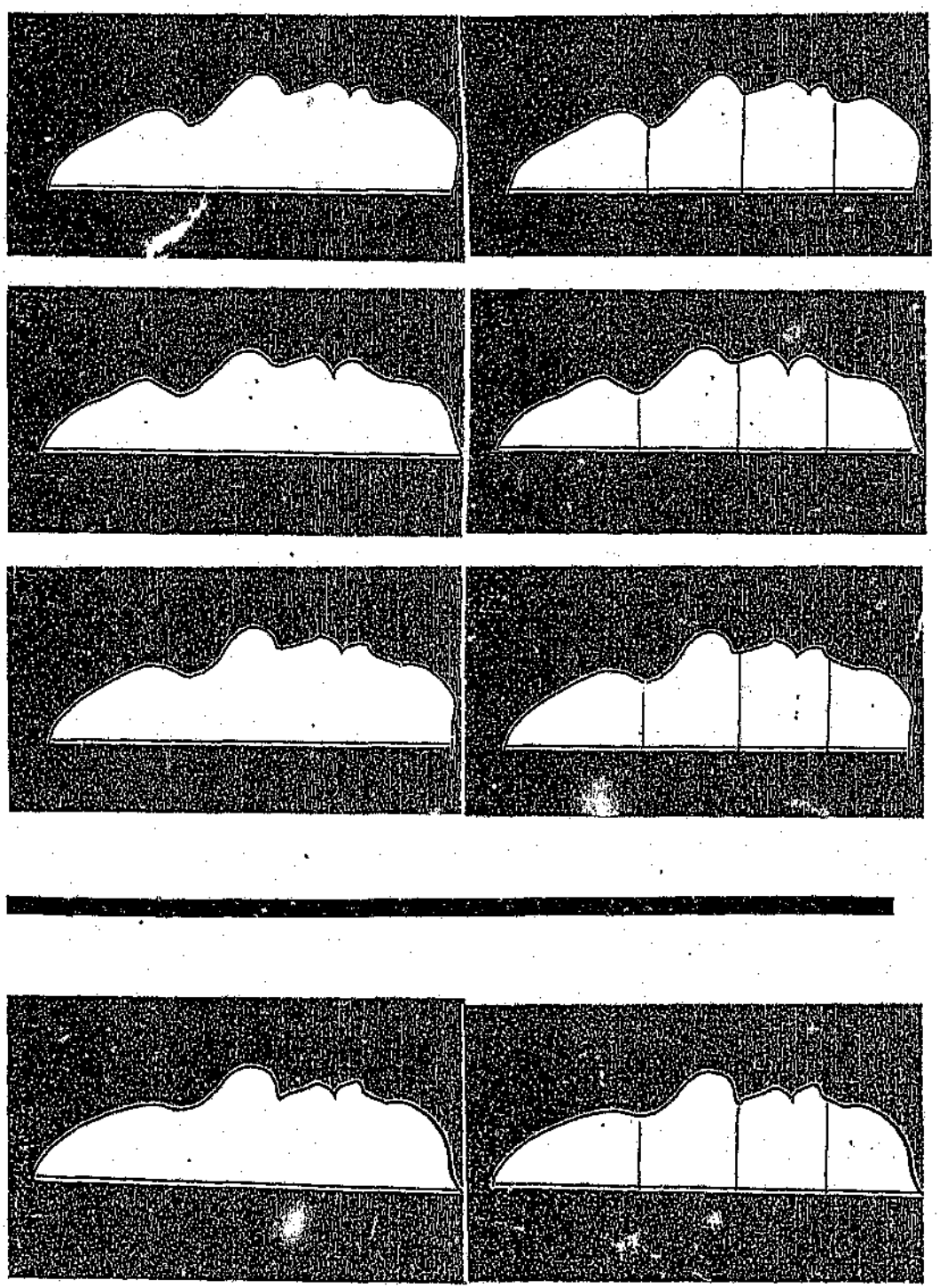


FIGURE 40 - Example of the visual test sheet

(see the text for a full explanation)

Lines et al. (1978) decided to make use of professional people divided into three categories: moderately trained subjects for example orthodontists; slightly trained subjects such as oral surgeons and untrained subjects like dentists, students and non-professionals. Rayson et al. (1971) found that in subjective evaluation, reliability existed when several dentists used the same evaluative characteristics and their results were averaged. Cox and van der Linden (1971) used a combination of ten orthodontists and ten lay persons to judge silhouette photographs and found a sound agreement between the two groups. Albino et al. (1984) discovered that a patient's perception (or for that matter a layperson's perception) and a dental or professional perception were somewhat different. They noted that a patient's view was characterised by attention to narrow aspects of appearance and at the same time by a global sense of acceptability or non-acceptability.

This latter observation fits in well with the two modes of assessment mentioned above, namely the overall assessment and the analytical analysis. Because of this and since most people judging a facial reconstruction are likely to be non-professionals, young male and female pupils of mixed race, in the same class and aged between 15 and 16 years, were selected to take part in the visual perception test. All scholars were studying art, science or both subjects together.

E. CONDUCTING THE TEST

The pupils were told that the purpose of the test was a series of comparisons of silhouetted profiles of faces. The method of conducting the test was clearly explained beforehand and the way they should score the sheets was demonstrated on a mock-up sheet of profiles not included in their booklets. The pupils were assured that except for the real profile, which was always to be found on the left of the page, the other faces for comparison on the right were layed out in random order. They were therefore not to waste time by looking for a pattern for the positioning of the faces. Their only task was to decide which of the three face profiles on the right of the sheet most closely resembled the real profile on the left of that sheet and to register their answers by placing a cross inside the white silhouette of their choice.

It was also explained that in the top row of profiles they were to carry out an overall and rapid scanning and should record their first general impression of which face was best. It was impressed upon them not to linger and become critical. The bottom row of faces that were subdivided were the faces that were to be subjected to analytical scrutiny. Each feature module was to undergo examination and be marked accordingly. This meant that every page had to eventually have five crosses on it as

it was not permitted to omit a profile. Although they were not allowed to alter their snap decision in the upper row, the marks in the bottom rows (since they were the result of critical analysis) could be erased if made in error and a new decision could be recorded. The viewers were afforded a reasonable time in which to make their choices whereafter their forms were shifted one to the right so that the scholar on the right could check his classmate's paper for any omissions. The last person on the right of the row handed his paper to the first person in the same row. At the end of the session the papers were collected and those with omissions were given back to the scholars concerned to be revised under the same conditions as the test. Although this took up a bit more time it reduced the number of spoiled papers which in any event was a mere 1.2 percent.

F. RESULTS OF THE TEST

Table 12 summarises the results of the visual perception tests carried out on 114 pupils. The raw data are the values in each block of the table. They represent the number of decisions made by the pupils for any one profile in all of five different faces. They were numbered by their case numbers 18, 24, 37, 42 and 44. Every pupil was allowed only one vote for any choice that they made. In the case of the undivided face they could vote once

TABLE 12 - Results of the Visual Perception Test

(for explanation - consult text)

CASE:		18	24	37	42	44
TOTAL FACE	A	106	45	56	36	98
	B	5	1	50	64	12
	C	3	68	8	14	4
FOREHEAD	A	93	8	40	51	56
	B	0	5	55	53	39
	C	21	101	19	10	19
NOSE	A	87	32	44	13	80
	B	9	10	8	50	25
	C	18	72	62	51	9
LIPS	A	80	55	35	49	92
	B	15	0	77	56	19
	C	19	59	2	9	3
CHIN	A	35	70	22	25	81
	B	70	4	75	76	24
	C	9	40	17	13	9

KEY:
A = mean profile
B = American profile
C = estimated profile

for only one of the three methods. In the subdivided face they could again only make one vote each, for the four subdivisions for any one of the three methods. The underlined values were considered to have been the winners.

The letters A, B and C respectively (Table 12) represent the mean profile, the American profile and the estimated profile. Looking at the total face only, we see that for faces 18 and 44, profile A has scored well. In the case of face 37 both profiles derived from mean values, that is the mean profile and the American profile (A and B), have similar scores. However, profile A still wins. The other two wins in the total face are profile C in face 24 and profile B in face 42. The final score then is three for profile A and one each for profiles B and C. Based only on these five observations the tendency would be to claim that the mean profile is best as far as the total face is concerned.

In judging the subdivided face there are four categories to consider, forehead, nose, lips and chin.

Looking at the forehead there are two big winners. They are profile A in face 18 and profile C in face 24. The rest of the scores all seem rather marginal. Profile B had similar scores for faces 37 and 44 and were close to the score for profile A in face 44. It appears from these

three scores that there is not much to choose from here. However if one were to select one of these three profiles it must again be profile A, for two reasons. It had a marginal win in face 44 and a marginal defeat in face 42.

As far as the nose is concerned there were again two good victories for profile A in faces 18 and 44. Profile B seemed not to do too well in the first three faces though it vied for a win with profile C in face 42. In fact profile C did quite well in faces 24 and 37 and attained a marginal win in face 42. Thus profile C preformed better in three cases and profile A in two. If a choice were to be made based on this sample of five faces the preference would have to fall on profile C.

In the case of the lips there were two strong victories for profile A in faces 18 and 44. Profile B had a good win in face 37 and a marginal one in 42. There is only a marginal win for profile C over profile A in face 42 thus making little to choose from between the two profiles. On looking at the score for profile A in this category there is also not that much difference between the scores for profiles of A and B, in face 42. Once again, the two out-right victories plus the two marginal defeats of profile A make it the profile of choice for the lips.

Finally, on inspecting the data in the chin category, it can be seen that there were three quite healthy victories for profile B (in faces 18, 37 and 42) as opposed to two equally healthy wins for profile A in faces 24 and 44. If we were to make a choice based on this sample only it would lean towards profile B. Here is a good example of a situation that could easily be changed by an increase in the test sample size.

The final score in this test shows the following preferences:

Whole face:		- profile A (mean profile)
Subdivided face:	forehead	- profile A (mean profile)
	nose	- profile C (American profile)
	lips	- profile A (mean profile)
	chin	- profile B (estimated profile)

Counting the wins only it can be seen that the mean profile scores the highest of the three.

G. DISCUSSION

In evaluating the results, the value of a "win" must be examined. A win does not necessarily have to be a big one to be of value. A "marginal victory" or even a "marginal defeat" have distinct inferential values. Also, a posi-

tive score for a profile does not imply that the profile looks just like the real face. It merely informs us that the pupil is of the opinion that the profile he has just scored looks more like the real face than do the other two profiles. This type of evaluation is quite acceptable. If the test were to be constructed to decide which profile looked like the real face, it may well have got no scoring. No matter how good a reconstruction is, there will always be some difference of opinion as to exactly what constitutes a likeness.

Refering to the scoring above, it will be seen that there was a preference for the mean profile. Yet the scoring of the subdivided profiles indicated that no one technique was best at rendering every feature. This is significant as it suggests that until our databanks of faces recorded in this way are fuller, we could perhaps combine methods. In so doing we may find that specific methods may be more successful for certain parts of the face, or even for certain types of face. This thought gave rise to the construction of a composite face (see section H).

The estimated profile was a mathematically derived one and so could have been expected to give the best results. It did not. Once again we must realise that statistics based on single entities are not what we should be examining. It is probable that there will be the occasional

face where the estimated profile will produce the best results. This will most likely occur in those skulls that most closely resemble the standard skull. Where the estimated profile did do well was in the case of the nose. Possibly by using statistically estimated values, some structure was brought to the nose. In estimating the nose we made provisions for subtle variations in that particular face. Whatever variations are found, they are going to be different for every skull and that information is going to be taken into account every time the nose is estimated. The mean nose on the other hand is likely to look the same in every case. This value in itself may be a good enough reason to include the estimated profile in a combination of the systems.

It was evident that the faces based on mean values in all cases showed the best results. The RSA profile did better in all likelihood because it was derived from local data. If the number of times in which the American face was the winner is examined, it will be seen to be by far in the minority, whereas those that won were the RSA profiles, irrespective of whether they represented mean or estimated profiles. The overall points winner however was the mean profile.

H. FURTHER CONFIRMATION

For the sake of interest only, the tracings of the fabricated profiles were superimposed over those of the real face profiles to determine which full profile of the fabricated face profiles best matched the full real face profile, and which individual feature of the fabricated face profiles best matched its equivalent in the real face profile. The results confirmed those of the student visual tests both in the choice of full profile and part profiles.

Although not forming part of the visual test it was decided to construct a composite profile, built up from the assembled parts of those features from each fabricated profile that had performed best. A sheet of tracing paper was placed over tracing A (the real Profile) and the forehead traced out from hairline to down to the dip at the soft tissue nasion. To this tracing were added the nose from tracing C (the American profile) the lips from tracing A again and the chin from tracing B (the estimated Profile). The resultant composite profile is compared to the drawing of the real face profile in Figure 41.

Quite clearly, at least until our databanks are fuller, the composite profile appears to have no advantage over any of the other fabricated profiles. When it was super-

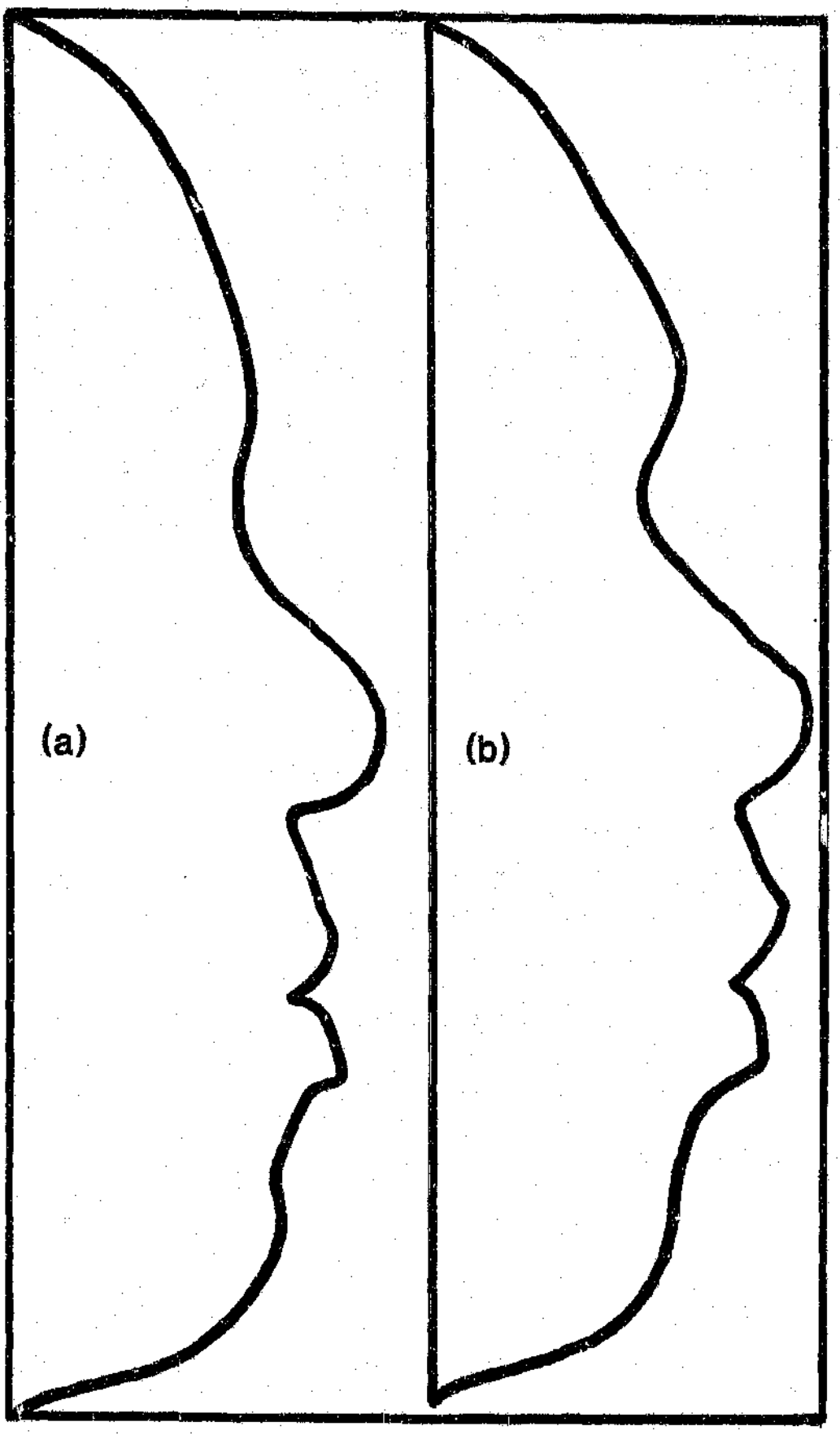


FIGURE 41 - Comparison of Real and Composite profiles

The real profile (a) is on the left and the composite profile (b) on the right

imposed over the real face profile it had a similarly poor fit. This should not act as a deterrent. On the contrary it supports the view that it is the general assembly of the face that is of importance in identification. It is certainly of greater value than the sum of the parts. This summative effect supports the theory of "Gestalt" (the common German name for shape or form) as it applies to perception in the world of art. It once again lays stress on the fundamental need to investigate underlying structure and relative positioning.

I. CONCLUSIONS

It general it was felt that a geometrically created continuous profile generated by the profile system using RSA data, was preferable to a profile that is hand drawn from single depth measurements taken from the American Negroid when it came to reconstructing an adult male Zulu face. The mean profile was considered the overall best at producing an identifiable face. None of the systems evaluated by the test have in themselves all the answers that were sought. Indeed this test was not expected to isolate any one system as being the best. At this early stage it was designed to reveal just where the strong points and weak points of each of the systems occur. Suggestions for improving the test can be found in the next chapter.

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CHAPTER IX.

SUMMARY, CONCLUSIONS AND SUGGESTIONS

A. SUMMARY

1. The depth system

The depth system had its deficiencies: the landmarks for the collection of data on the face (they were too few and not always at a significant site); the type of data (they were distance measurements with no angular readings); and the method employed for establishing outlines of the soft profiles (artistic retouching can permit the introduction of error). These shortfalls of the depth system somewhat lessened its value especially when it was compared to the profile system. Despite this the depth system of facial reconstruction has been used for many years and in many cases quite successfully.

What can be claimed is that because of the present study the depth system has now been enriched: there are extra standards available for difficult areas such as nose and lips; the data have been acquired from living subjects; and we now have standard measurements for the adult males of a local population group. Should taxonomic comparisons of facial tissue thicknesses need to be made between the various race groups, the data from this study can be used

since many of the landmarks are the same as those used in other studies.

2. The profile system

The standard profile has two values. It is a standard against which faces of the same group of people can be compared, and it is the origin for a mean profile which can be adapted to a tracing of the b[illegible]le of an unidentified skull.

The mean profile also has valuable attributes. It can be incorporated into other depth systems in present use. For example it can be turned into a cardboard cut-out which can be stuck to the midline of a found skull, where it acts as a continuous depth indicator for modelling the soft tissues in that plane. The mean profile keeps to the middle path of soft tissue depths, neither leaning too heavily to excess nor to deficiency. This concept is in keeping with the cautious approach of forensic facial reconstruction.

It has already been mentioned that Bookstein (1982) feels coordinate pairs are not by themselves good variables and therefore not conducive to a statistical analysis. This view is supported by the writer. However, it should be clearly pointed out that the points used in this study

are not the same points referred to by Bookstein, namely single and isolated meaningless anatomical landmarks. They are points that may not have value as singularities but have become powerfully descriptive when combined into groups (as in the case of triples). The coordinate pairs for a single landmark describe the position of one point in space or one point along a line. The triple, however, is a collection of coordinate pairs that together create a formula for a shape.

It is the shapes we should be manipulating, transforming and comparing, not the points.

Newman and Sproull (1981) point out that any scheme for modelling curves and surfaces should be mathematically tractable, computationally convenient and economical of storage. The arc-seeking system used in this study meets those requirements most satisfactorily.

The outcome of the visual test summarises and underlines the value of this study. It points out that there is distinct merit in using the mean profile. The mean profile was rated higher than the estimated profile, in all probability partly due to the wide variation in soft tissue thickness and partly due to a small sample size. In time as the databank of information increases it is possible that the estimated profile will be far better able to

predict facial shapes. In that case it may well replace the mean profile. However, until that time the mean profile will remain a useful and safe alternative.

B. CONCLUSIONS

1. The accuracy of diagnostic ultrasound in measuring the thicknesses of the facial soft tissues and the known accuracy of radiography as a measuring instrument have been shown to be equally matched.

2. Employed as a combined mensuration system radiography and ultrasonography have yielded information on the depth and shape of the soft integument of the face of a nature that has not before been acquired with needle-puncturing techniques. It can be concluded that this combined system has a place as a valid research tool for measuring soft tissue depths in the face.

3. A table of mean soft tissue depths of the male Zulu face has been compiled. This was compared with a table of similar measurements on the American Negroid. Comments were made in an attempt to explain the differences of the measurements at similar landmarks. This relationship will alter as the sample size increases. The comparisons made between the data of this study and those of the American study showed that the former was better controlled, more

appropriate to the living, and yielded a wider range of information. It was also considered more applicable to the Southern African Negroid, and in particular the young Zulu male.

4. The new profile system was described for recording the hard and the soft profiles off the lateral cephalogram. It was able to capture, record and reproduce those coordinates that are significant for describing the shape of the profiles in a simple and effective manner.

5. From the data collected a set of standard hard and soft face profiles has been derived.

6. Methods for plotting a mean profile and for calculating an estimated profile for a found skull have been suggested.

7. Fabricated profiles were subjected to a perception test of visual comparison with the real profile and the results were evaluated. From the test results it can be safely concluded that the profiles that were the most successful were the RSA profiles whether they were made from mean values or estimated values. This in itself justifies why new South African standards were necessary. In the light of the above is felt that the aims of this

study have been successfully accomplished. A proposal is advanced that funds and research opportunities be made available for the further investigation and expansion of these standards.

C. SUGGESTIONS FOR FUTURE STUDIES

In all future studies the maximum efforts must be made to keep the sample as genetically pure as possible. As an example, in studying the Zulu not even members of closely related tribes like the Swazi, the Ndebele or the Xhosa were accepted for the sample. Extremes in weight and size and any abnormality in shape or health are of necessity strong excluding factors in future primary studies. At a later date when core standards have been formed secondary studies can always incorporate extremes and combinations.

The most comprehensive method of collecting information is of course the imaging of the whole head and neck complex. This total evaluation of the craniofacies in order to capture structure and surfaces has already been accomplished by the use of computed tomography and magnetic resonance imaging. The number of data points for describing shape entrapped in collections of information such as these is enormous. In 1988 the writer conducted a study at the Research Institute of Biophysics (at Tygerberg Hospital in the Cape) to investigate the use of magnetic

resonance imaging for profile capture. The images that were gathered were ideal sources of the joints and control points mentioned in this study. The address of any datum point can be located in space by the instructions embedded in the three polar coordinates: two angles and a distance from the centre of the measuring system. With the image capture afforded by MRI these coordinates can be reached for in any direction desired, outwards from the geometrically positioned head center which is conveniently registerable by MRI. The coordinates in three dimensions can be cross related through the use of computer graphic functions, thus allowing the simulation of three-dimensional form. A computer programme is already in the making for just this purpose.

At the outset it is evident that the more data we gather the finer will be the image. However we should cautiously guard against the mistaken belief that if we were armed with the coordinates of all the tissues in the head (an impossible situation anyway) we would automatically be in a position to understand the spatial relationship between soft and hard tissues. In order to create a characteristic resemblance of a face we must understand just what feature goes where. An accomplished artist knows it is not <u>how much</u> detail you draw that captures likeness, but <u>what</u> you draw and what you <u>leave out</u>. If we can transpose this selective attitude to the present study: it is not

the amount of data collected that is important but the type and location of data, rated as being significant, that matters.

Further caution should be exercised when we aim studies at establishing mean values for faces. There is no such animal as a mean-valued human being. Admittedly the mean gives us a starting point from which to work, but Man in all his variety should preferably be seen as fitting into ranges of measurements or similar groups of appearances. Zylinski et al. (1992) support this when they advise us that a "range of values, rather than means, should be used in clinical cephalometric evaluation".

In order to determine just what are significant data and what are not, we require a better understanding of the mathematical rules that determine the structure of the smaller shapes composing a feature. We must also uncover the factors that govern the spatiomorphic relationships between features, thus enabling us to fit the shape of a subfeature into that of a feature and a feature into the face. It will be then that we will begin to understand identity. It may well surprise us to find that the amount of data we require to plot the basic underlying rules of structure, giving rise to and supporting the topological contours of the soft part of the face, is very little. That is with the provisor that the information we stalk

is the correct information. It is often seen in sculpture that a few critically placed lines, lumps or dents can "pull" the face together. Essentially we require surprisingly little visual information to prod the visual memory into recognising a face.

It is suggested that an improvement in the use of visual perception tests, would be to ask candidates to rank the silhouette profiles in order of their preference rather than requiring them to elect a winner on a single vote. If further expanded and honed this test could act as a model for future testing systems of this type.

The powerful role of the computer in this type of work cannot be overemphasised. Without the computer a spatial investigation of this type would be not just formidable but veritably impossible. In fact, in the future it could be the scientist using his computer who will produce an acceptable rendering of the human face.

Finally, if the end result of all future work of this nature still only achieves one purpose, that of narrowing down the number of suspects in a missing persons list, it will still have accomplished a valuable function. Perhaps this fundamental goal is not as elusive as we think.

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GLOSSARY OF TERMS.

Most of these terms have been defined in consultation with the works of accepted authorities like Stewart (1936), Hrdlička (1947), Montagu (1960), Krogman (1962), Martin and Saller (1962), de Villiers (1968), van der Linden (1971), Salzmann (1974), Jacobsen and Jacobsen (1980), Rakosi (1982) and Rogers (1984). Some are terms coined by the writer for defining new landmarks or to give a more descriptive name to a set of circumstances. Others are short descriptions or explanations. Unless otherwise stated any reference to position is related to the Frankfort Standard Horizontal plane.

****

A-mode: The mode in which the ultrasound probe is used to register singular probings and depth readings of changes in tissue density.

A-Point: See Subspinale

Acanthion : Salzmann (1974) simply defines the acanthion as the tip of the anterior nasal spine. The acanthion is the summit of a peak of bone formed by the meeting in the midline of the curved lower borders of the pyriform aper-

ture, the forward prolongation of the upper border of the vertical plate of the palate, and the upward sweep of the raised midline crest of the intermaxillary suture.

Ala-tragus line: This is the external equivalent of what is called Camper's line. There seems to be some confusion over the exact location of this line. The Glossary of Prosthodontic Terms states that it is the line from the inferior border of the ala of the nose to the superior border of the tragus of the ear. Spratley (1980) claims it runs from the centre of the ala to the centre of the tragus. Ismail and Bowman (1968) refer to it as the line between ala of nose & the centre of the tragus. Van Niekerk et al. (1985) defined the ala-tragus line as running from the base of the ala to base of the tragus. Spratley's modification is used in this study.

Anterior nasal spine: The median, sharp bony process of the maxilla at the lower margin of the anterior nasal (pyriform) aperture (see Acanthion).

Attenuation: The reduction in beam intensity occuring with depth in tissue, caused by absorption, scattering and beam divergence.

B-mode: The method in which the ultrasound probe is used to produce continuous scans of tissue configuration.

B-Point: See supramentale.

Camper's line: Defined by Salzmann (1974) as a line from the tip of the anterior nasal spine (acanthion) to the external auditory meatus. It is called the EAMAC line in this study and should be understood in conjunction with the definition of the external ala-tragus line of Camper as modified by Spratley (1980).

Camper's plane: The tip of the anterior nasal spine (the acanthion) to the centres of the bony external auditory meatuses on the right and left sides.

Central Data Point (CDP): Is a point on the surface of the skin of the face that is a landmark for ultrasonic depth measurement.

Centric Occlusion: Centric occlusion is a static position. It is the extreme or maximum occlusal and incisal contact position of the teeth in the maxillary and mandibular arches.

Cheilion: The lateral terminus of the oral slit, ie. the outermost corner of the mouth aperture.

Contour: The path described by a line travelling over the surface of an object.

Form: The three-dimensional bulk of an object described by its outer surface (compare this to the two dimensional description of Shape).

Frankfort Horizontal Plane: Although involving both orbitales in it's original concept, the Frankfort Horizontal Plane (alternatively Frankfort Standard Horizontal, FSH) has become accepted as the plane passing through both porions and the left orbitale.

Glabella: The most anterior point in the median sagittal plane of the bony prominence joining superciliary ridges.

Gonion: The most lateral external point of the junction of the horizontal and asc ding ramuses of the mandible.

Infradentale: The highest interdental point on the alveolar mucosa between the mandibular incisors.

Interface: The contact surface formed by the juxtaposition of two different media or tissues, for example muscle and bone.

Inter-porionic axis: The transverse line joining both porions. Also termed the bi-porionic axis.

Median sagittal plane: Often called the median plane or mid-sagittal plane, it is the plane which passes through the mid-point of the fronto-nasal suture (nasion) and both extremities of the sagittal suture. In some cases owing to asymmetry of the cranium it may not be perpendicular to the other cranial planes.

Menton: The lowest point on the chin from which face height is measured. It is somewhat forward to gnathion.

Nasion: The mid-point of the fronto-nasal suture.

Nasospinale: The point at which a line tangent to the lower margins of the pyriform aperture is intersected by the mid-sagittal plane, or the midpoint of the anterior margin of the pyriform aperture at the base of the anterior nasal spine.

Orbitale: The lowest point on the inferior margin of the orbit.

Piezo-electric crystal: A crystalline material such as quartz, that oscillates in unison with the changing polarity of an electrical signal applied to it. The crystal vibrates mechanically, producing sound waves of identical frequency to the electric signal.

Pogonion: The most anterior midpoint of the bony chin.

Porion: The highest point on the superior margin of the bony external auditory meatus.

Pronasale: The most anterior point of the nasal apex.

Prosthion: The lowest interdental point on the alveolar mucosa in the median plane between the maxillary central incisors.

Pulse-Echo: The rapid vibration of the transducer face for three to five cycles produces an emitted pulse, the "pulse-echo", which is received by the same transducer after a time delay.

Regional Data Point (RDP): One of four points, positioned superiorly, inferiorly, distally or mesially to the central data point, and 5 mm away from it.

Rhinion: The lowest point on the internasal suture.

Sella: This is the cephalometrist's term for the centre of the sella turcica as seen on the lateral cephalometric radiograph.

Shape: A perceived two-dimensional area separated from its surroudings by its perimeter, whether that be defined by a change in value, colour or texture (see Form).

Soft-tissue Glabella: This is the most prominent midline point on the skin surface between the eyebrows, lying superficial to its bony counterpart on the frontal bone.

Soft-tissue Gonion: Difficult to locate, it is determined by palpation. It is the most lateral point at the mandibular angle on the skin surface directly superficial to the bony gonion.

Soft-tissue Nasion: This is a midline point in the dip between the bridge of the nose and the forehead. It is located more or less over the bony nasion, at the root of the nose. Hrdlička (1947) claims the point to be always above the line that connects the two inner canthi. It is perhaps conveniently located by the method described by Montagu (1935), namely, lying in the mid-line on a line joining the upper limits of the two upper eyelid folds.

Soft-tissue Orbitale: Identified by palpation and lies superficial to the bony orbitale.

Soft-tissue Pogonion: Is the most anterior midpoint of the chin located on the skin surface, lying directly in front of its bony counterpart on the mandible. It may lie within a soft tissue cleft.

Soft-Tissue Porion: The highest point on the upper border of the cutaneous external auditory meatus.

Soft-tissue Zygion: It is the most [illegible] point on the zygomatic arch lying directly ove[illegible] b[illegible] ygion.

Standard Horizontal Plane: Another name for the Frankfort Standard Horizontal plane or FSH.

Standard Transverse Plane: The plane passing through the bi-porionic axis perpendicular to the Frankfort Standard Horizontal.

Stomion: This is an imaginary point at the junction of the vertical median plane and the horizontal interlabial fissure between gently closed lips, with teeth in centric relation.

Subnasale: The midpoint of the columella base at the apex of the angle where the lower border of the nasal septum and the surface of the upper lip meet. This point is not identical to the bony nasospinale.

Subspinale: This corresponds to Downs' A-Point and is the deepest point on the midline contour of the alveolar process between the anterior nasal spine and the prosthion. It represents the anterior limit of the maxillary basal arch as seen on a lateral cephalometric radiograph.

Supramentale: This corresponds to Downs' B-Point and is the deepest point on the contour of the alveolar process between infradentale and pogonion. It represents the anterior limit of the mandibular basal arch as seen on the lateral cephalometric radiograph.

Surface: The phase change that occurs between a three-dimensional object and the surrounding medium.

Topology: The study of the continuity and connection of surfaces.

Transmeatal axis: A line running between the centres of the two external auditory meatuses.

Traversion Map: A diagram of the face showing regional data points (with their central data points) displayed as circles. Lines within the circles indicate directions and distances from the central data point where measurements may be made without any significant differences in the depth reading.

Trichion: Is the point on the hairline in the midline of the forehead, or its equivalent on the balding head.

Zygion: Is the point on the zygomatic arch such that it is fu thest from a corresponding point on the opposite zygomatic arch in the same coronal plane. This point is determined, not by anatomical relations but by trial measurements of the maximum bizygomatic breadth.

****

HEALTH QUESTIONNAIRE

Name _____ Sex _____ Age _____

Address _____

Telephone _____ Height _____ Weight _____

Date _____ Occupation _____ Marital status _____

Directions

If your answer is "YES" to the questions, put a circle around "YES".
If your answer is "NO" to the questions, put a circle around "NO".
Answer all questions and fill in blank spaces when indicated.
Answers to the following questions are for our records only and will be considered confidential.

1. Are you in good health _____ YES NO
   a) Has there been any change in your general health within the past year ..... YES NO
2. My last physical examination was on _____
3. Are you now under the care of a physician ..... YES NO
   a) If so, what is the condition being treated _____
4. The name and address of my physician is _____

   _____
5. Have you had any serious illness or operation ..... YES NO
   a) If so, what was the illness or operation _____
6. Have you been hospitalized or had a serious illness with the past (5) five years ..... YES NO
   a) If so, what was the problem _____

   _____
7. Do you have or have you had any of the following diseases or problems:
   a) Rheumatic fever or rheumatic heart disease ..... YES NO
   b) Congenital heart lesions ..... YES NO
   c) Cardiovascular disease (heart trouble, heart attack, coronary insufficiency, coronary occlusion, high blood pressure, arteriosclerosis, stroke) ..... YES NO
   1) Do you have pain in chest upon exertion ..... YES NO
   2) Are you ever short of breath after mild exercise ..... YES NO
   3) Do your ankles swell ..... YES NO
   4) Do you get short of breath when you lie down, or do you require extra pillows when you sleep ..... YES NO
   d) Allergy ..... YES NO
   e) Asthma or hay fever ..... YES NO
   f) Hives or a skin rash ..... YES NO
   g) Fainting spells or seizures ..... YES NO
   h) Diabetes ..... YES NO

2/...

APPENDIX A2 - Health questionnaire

i) Do you have to urinate (pass water) more than six times a day ..... YES NO

2) Are you thirsty much of the time ..... YES NO

3) Does your mouth frequently become dry ..... YES NO

i) Hepatitis, jaundice or liver disease ..... YES NO

j) Arthritis ..... YES NO

k) Inflammatory rheumatism (painful swollen joints) ..... YES NO

l) Stomach ulcers ..... YES NO

m) Kidney trouble ..... YES NO

n) Tuberculosis ..... YES NO

o) Do you have a persistent cough or cough up blood ..... YES NO

p) Low blood pressure ..... YES NO

q) Veneral disease ..... YES NO

r) Other _____

_____

8. Have you had abnormal bleeding associated with previous extractions, surgery or trauma: ..... YES NO

a) Do you bruise easily ..... YES NO

b) Have you ever required a blood transfusion..... YES NO

If so, explain the circumstances _____

_____

_____

9. Do you have any blood disorder such as anemia ..... YES NO

10. Have you had surgery or x-ray treatment for a tumor, growth, or other condition of your mouth or lips ..... YES NO

11. Are you taking any drug or medicine ..... YES NO

If so, what _____

12. Are you taking any of the following:

a) Antibiotics or sulfa drugs ..... YES NO

b) Anticoagulants (blood thinners) ..... YES NO

c) Medicine for high blood pressure ..... YES NO

d) Cortisone (steroids) ..... YES NO

e) Tranquilizers ..... YES NO

f) Aspirin ..... YES NO

g) Insulin, tolbutamide (Orinase), or similar drug..... YES NO

h) Digitalis or drugs for heart trouble ..... YES NO

i) Nitroglycerin ..... YES NO

J. Other _____

_____

3/...

13. Are you allergic or have you reacted adversely to:

a) Local anesthetics ..... YES NO

b) Penicillin or other antibiotics ..... YES NO

c) Sulfa drugs ..... YES NO

d) Barbiturates, sedatives, or sleeping pills ..... YES NO

e) Aspirin ..... YES NO

f) Iodine ..... YES NO

g) Other _____

_____

14. Have you had any serious trouble associated with any previous dental treatment ..... YES NO

If so, explain _____

_____

_____

15. Do you have any disease, condition, or problem not listed above that you think I should know about ..... YES NO

If so, please explain _____

_____

_____

16. Are you employed in any situation which exposes you regularly to x-rays or other ionizing radiation ..... YES NO

WOMEN

17. Are you pregnant ..... YES NO

18. Do you have any problems associated with your menstrual period. YES NO

Remarks: _____

_____

_____

SIGNATURE OF PATIENT

SIGNATURE OF STUDENT

DR WA AULSEBROOK

INFORMED CONSENT
UNIVERSITY OF DURBAN-WESTVILLE
ORAL & DENTAL TRAINING HOSPITAL

I, ... (insert name of subject) aged .... years, consent to the following procedure being performed on myself, namely: Lateral and Oblique Head Radiographs, Ultrasonic Tissue Depth Measurements, Photographs of Head and Neck, Anthropometric Head Measurements.

Dr. W.A. Aulsebrook, through an interpreter has fully explained the procedure and its purpose, and I understand and appreciate :-

a.- such possible harmful effects including pain or discomfort as may according to medical knowledge be involved;

b.- the degree of likelihood according to medical knowledge of the occurrence of any such effects; and

c.- to what extent (if any) the procedure may be considered of benefit to myself.

I also appreciate that my consent to the above conditions may be withdrawn at any time.

d.- That my permission to use and publish any photographs of myself is hereby also granted to Dr. W.A. Aulsebrook only.

WITNESSES:

....
(Signature of Subject)

I, Dr. W.A. Aulsebrook, declare that I have fully explained the above procedure, its purpose, such possible harmful effects including pain or discomfort as may according to medical knowledge be involved, the degree of likelihood according to medical knowledge of the occurrence of any such effects, and to what extent (if any) the procedure may be considered of benefit to the subject.

I verily believe my explanation, and that given by my interpreter, to have been fully understood by the consenting parties.

.....
(Signature of Doctor)

APPENDIX A3 - Informed consent form

ERROR CONTROL - ULTRASONIC.

DR. W.A. AULSEBROOK

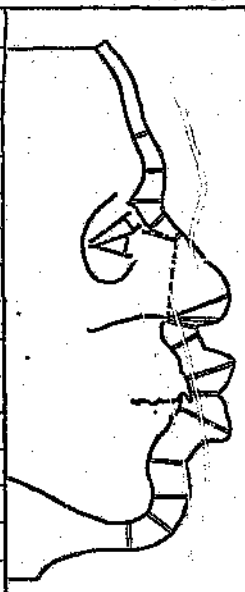
POINT	FRIDAY		THURSDAY		WEDNESDAY		TUESDAY		MONDAY	
	am	pm	am	pm	am	pm	am	pm	am	pm
1.1	4.93	4.96	5.04	4.99	4.78	4.80	4.95	4.89	4.96	4.99
1.2	4.90	4.84	5.03	5.11	5.00	5.12	5.11	4.94	5.00	5.03
1.3	5.00	4.97	5.07	5.05	4.94	4.96	4.97	5.01	5.05	5.03
1.4	5.01	4.85	5.02	5.14	4.96	5.08	5.00	4.98	5.01	5.05
1.5	5.01	4.90	4.99	5.06	5.02	5.11	5.07	5.02	5.00	5.00
2.1	5.17	5.09	5.16	5.09	5.35	5.26	5.05	5.03	5.17	5.26
2.2	5.10	5.06	5.10	5.07	5.32	5.00	5.07	5.11	5.29	5.19
2.3	5.19	5.04	5.28	5.19	5.21	5.28	5.18	5.09	5.26	5.22
2.4	5.18	5.05	5.21	5.23	5.30	5.19	5.24	5.09	5.22	5.23
2.5	5.20	4.98	5.11	5.25	5.32	5.17	5.20	4.99	5.23	5.29
3.1	5.20	5.39	5.19	5.49	5.56	5.07	5.40	5.27	5.21	5.33
3.2	5.29	5.41	5.24	5.38	5.49	5.28	5.36	5.46	5.39	5.46
3.3	5.33	5.47	5.15	5.36	5.25	5.38	5.39	5.29	5.35	5.42
3.4	5.33	5.49	5.22	5.49	5.39	5.05	5.45	5.38	5.41	5.41
3.5	5.40	5.48	5.31	5.44	5.37	5.48	5.41	5.45	5.44	5.31
4.1	7.12	7.14	7.18	7.14	7.08	7.02	7.31	7.05	7.25	7.15
4.2	7.27	7.30	7.33	7.46	6.98	7.10	7.29	7.19	7.27	7.23
4.3	7.23	7.04	7.30	7.04	7.07	7.39	7.19	7.06	7.21	7.29
4.4	7.10	7.37	7.35	7.12	6.99	7.20	7.13	7.27	7.22	7.23
4.5	7.03	7.39	7.40	7.02	7.02	7.08	7.10	7.21	7.24	7.39
5.1	3.42	3.53	3.32	3.29	3.25	3.20	3.22	3.33	3.33	3.29
5.2	3.29	3.28	3.24	3.37	3.36	3.45	3.39	3.34	3.45	3.15
5.3	3.30	3.37	3.17	3.23	3.46	3.41	3.41	3.35	3.41	3.13
5.4	3.35	3.20	3.28	3.23	3.37	3.39	3.35	3.40	3.28	3.09
5.5	3.31	3.23	3.02	3.25	3.34	3.46	3.32	3.30	3.32	3.11
6.1	3.04	3.09	3.32	3.22	3.25	3.27	3.30	3.29	3.22	3.19
6.2	3.18	3.05	3.17	3.19	3.36	3.36	3.11	3.20	3.29	3.20
6.3	3.16	3.29	3.18	3.19	3.27	3.29	3.18	3.09	3.09	3.24
6.4	3.10	3.19	3.23	3.10	3.25	3.12	3.27	3.16	3.14	3.28
6.5	3.12	3.22	3.26	3.21	3.40	3.23	3.21	3.19	3.22	3.22
7.1	9.00	9.22	8.89	9.05	9.13	9.26	9.05	9.01	8.87	9.02
7.2	8.91	8.97	8.90	9.09	8.83	8.98	8.99	8.95	8.89	8.96
7.3	8.89	8.88	9.03	9.29	8.87	9.12	8.96	9.01	8.88	8.96
7.4	9.19	8.97	8.90	9.30	9.33	8.89	8.09	8.07	9.09	9.01
7.5	9.18	8.63	9.05	9.02	8.71	9.19	8.03	8.93	9.05	9.02
8.1	12.31	12.48	12.46	12.48	12.37	12.45	12.34	12.41	12.49	12.53
8.2	12.44	12.45	12.65	12.43	12.60	12.36	12.39	12.45	12.40	12.59
8.3	12.50	12.60	12.55	12.53	12.23	12.46	12.33	12.5[illegible]	12.48	12.56
8.4	12.46	12.59	12.49	12.34	12.52	12.57	12.46	12.55	12.50	12.49
8.5	12.28	12.55	12.33	12.52	12.45	12.[illegible]	12.44	12.59	12.54	12.57
9.1	16.32	16.19	16.16	16.29	16.24	16.[illegible]	.33	16.18	16.22	16.23
9.2	16.29	16.21	16.36	16.30	16.38	16.[illegible]	22	16.21	16.19	16.20
9.3	16.25	16.19	16.31	16.[illegible]	16.62	16.20	16.31	16.17	16.19	16.30
9.4	16.19	16.26	16.23	16.23	16.23	16.17	16.18	16.20	16.21	16.25
9.5	16.27	16.38	16.27	16.61	16.25	16.27	16.12	16.24	16.22	16.23
10.1	18.52	18.81	18.99	18.96	18.57	18.80	18.82	18.57	18.97	18.75
10.2	18.61	18.75	18.97	18.79	18.65	18.77	18.62	18.68	18.76	18.53
10.3	18.81	18.63	18.59	18.66	18.62	18.65	18.73	18.90	18.66	18.73
10.4	18.76	18.88	18.68	18.73	18.52	18.96	18.86	18.51	18.65	18.72
10.5	18.78	18.69	18.90	18.55	18.66	18.75	18.55	18.56	18.56	18.71

APPENDIX A4 - Ultrasonic error control
An example of a filled-in sheet of data

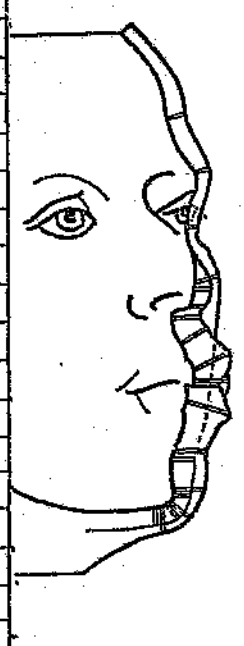
CEPHALOMETRIC RADIOGRAPHY DATA

(Tissue depths at 0 and 45 degrees)
Dr W A Ausebrook

0 DEGREE MERIDIAN

	LANDMARK	POSITION	VALUE
LR1	SUPRAGLABELLA		3.86
LR2	GLABELLA		5.00
LR3	NASION		6.38
LR4	MID NASAL BONE		5.34
LR5	END NASAL BONE		2.99
LR6	NOSE TIP FRONT		28.10
LR7	NOSE TIP BOTTOM		20.00
LR8	NOSE BASE		26.44
LR9	MID-PHILTRUM		14.36
LR10	UPPER LIP MARGIN		15.59
LR11	LIPLINE		8.35
LR12	LOWER LIP MARGIN		16.00
LR13	CHIN-LIP FOLD		12.41
LR14	MENTAL EMINENCE		13.25
LR15	MID-CHIN		7.49
LR16	BENEATH CHIN		9.15

45 DEGREE MERIDIAN

OR1	LATERAL FRONTAL		4.55
OR2	LATERAL SUPRAORBITAL		5.28
OR3	LATERAL ORBITAL		4.76
OR4	LATERAL ZYGOMATIC		9.91
OR5	LATERAL ALAR		6.21
OR6	INF. BORDER ZYG.		12.08
OR7	SUB-ZYGOMATIC		23.76
OR8	SUB-ALAR		10.51
OR9	LAT. U. LIP MARGIN		11.65
OR10	ANGLE OF MOUTH		14.36
OR11	LAT. LIP LINE		9.95
OR12	LAT. L. LIP MARGIN		11.78
OR13	LAT. LOWER MOLAR		13.80
OR14	LAT. LABIOMENTAL		8.12
OR15	LATERAL MENTAL		9.11
OR16	INTERMED. MENTAL		7.84
OR13	INFERIOR MENTAL		8.10
OR14	LATERAL MANDIB.		5.37
OR15	INTERMED. MANDIB.		4.24
OR16	INFERIOR MANDIB.		4.70

Case No 7. Name S.NYUMALA. Date 15/1/89

APPENDIX A5 - Radiographic data sheet (Depth System)
An example of a filled-in sheet of data

HARD AND SOFT COORDINATES FOR THE PROFILE SYSTEM

(Dr W A Atlasbrook)

TRIPLE No:	HARD COORDINATES		SOFT COORDINATES	
	ANGLE	DISTANCE	ANGLE	DISTANCE
T1	65.0	125.0	64.0	128.5
	56.5	121.5	56.0	125.0
T2	48.5	113.0	48.0	116.0
	42.5	106.0	44.0	113.0
T3	36.5	103.5	39.0	110.0
	34.0	102.0	34.5	108.0
T4	32.0	98.0	30.5	104.5
	31.5	96.0	29.0	103.5
T5	30.0	95.5	27.5	102.5
	24.0	98.5	28.5	106.5
T6	19.0	105.0	20.0	110.0
	10.0	100.0	19.5	116.5
T7	0.0	100.0	9.5	123.5
	0.0	100.0	3.0	126.5
T8	0.0	100.0	-0.5	116.0
	-2.5	99.0	-0.5	110.0
T9	-4.0	100.0	-0.5	116.0
	-6.5	105.5	-4.0	118.0
T10	-9.0	108.0	-5.0	125.0
	-11.0	113.5	-8.5	127.0
T11	-16.0	118.0	-12.0	123.0
	-18.0	120.0	-13.0	131.5
T12	-20.5	120.5	-15.0	134.0
	-22.0	121.5	-16.0	133.5
T13	-22.5	122.0	-17.0	131.5
	-28.0	125.5	-17.5	132.5
T14	-31.0	131.5	-22.0	133.5
	-33.0	134.5	-26.0	142.0
T15	-34.5	135.5	-31.0	145.0
	-36.0	132.5	-36.0	143.0
T16	-37.5	128.0	-39.0	139.0
	-41.0	109.5	-47.5	127.0

Case No: 7 Name: S. NXUMALA. Date: 15.01.89

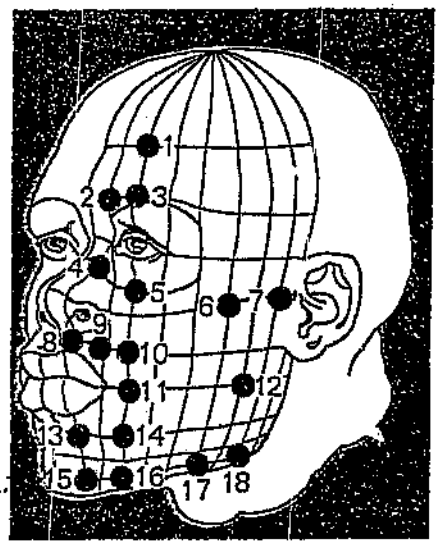
APPENDIX A6 - Radiographic data sheet(Profile System)
An example of a filled-in sheet of dat

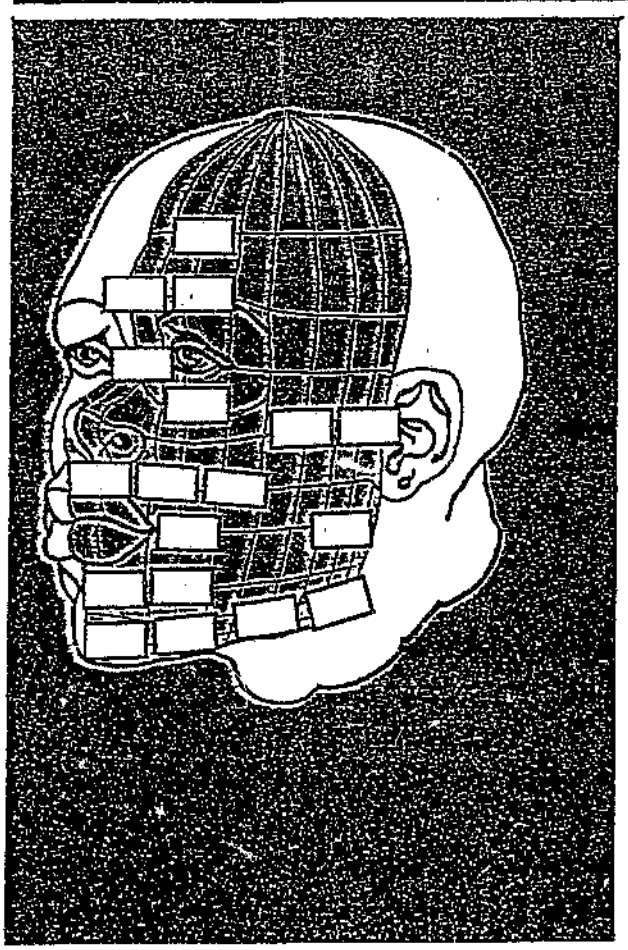
ULTRASONIC DEPTHS MEASUREMENTS

(Dr W A Aulsebrook)

Code: 7 Name: S. NIRMALA Date: 15.1.89

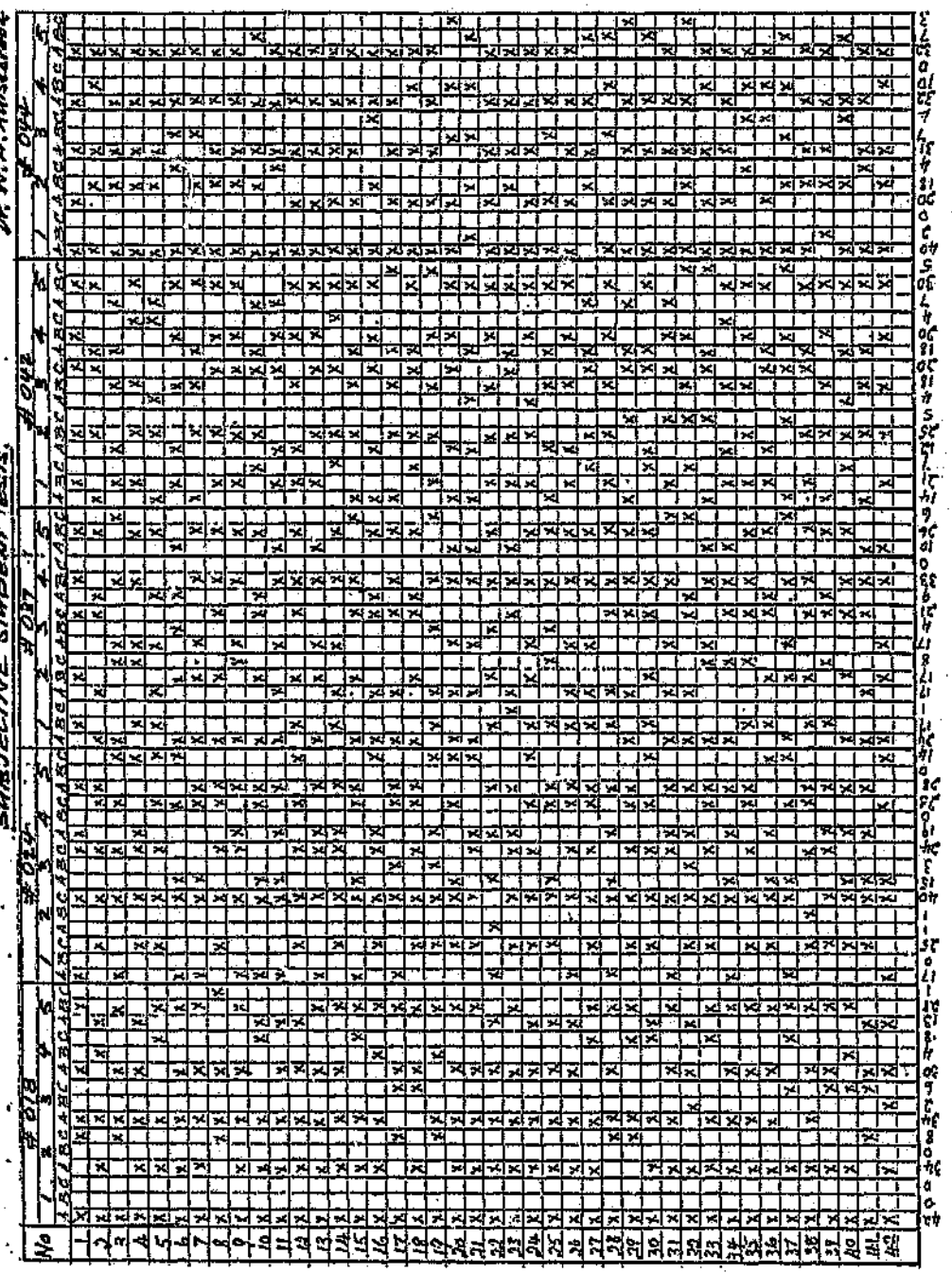
US 1	FRONTAL
US 2	LATERAL GLABELLAR
US 3	SUPRA-ORBITAL
US 4	LATERAL NASAL
US 5	INFRA-ORBITAL
US 6	MID-ZYGOMA
US 7	ROOT OF ZYGOMA
US 8	PHILTRUM RIDGE
US 9	SUPRA-LABIAL
US 10	SUPRA-COMMISSURAL
US 11	COMMISSURAL
US 12	MID-MASSETERIC
US 13	SUB-LABIAL
US 14	SUB-COMMISSURAL
US 15	MENTAL TUBERCLE ANT.
US 16	MENTAL TUBERCLE LAT.
US 17	INSERT MASSETER ANT.
US 18	INSERT MASSETER POST.





	3.87	A	3.90
	3.92	B	3.82
	3.91		3.84
3.69	4.19	C	3.62
3.58	4.26		3.59
3.70	4.24		3.60
			3.89
			3.95
			3.93
4.69	4.82	6.73	3.11
4.61	4.87	6.65	3.13
4.57	4.83	6.78	3.16
3.95	8.01	14.99	
3.94	8.13	14.76	
3.88	8.14	14.99	
	13.16		15.24
	13.18		15.00
	13.07		15.31
7.87	12.26		
7.85	12.27		
7.79	12.20		
4.93	5.18	7.46	13.29
5.02	5.17	7.39	13.24
5.07	5.10	7.42	13.30

APPENDIX A7 - Ultrasonic data sheet (Depth System)
An example of a filled-in sheet of data



APPENDIX A8 - Visual test data sheet
Positive response marked by a cross

Author: Aulsebrook W.A
Name of thesis: The establishment of soft tissue thicknesses and profiles for reconstruction of the adult male zulu face

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