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DEVELOPMENT OF A TWO-DIMENSIONAL RADIOGRAPHIC  
STUDY MODEL IMAGING PROCESS AND ANALYSIS

Theo Baisi BDS

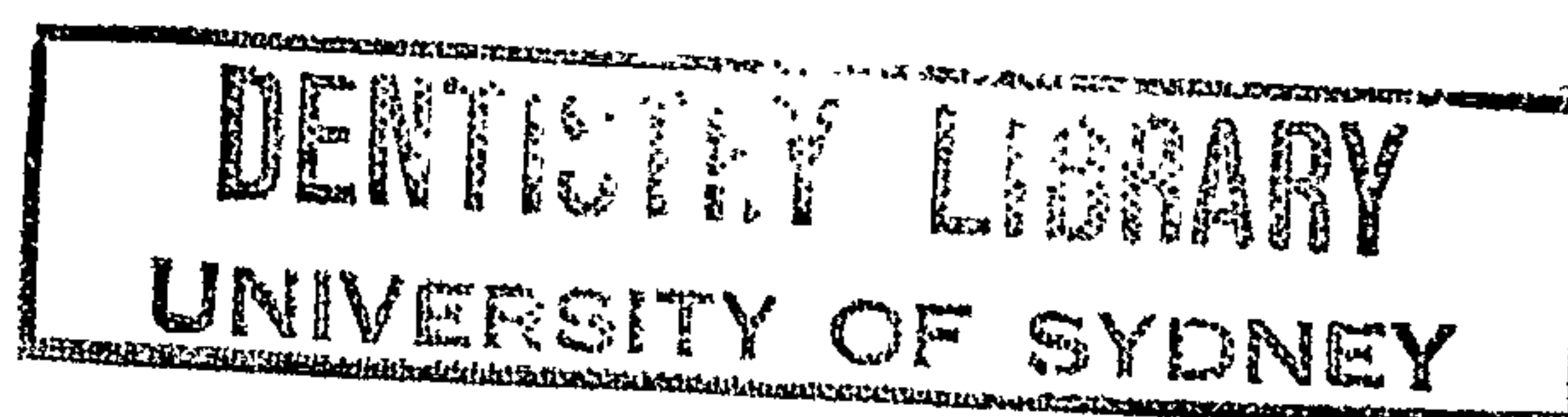
A thesis to be submitted in partial requirement  
for the degree in Master of Dental Science

Department of Preventive Dentistry

Faculty of Dentistry

University of Sydney

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To my late mother Lydia  
who always wanted so much for me.

to the late Bob McCrossin  
It was his enthusiasm that has led me to  
the beginning of a wonderful new adventure

## ABSTRACT

This study was undertaken to investigate and evaluate a two-dimensional radiographic study model imaging process developed by Dr Hilton Wasilewsky as part of his thesis in 1985. It was felt that there was a place for this analysis in the diagnosis, treatment planning and later treatment evaluation of a malocclusion.

The proposed method involves trimming, to the functional occlusal plane, and marking, with radio-opaque markers, a series of sets of study models from an individual. These are then radiographed. The radiographic images are then digitised and measurements are carried out. In order to relate these measurements longitudinally, it was felt that the palate could be used as a stable reference plane from which to carry out such analyses.

It was the purpose of this study to determine the variability and reliability of the method with respect to its ability to measure lengths and its ability to use the palate as a stable longitudinal reference plane.

The evaluation involved the duplication of ten sets of study models from one master set. These were all trimmed and marked in a specified manner. Digitisation involved establishment of a mid-palatal reference line and origin point from markers on the study models. Canine and molar markers were also digitised. Three markers were also used to allow superimposition of the maxillary image onto the corresponding mandibular image.

Measurements made, were designed to test the effects of duplication and trimming of the study models, as well as the reliability of the chosen palatal reference points. Repeat measurements were made to test for measurement error. Statistical analysis of variance was used to test the measurement reliability. The radiographic inter-marker length measurements were compared to the actual model length measurements and analysed using the Student's t-test. Two different methods of radiography were test in order to determine the effect of varying the distance of the study model from the central ray.

Results showed that the was a large measurement error involved in the marking and digitisation. It was also found that the trimming method was reliable. Radiographic inter-marker length measurements showed a variability of less than  $\pm 0.5\text{mm}$ . The measurements relying on the mid-palatal reference line and origin points as longitudinal markers were found to be unreliable. The distance of the study model from the central ray was found to effect the position of the palatal origin point when projected onto the x-ray film.

Future study in this area should be directed towards reducing the measurement error, particularly directed towards radio-opaque marking and digitising.

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## DEVELOPMENT OF A RADIOGRAPHIC TWO DIMENSIONAL STUDY MODEL IMAGING PROCESS AND ANALYSIS

### INTRODUCTION

Study models have been measured, cut into pieces, photographed, photocopied and scanned. Today three-dimensional imaging and computer technology allow the most complex of measurements to be used, stored and processed in a fraction of the time previously required. Why then should one use a "new" two-dimensional imaging process?

This imaging process and analysis is designed to be cost-effective and within reach of practitioners who wish to do case analysis on an individual basis, or possibly conduct comparative data analyses over a range of cases and treatments. It is to be used as an on-going learning tool available to all without the prohibitive costs of high-technology.

The two dimensional radiographic study model imaging process and analysis is designed to use consistent study model trimming, a lateral cephalometric radiograph film size and the digitising hardware and software is optional as the measurements can be done by hand.

Dr Hilton Wasilewsky in 1985, wrote a thesis in which he evaluated overbite relapse in three dimensions. To accomplish this, he digitised and analysed longitudinal lateral cephalometric radiographs and serial x-rays of dental study casts

from a sample of 65 orthodontically treated patients. These patients were available for re-evaluation of their treatment at least ten years after removal of appliances.

With Dr V. Saini he developed this two dimensional radiographic study model imaging process and analysis.

Dr Wasilewsky felt that this imaging process may be consistent and accurate enough to use as a research tool in longitudinal analyses, using the stability and reliability of identification of a palatal reference point and mid-palatine reference line. This would provide a tool to show tooth movement in an antero-posterior and transverse direction. Left and right could also be distinguished. It is also possible that if all the mesial and distal points of the teeth could be digitised, as well as a method of arch length determination used, then it would be a simple matter to produce a Bolton's Analysis as well as an assessment of space requirements. As will be seen, the information obtainable could be used in diagnosis, or later in case analysis or treatment comparisons.

It has been left to the author to test the imaging method and detail the possible errors involved.

The aim of this thesis is to describe, test and evaluate the reliability of the proposed two dimensional radiographic study model imaging process and analysis and comment on its overall application as a research tool.

## CHAPTER 1

### REVIEW OF THE LITERATURE

#### A REVIEW OF STUDY MODEL ANALYSES AND IMAGING PROCESSES PAST AND PRESENT

##### 1.1 General Overview

Study models have been used as diagnostic tools with which to gather information to aid in diagnosis and treatment planning of a malocclusion. They have also been the tools used to study longitudinal changes of normal development and orthodontic treatment effects.

It is not the purpose of this literature review to cover every study which has used study models as a tool. As this analysis involves a form of two-dimensional imaging, it is appropriate to look at the use of study models relative to the way in which the study models are used more than the actual measurements which are taken.

One can therefore categorise the studies using study models into those which involved:

##### a) Physical Measurement

By far the largest category involving the use of data derived from the actual measurement of the models themselves.

b) Two Dimensional Imaging methods

This category involves the use of measurements taken from study models after being projected onto a 2-D reference plane.

c) Three Dimensional Imaging methods

This category involves the use of measurements taken from 3-D representations of study models.

## 1.2 Physical Measurement of Study Models

Studies involving the physical measurement of study models represents the bulk of the studies carried out in the past. The major types of measuring instruments have been instruments used to measure straight line distances such as rules, dividers and Vernier callipers.

These studies have taken many forms and many different measurements have been taken and analysed. In order to look at these studies it is again appropriate to examine the different types of measurements used and not attempt to analyse all the studies done.

### 1.2.1 Measuring Tooth Dimensions

This group of studies involves itself with the measurement of the size and proportion of the teeth, known as anthropometry.

G.V.Black in 1902 published mean figures of tooth size for each tooth in the dental arch. Ritter (1933) and Selmar-Olsen (1949) also studied the maxillary and mandibular tooth widths and their relationships.

Korbitz (1930) compared maxillary anterior segment lengths to the mandibular segment of the central and lateral incisors, canines and one half of the first premolar width. He related this difference to the overbite.

Neff (1949) developed an anterior coefficient by dividing the sum of the mesio-distal widths of the mandibular anteriors into the sum of the widths of the maxillary anteriors.

The most common clinically used ratio is the Bolton ratio. Bolton (1958, 1962) developed anterior and overall tooth size ratios which would show tooth size incompatibilities and the likelihood of obtaining good interdigitation, or a good overbite and overjet relationship.

Peck and Peck (1975) studied the relationship between the mesio-distal and bucco-lingual dimensions of mandibular incisors. They formulated an index of ideal size ranges to allow good alignment.

Ballard (1944) studied the asymmetry of tooth sizes and in 500 sets of study models found that 90% of the sample exhibited a right to left discrepancy.

Little (1975) described a method of measuring the linear displacement of the contact points between the mesial contact point of the right mandibular canine and the mesial contact point of the left canine. These five values, (Fig 1), formed the irregularity index which Little felt removed the subjectivity of estimating the amount of crowding present. Measurements were obtained using a dial Vernier calliper held parallel to the occlusal plane, measuring only the horizontal displacement between contact points. The calliper must be calibrated to at least 0.1mm.

#### 1.2.2 Arch Perimeter Measurements

In assessing space excess or deficiency it is important to know the length of the perimeter of the arch into which these teeth must fit. This as Lundstrum in 1923 points out, is determined largely by the apical base. Howes (1952) felt that the apical base width predetermined the available arch length.

Three different types of arch perimeter measuring methods which have been used, (Fig 2), are :

- 1....A brass wire adapted to the buccal and labial surfaces of the teeth mesial to the first permanent molars. This was described by Nance and modified by others such as Huckaba, Curey and Moorrees.
- 2....Measurements of arch segments as straight line approximations of the arch perimeter. This method is described by Proffit (1983).

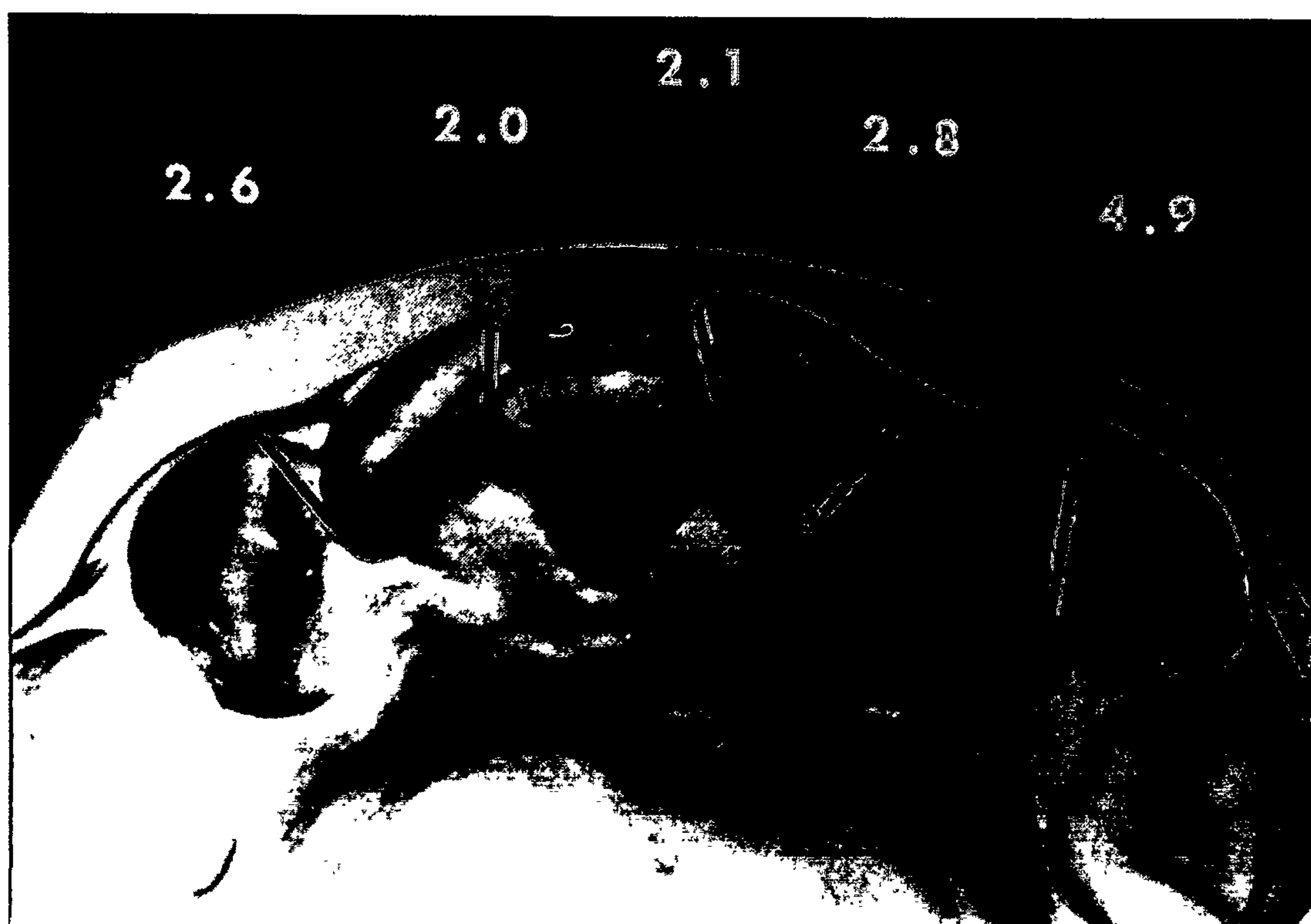
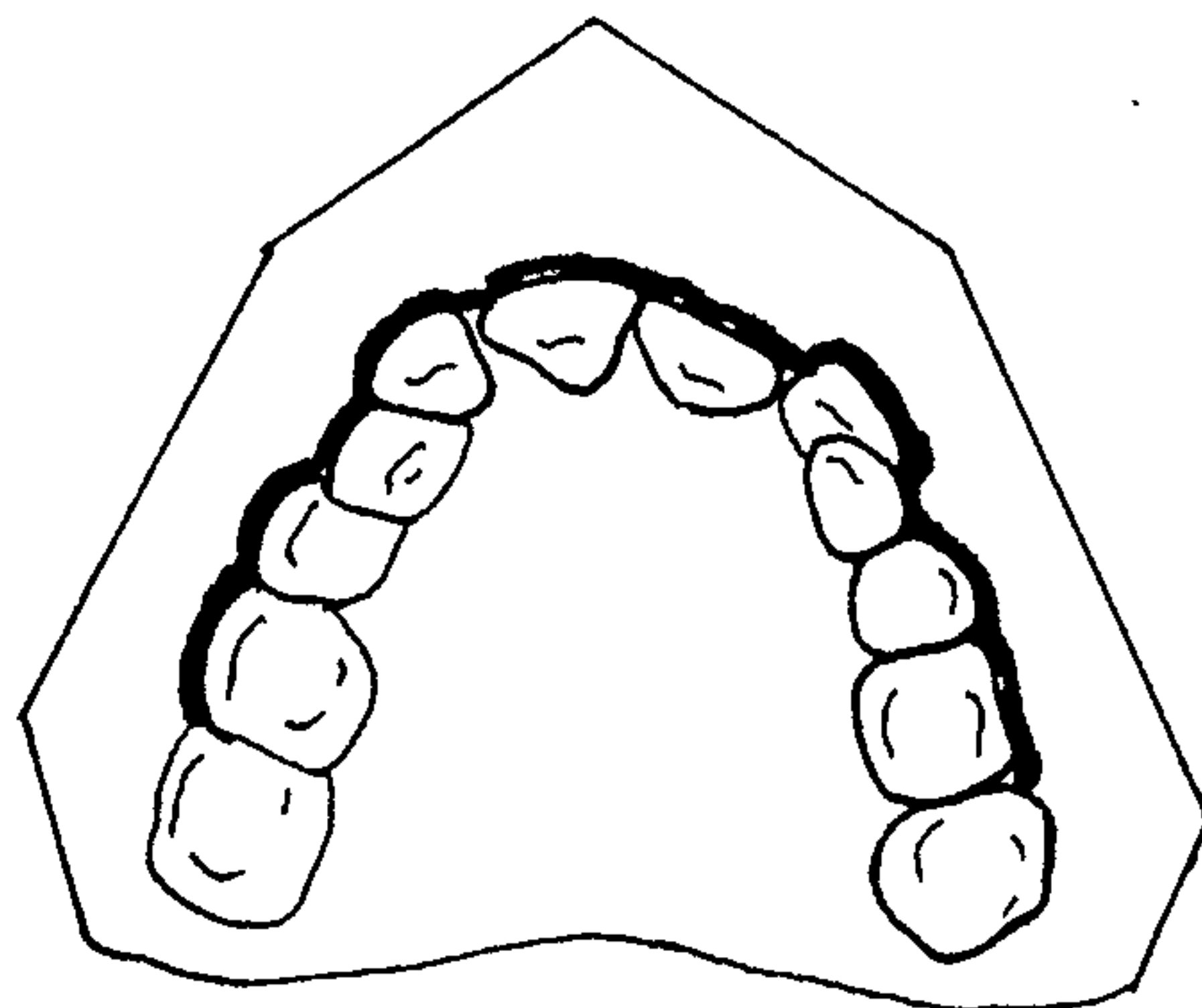
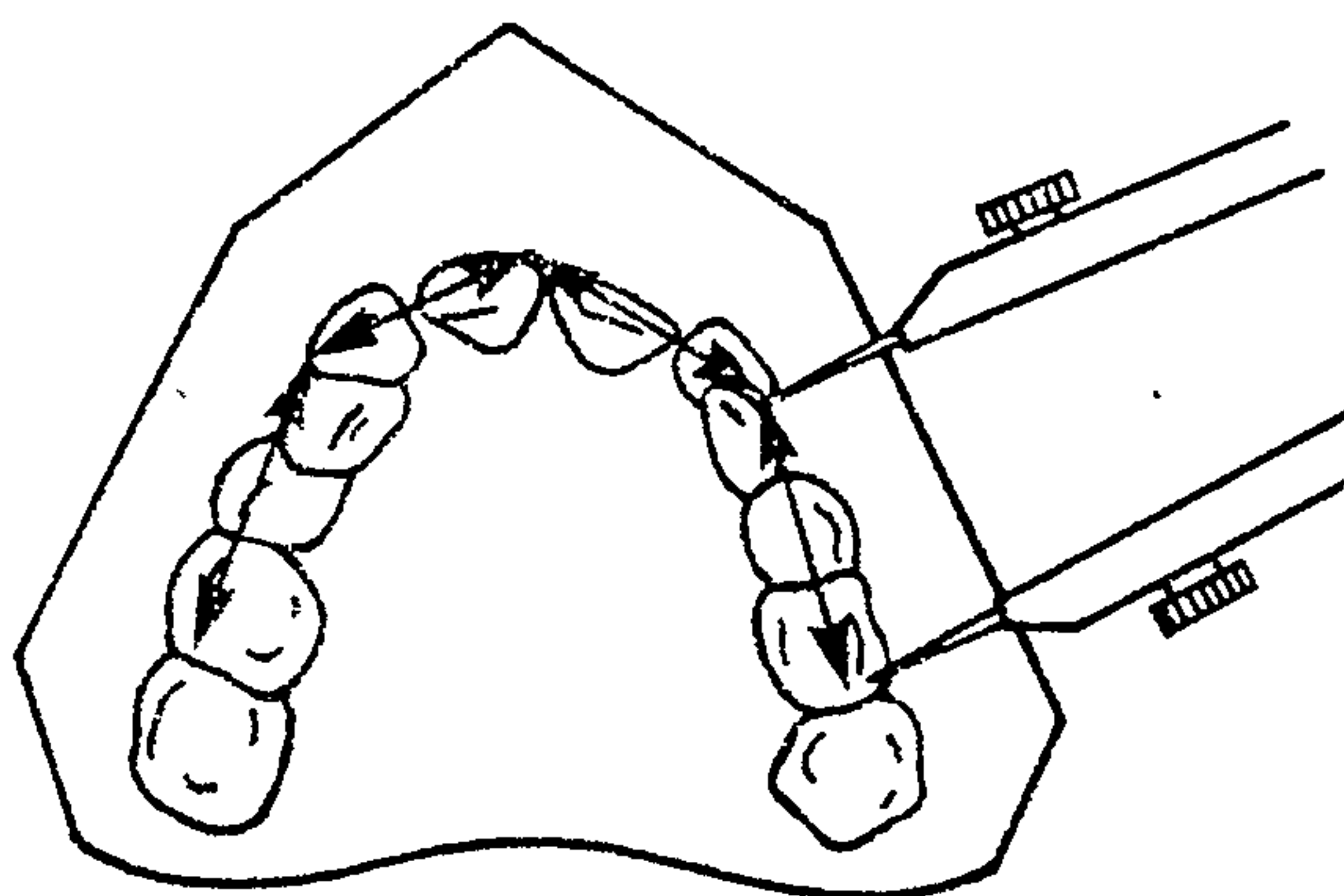


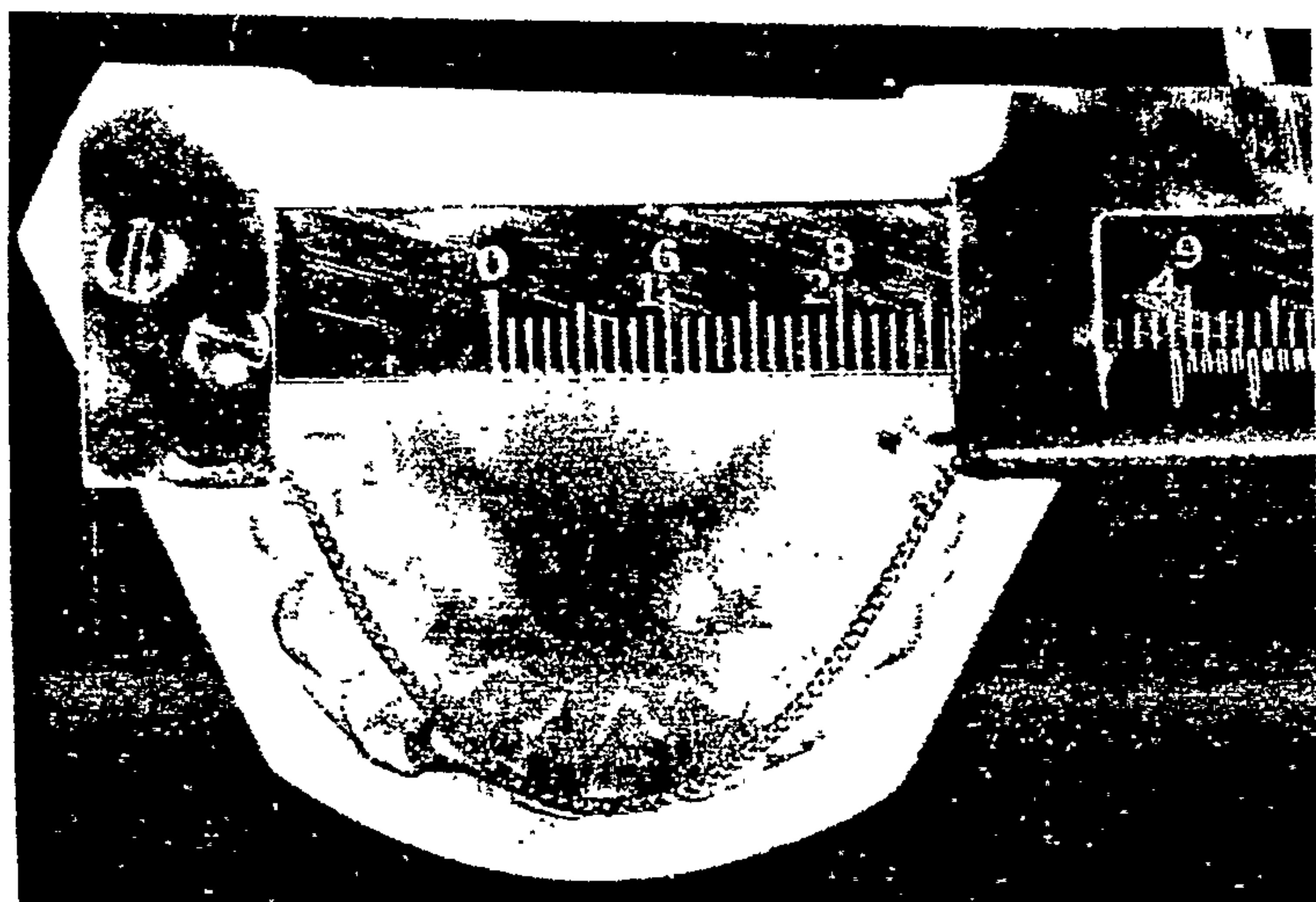
FIG 1 Little (1975) The irregularity index



1...



2...



3...

FIG 2 Proffit (1986) Arch perimeter measurements

- 1...Brass wire method
- 2...Arch segment method
- 3...Hanging chain method

3....Use of a hanging chain to approximate the natural catenary curve of a dental arch. Musich and Ackerman (1973), used this method with the hanging chain attached to a modified Boley gauge.

### 1.2.3. Arch Width Measurements

In 1909 Pont found a correlation between the measurement of the four maxillary incisors and the widths of the arches in the premolar and molar regions.

Howes (1954) considered that the underlying stability of a case came from basal arch width and he developed an analysis relating the width of the casts at the apices of the first premolar to the sum of the mesio-distal widths of all the teeth forward of and including the first permanent molars. This ratio described as a percentage gave a diagnostic range from extraction to non-extraction.

Moorrees and Reed (1965) investigated the changes of inter-canine width and arch length during development.

Dineen (1988), in his thesis, measured mandibular arch width stability using dial callipers calibrated to 0.02 mm. He measured the intercanine widths, cusp tips and buccal surfaces and the intermolar widths, cusp tips. The range of consistency achievable measuring the distance between the cusp tips was  $\leq 0.06$  mm. The range of consistency achievable measuring between the buccal surfaces was  $\leq 0.1$  mm.

### 1.3 Two-dimensional Imaging Processes

The points of measurement involved in this category are first projected onto a specific plane allowing measurements to be carried out on an x-y co-ordinate grid. In most of the studies the x-y plane is the maxillary occlusal plane and the x-axis is the mid-sagittal plane defined by the mid-palatine suture.

There are three major methods of projection :

- 1....Physical projection
- 2....Photographic projection
- 3....Radiographic projection

#### 1.3.1. Physical Projection

This term is used to describe any method where the measurement is taken directly from the study model itself. The projection is created physically.

##### 1.3.1.1. The Symmetrograph

One such instrument developed to allow this mapping is the symmetrograph. This procedure was originally developed by Korbitz using instruments called symmetrosopes. Korbitz initially used this method to study symmetry and it was called symmetrical comparison.

The symmetrosopes were used to locate the mid-sagittal plane on casts and transverse lines running perpendicular to it. If a

pencil was added then it was possible to draw directly onto the study model. This became the symmetrograph.

Korkhaus (1930) designed a symmetrograph which allowed the plotting of direct measurements onto paper projecting onto a two dimensional plane, (Fig 3).

The symmetrograph was used to orient the study model in a fixed constant plane of choice. All measurements were able to be taken from this position. The study model was then able to be relocated at any time to the exact same orientation.

Simon (1924) also was concerned about the orientation of study models and had developed his own gnathostatic system of record taking and diagnosis which enabled him to relate the dentition to the cranium using a system of face-bow, gnathostat and symmetrograph, (Fig 4). Today much of the same information can be simply obtained using the lateral cephalometric radiograph.

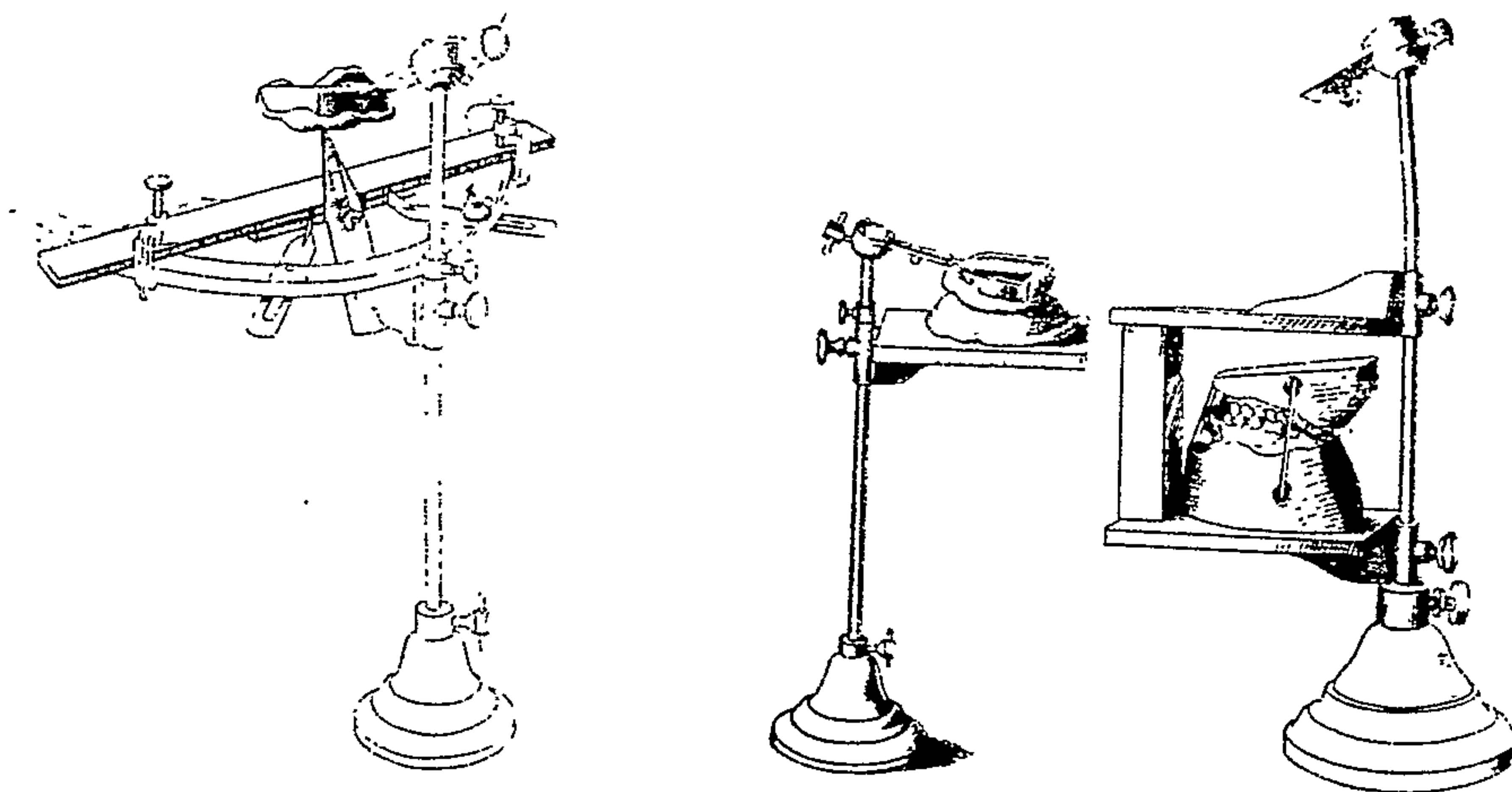
The ability to fix the study model in a stable, repeatable position allows a method of orientation in longitudinal studies where a series of casts can be studied relative to the occlusal plane. It would then be possible to study longitudinal change in dental and palatal development. The symmetrograph was the instrument used in the early studies which described the palatal and dental changes. These aspects will be discussed at length later in this paper.



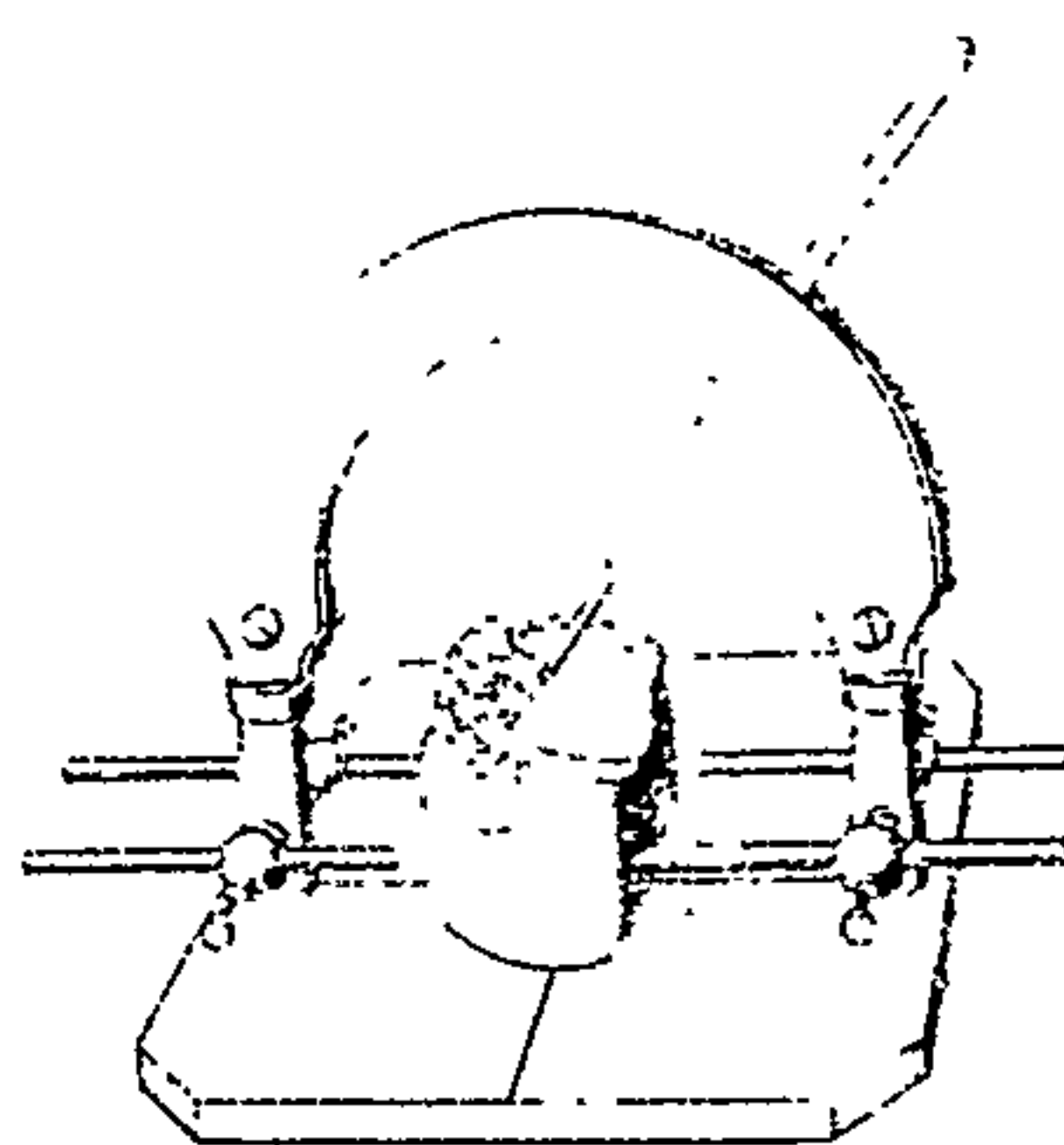
FIG 3 Korkhaus (1930) The Symmetrograph



a...



b...



c...

FIG 4 Simon (1924) Gnathostatic diagnosis

- a...Face-bow record
- b...Gnathostatic mounting of casts
- c...Cast analysis using symmetrograph

#### 1.3.1.2. The Comparator

Savara et al. (1969) describe a modified comparator attached to a decimal converter and a key punch which allows direct readings to be taken from the study model and have these readings converted to a computer punch card, (Fig 5). Importantly the comparator is a sliding vernier scale which can move along an x-y axis. Points are located via two sets of cross-hairs, one on either side of a 1.5 cm. block of perspex to avoid parallax error. The point is located and marked, in this case directly converted into computer data. This is an early form of digitisation. This method also relies on a fixed study model position from which all measurements are made.

#### 1.3.1.3. The Occlusogram

Garner (1971) used the occlusogram to analyse cleft palate occlusions. The occlusograms were obtained from photographs made from a camera set-up to give 1:1 images. The trimmed study models were then traced on acetate and superimposed in centric occlusion.

The occlusogram as described by White (1982) is similar in its approach but bypasses the need for a camera, (Fig 6). It involves the use of trimmed maxillary and mandibular study models with a locating groove cut into the back of the models. The models have been trimmed so that their backs are perpendicular to their bases and the bases are parallel to one another and the occlusal platform. The occlusal platform is clear and the models are each

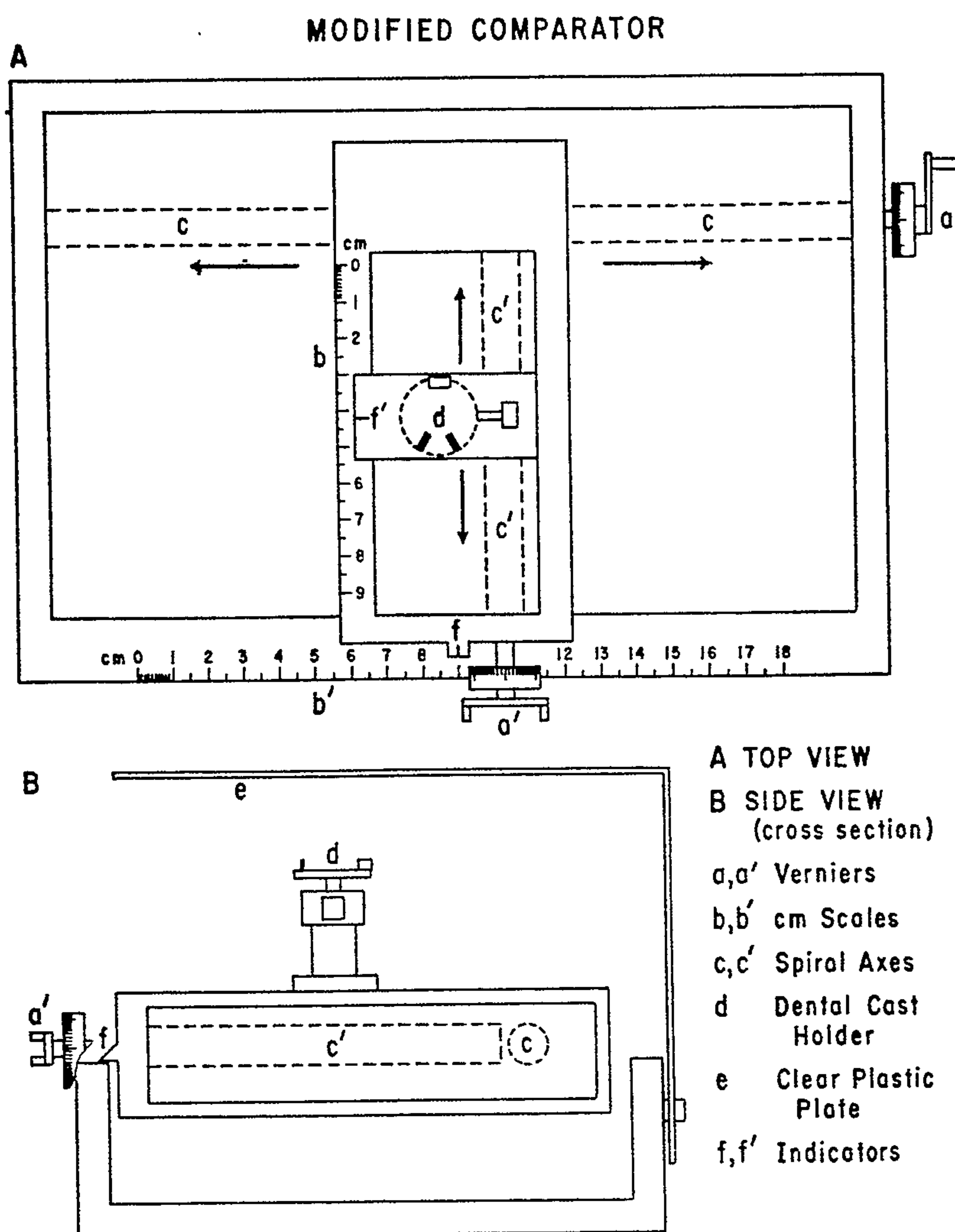


Fig. 1 Modified Comparator, utilized in recording landmarks as Cartesian coordinates.

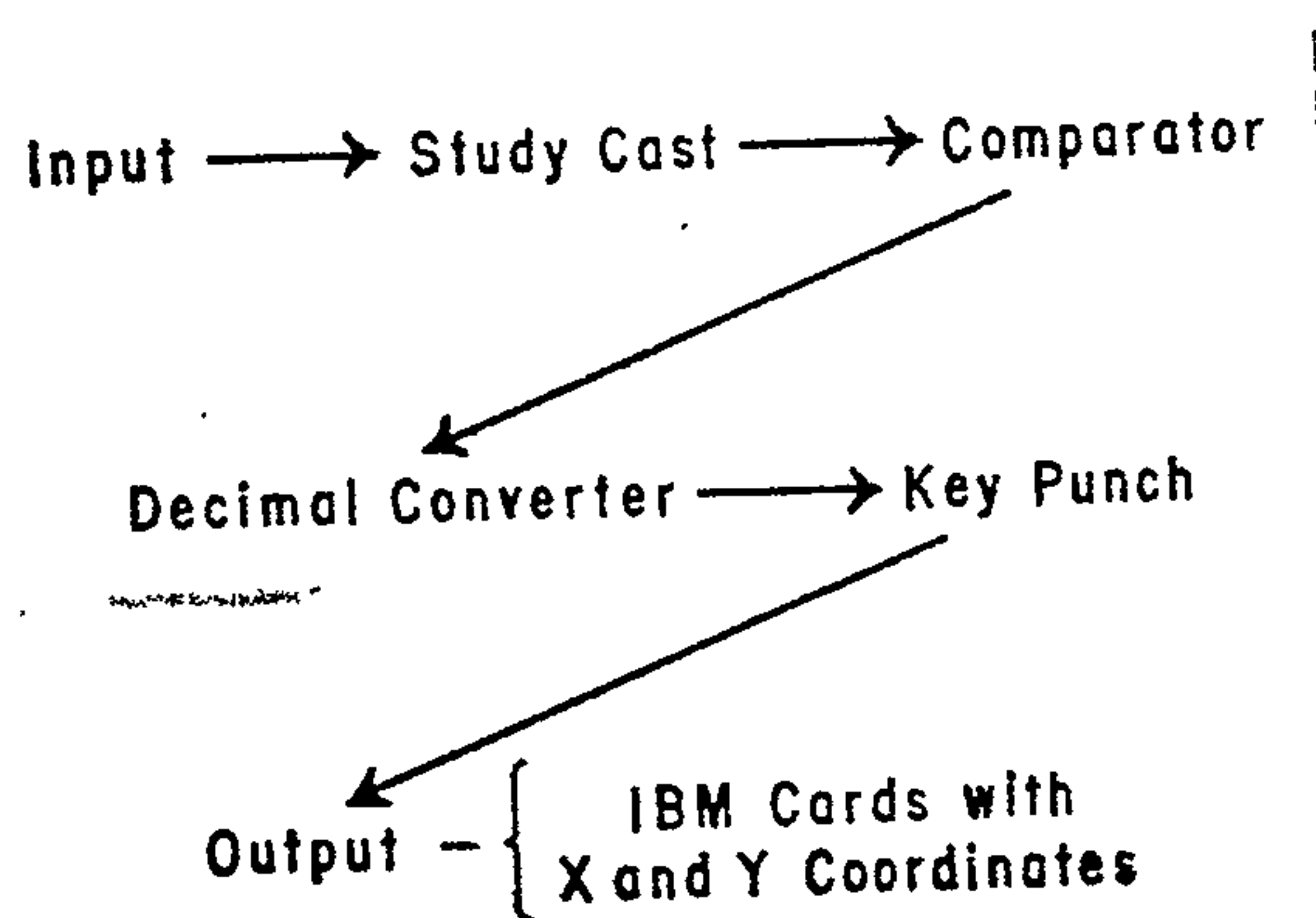


Fig. 2 Flow Chart of the procedures.



a...



b...

FIG 6 White (1982) The Occlusogram

a...Grooving the back of the models  
b...A model under the tracing table

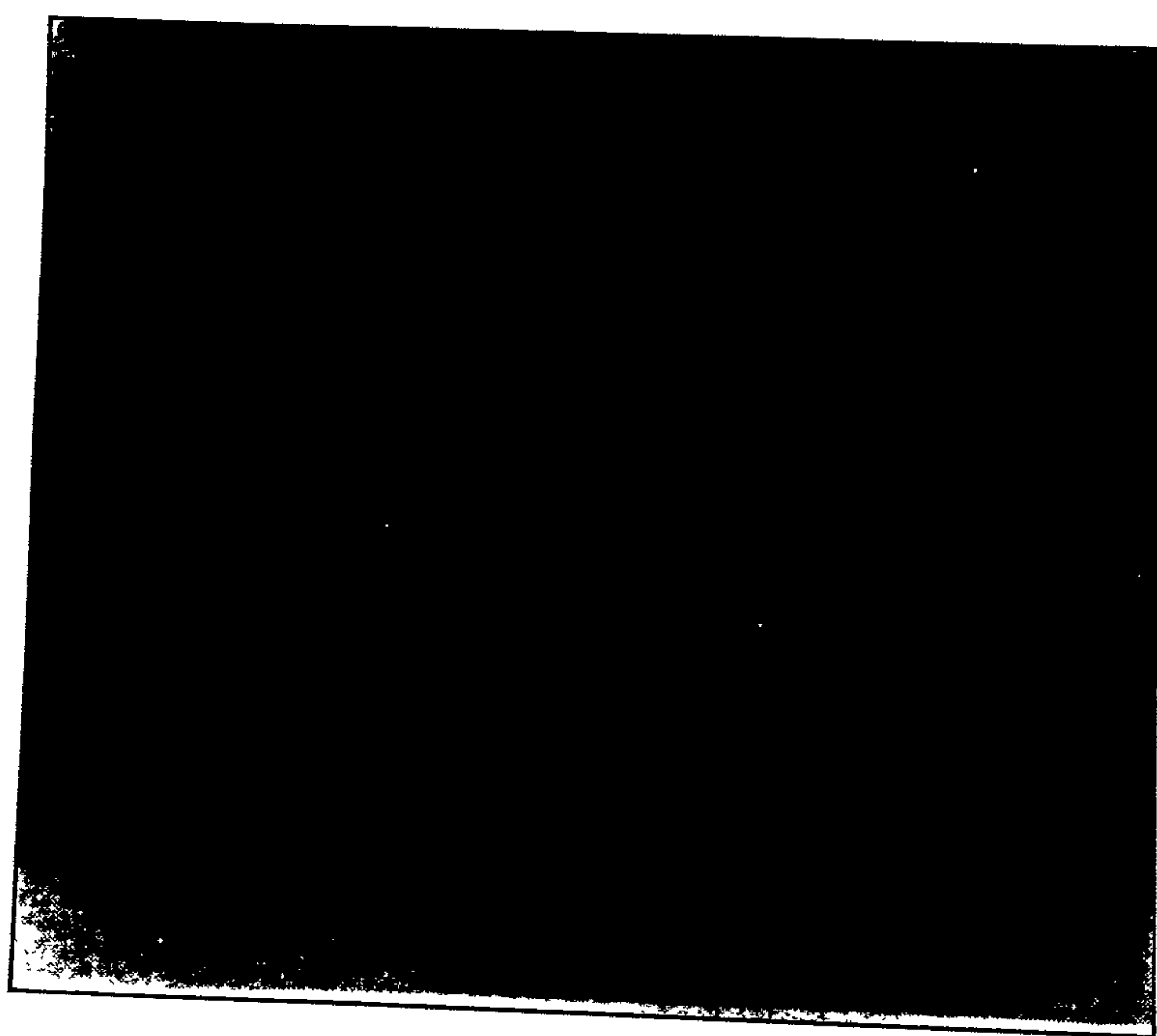


FIG 6 (cont'd)      White (1982)      The Occlusogram

c...A tracing showing the Mx/Md superimposition

placed under it. The respective occlusal surfaces are traced, freehand on a piece of acetate sitting on the occlusal platform. The tracing of the locating groove allows the two pieces of acetate to be superimposed giving a representation of the interrelationship of the maxillary and mandibular teeth. White explains that with practice the parallax error is overcome. This may be useful in clinical diagnosis. It would, however, be difficult to use in a longitudinal study as locating reference points on the maxilla would involve a parallax effect due to the distance between the palatal surface and the acetate.

#### 1.3.2. Photographic Projection

Photographic projection involves the use of fixed study models, generally oriented to the occlusal plane. The models are marked beforehand and then the photograph is taken. The magnification is generally on a 1:1 scale.

Biggerstaff (1969) describes a setup used to study the human post-canine dentition, (Fig 7). A 4x5 Crown Graphic camera and lights are mounted on a stand with the lens level. Directly below is a Williams surveyor used to fix the study model in position with the occlusal plane level. A plexiglas plate is placed on the occlusal surface so that the orientation lines lie adjacent to the anterior teeth and form a line of best fit between selected points along the mid-palatine suture. The relationship between the orientation line and the anterior and posterior parts of the

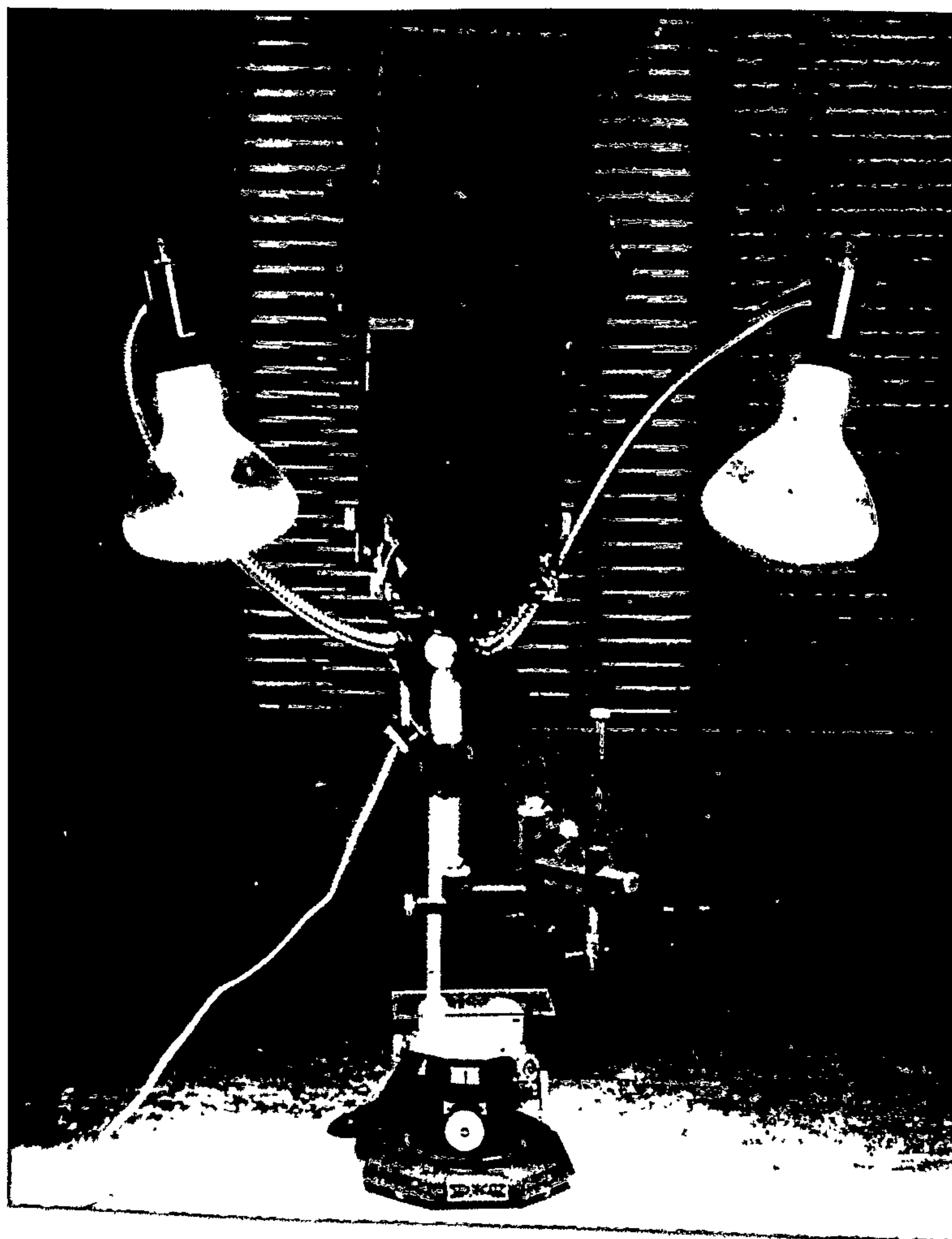


FIG 7      Biggerstaff (1969)      Photographic projection  
Apparatus and photographs

cast are recorded on the cast so that this can be transferred to the mandibular cast using an extension to the vertical arm of the surveyor.

Biggerstaff used some 150 landmarks on a maxillary cast. The accuracy was tested by duplicating one cast 10 times, with 10 individuals marking a cast. Each cast was then mounted and photographed as previously described. The digitised data found that variation in marking occurred in the range of  $0 \pm 0.15\text{mm}$ . Fossae and intersecting ridge points ranged from  $0 \pm 0.05\text{mm}$ , while sharply defined points ranged from  $0 \pm 0.10\text{mm}$  and rounded or worn tip ranged from  $0 \pm 0.15\text{mm}$ .

White (1982) refers to Burstone's Orthoscan camera as an occlusogram unit delivering polaroid prints. As can be seen by Biggerstaff's study the principal of photographic projection is reliable.

Another form of photographic imaging is the use of the photocopying machine. Singh and Savara (1964) tested the photocopier for accuracy of measurement and reproduction, and found that, provided the casts were placed in the middle 10cm of the photocopier plate, no significant enlargement would occur. Cast and photocopy measurements were equally reproducible.

### 1.3.3. Radiographic Imaging

Very little has been done by way of radiographic imaging. Brodie (1966) made reference to Downs regarding his use of radiographic images of study models to assess basal arch form. Apart from that

and the work done by Wasilewsky (1986) there has been nothing else to find.

#### 1.4 Three Dimensional Imaging Processes

Although three-dimensional imaging has been available for many years using stereoscopic methods as shall be discussed in this section, it has only been since the advent of the computer and the use of digitisation that the amount of information required to reproduce a three-dimensional measurement has been made readily accessible. Technology has allowed the rapid fixing and manipulation of a point in space by analysis of its X,Y and Z co-ordinates.

There are five processes which have been developed in order to allow the plotting of points in a three-dimensional manner, these are ;

- 1...Direct physical measurement
- 2...Stereographic projections giving three-dimensional images
- 3...Direct three-dimensional mapping
- 4...Holography
- 5...Radiography

##### 1.4.1 Direct physical measurement

Van der Linden (1972) developed the Optocom, (Fig 8). This instrument is essentially a sophisticated symmetrograph which allows direct measurement of a model, first in the x-y or

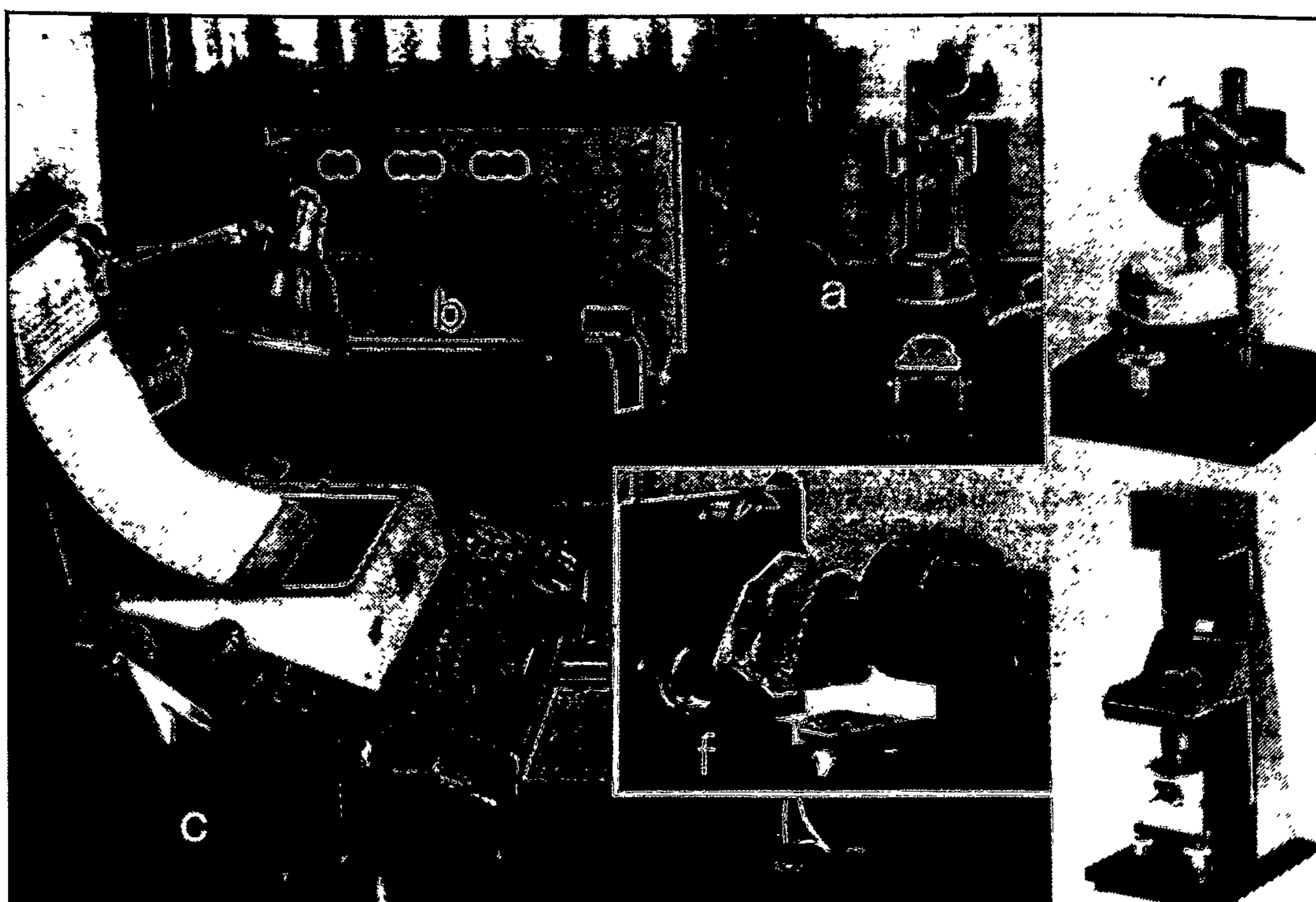


FIG 8      Van der Linden (1972)      The Optocom

occlusal plane and then in the z or sagittal plane. These two measurements are then processed to give a plotted three-dimensional position.

The Optocom consists of a microscope mounted over a two-dimensionally movable table. The cast is precisely fixed into position and a point to be recorded is aligned with the centre of the cross-hairs on the microscope. The magnification factor is 10 and the depth of field is 5mm without adjustment. The position is recorded by using two measuring rules with photoelectric screening heads mounted on the bottom of the sliding table. These rules record to tenths of a mm. The information is then converted through a data converter and onto the teletype. All the information is typed out on the teletype and punched out on paper tape.

The third dimension is recorded by transferring the base and cast vertically to a slot which is oriented to the microscope and using a pointer placed on the sliding base, again in a standard position, the base is moved until the pointer touches the point to be marked and the third dimension (z co-ordinate) is recorded. This information is then also converted.

In order to co-ordinate one arch to the other, van der Linden built an orientation tower with two parallel platforms. The maxillary model is oriented to have the occlusal plane parallel to the base. The mandibular cast on the upper platform is brought down into correct occlusion with the maxillary cast and the universal joint of the platform of the mandibular cast is

tightened to locate the mandibular cast. This is then transferred to the sliding table in a pre-oriented position.

Van der Linden states that this process, using 387 points takes an experienced operator approximately 20 minutes to record one set of casts.

Van der Linden also developed programs to spot operator error and check on the validity of the collected data.

It is with this instrument that he made his measurements in his studies regarding the stability of the palatine rugae, which will be elaborated on in a later chapter.

More recently Furukawa (1984) studied tooth marks regarding their reproducibility and accuracy of identification, using a three-dimensional measuring instrument. This instrument is called a Vectron, (Fig 9). It is equipped with a flexible arm which is made up of three joints giving three degrees of freedom and allows flexible movement in a given plane. A turntable, on which the casts sit, allows rotation in both directions and a monitor allows the display of x,y and z co-ordinates up to five digits. Measurements are achieved via a searching needle which is mounted on the end of the flexible arm. This needle can rotate about the arm's central axis and remains stationary at its point, which allows free movement when marking a point. The needle has a working range of 400 mm in the horizontal or x-y plane and 300mm in the vertical or z plane. The whole apparatus with associated computer facilities can transfer co-ordinates and measure

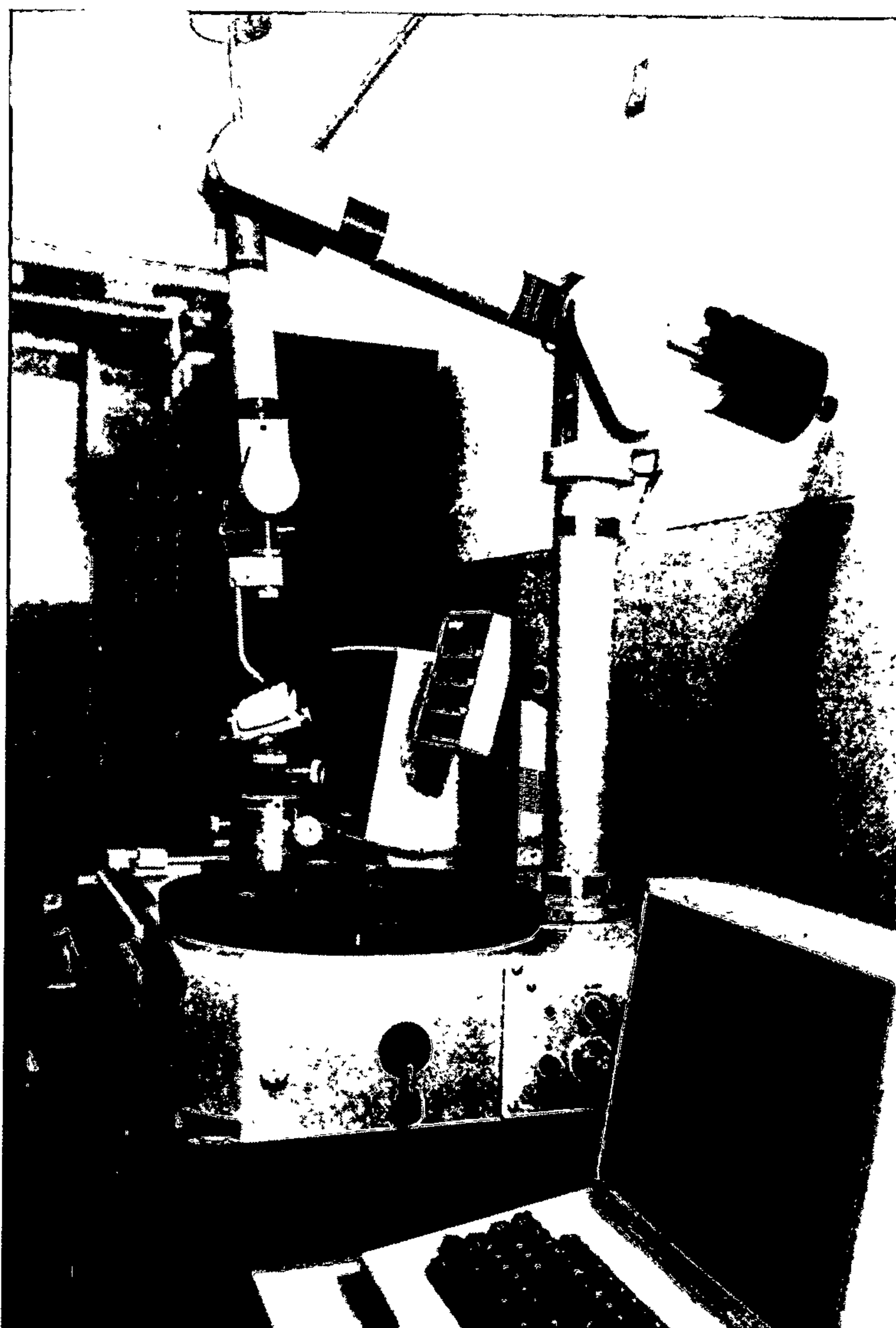


FIG 9      Furukawa (1984)      The Vectron      -      apparatus

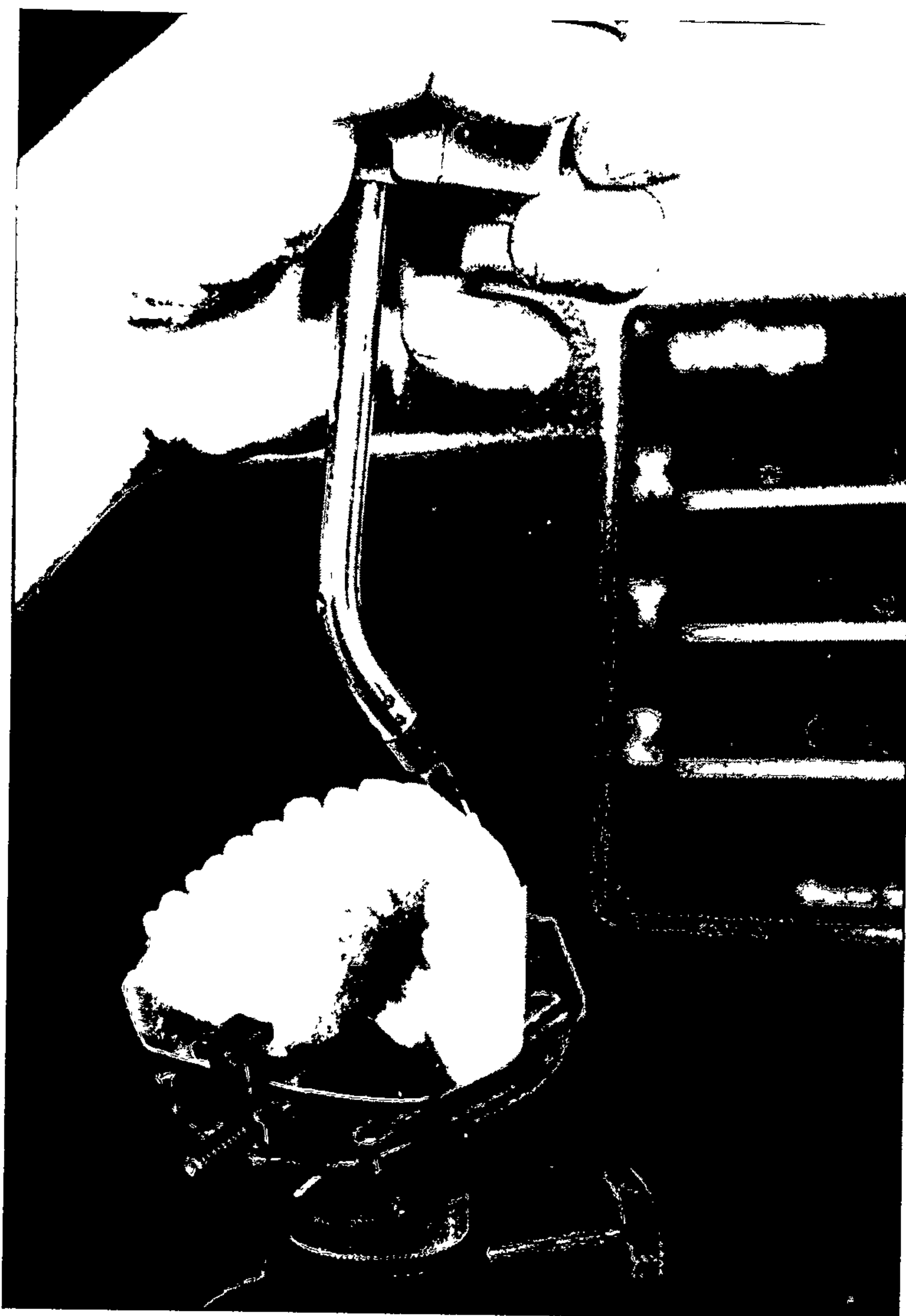


FIG 9 (cont'd) The Vectron - the measuring instrument

distances and diameters of circles and intersecting angles etc. The relative precision of the instrument was found to be  $\pm 0.1\text{mm}$  for points on an axis,  $\pm 0.2\text{mm}$  on an arbitrary point and  $\pm 0.4\text{mm}$  for a distance.

#### 1.4.2 Stereographic projection

This is the process which has generated the most development. It is possible to generate a three-dimensional image using the principle of binocular vision applied to two images of an object. The images which have been used are photographs, radiographs, the actual study cast and a reflected image to provide the two images. Photographs and radiographs develop a contour map from which the perception can be gained. The use of a reflected image and the study cast with a light source spotter uses the model for its contour but still needs the stereographic effect to locate each point.

##### 1.4.2.1 Stereophotogrammetry

Used by Mannsbach (Berkowitz and Prusansky 1968) in 1922 to study orthodontic casts, this method of three dimensional imaging has been applied in many fields including medicine and dentistry. Berkowitz and prusansky (1968) quoted form Hertzberg (1957), their description of stereophotogrammetry as an anthropometric tool:

"The basic principle of stereophotogrammetry is exactly that of binocular vision. The two eyes send slightly different images of

an object to the brain, where they are interpreted in terms of depth as well as length and breadth. Similarly if two binocular or stereophotographs of an object are juxtaposed so that the left eye sees the left photograph and the right eye sees the right photograph in proper relation, the perception of depth can be as clear as if the object were seen directly. By suitable optical devices, stereophotographs of nearly any size can be made to give the effect of relief."

In the field of dental applications work has been done by many authors. Bjorn et. al. (1954) measured facial swellings. Savara (1965) measured three-dimensional contours of tooth surfaces. Berkowitz and Pruzansky (1968), Berkowitz (1971) and Newton and Evans (1976) all studied aspects of palatal development using stereophotogrammetric methods.

There are two basic systems used to obtain stereophotogrammetric photographs for analysis. One involves the use of a single camera, where the object is moved to obtain the required change of angle. The other involves the use of two cameras with the target object immobilised in the centre.

Berkowitz and Pruzansky (1968), (Fig 10), have described a system which uses one camera. This particular system used a speed graphics camera with a Schneider-super angular lens with an angular field of view of 100 degrees. This field of view and a principal distance of approximately 150mm were chosen to ensure the true geometry of the plotting instrument, which was a

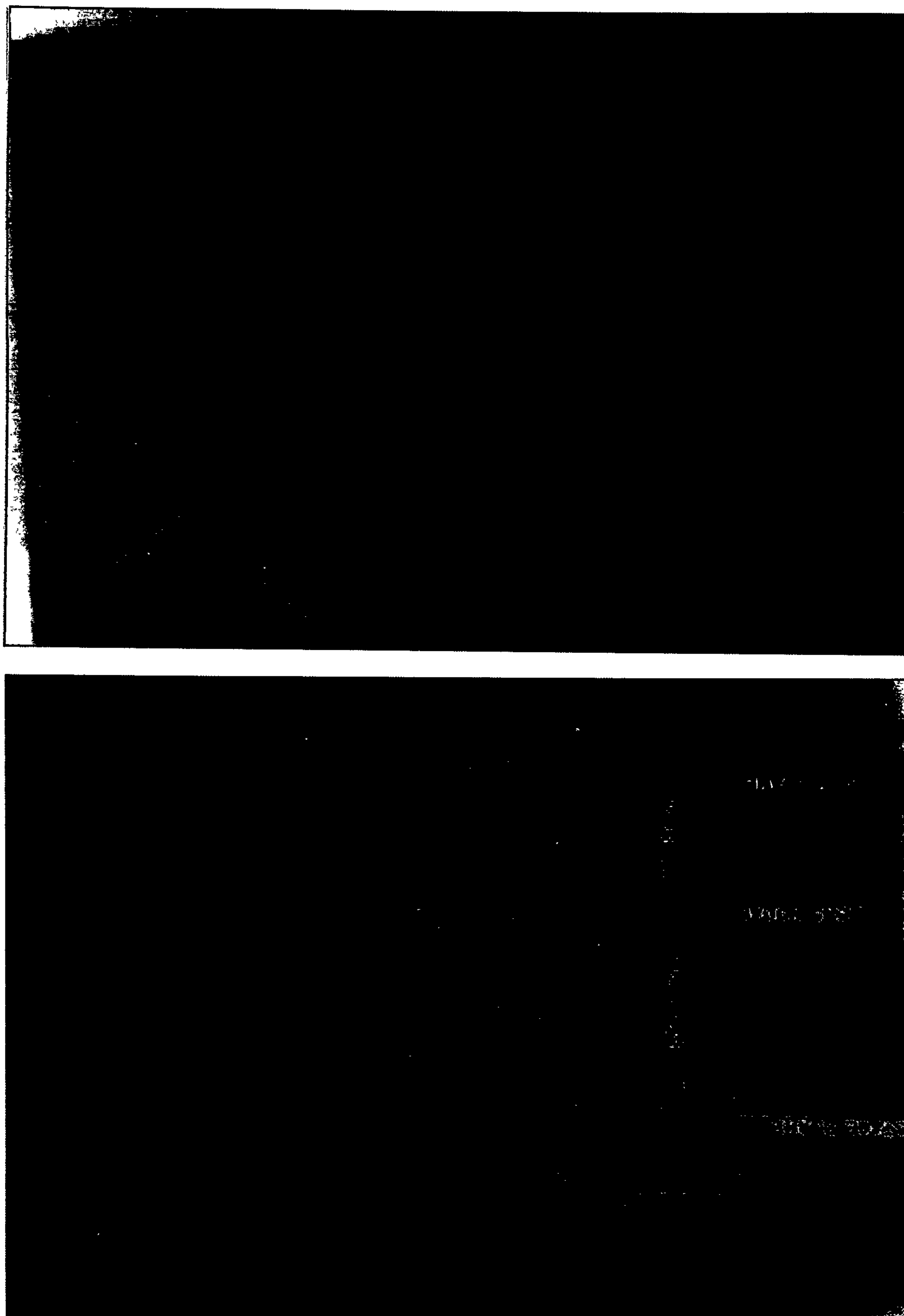


FIG 10      Berkowitz (1968)      Stereophotogrammetry - single camera

Galileo-Santini stereo-plotter, for contour mapping. The diagram shows the optical setup. The models are mounted on a stage plane which moves to allow the stereophotographs to be taken 100.5 mm apart. A grid is placed on the stage plane to allow for calibration of the measurements. It is also important to note that the study models must be oriented accurately in order to prevent distortions due to changes in the angle of photography. To improve accuracy in the technique Berkowitz (1971) used glass plates as negatives which were large enough to use as diapositives. This eliminated the need to enlarge the film in order to carry out measurements on the plotting image, another source of error. He placed collimating marks on the cassette to ensure accurate alignment of the film and the lens.

Berkowitz found this system to have an accuracy of standard deviations of  $\pm 0.055$  mm for the X co-ordinate,  $\pm 0.069$  mm for the Y co-ordinate and 0.358 mm for the Z co-ordinate. Savara (1965) found a plotting accuracy of 0.025 mm.

Savara suggested that it should be possible to obtain stereographic photos directly from the mouth. Savara also suggested that the problem of orienting the models be overcome by programming the effects of the mapping distortion into the analysis.

#### 1.4.2.2 X-ray stereophotogrammetry

As with photos, radiographs can be used to create a three-dimensional image using the same principles. This technique was applied to the location of impacted upper canines by Berghagen (1954).

Mc Neil (1966) described a system which could be used to analyse paired stereo-radiographs. He noted three differing conditions which exist in x-ray photogrammetry:

1....Radiology involves irradiating the object from a small source onto a receptor, while photography involves reflected radiation (light) being collected and focused onto a receptor.

2...The receptor and object planes in radiography are usually parallel so that tilting does not need to be considered when determining the spatial position of the points.

3...The radiographic images are either larger or approximately the same size as the objects.

Stereoradiographs can be produced in different ways (Fig 11), the most economical is configuration (d).

McNeil was impressed with the accuracy of the technique, to "a few thousandths of an inch" when using test objects but admitted that the critical problem is point identification.

Baumrind (1971) described the intricate procedure used to integrate frontal and lateral cephalometric radiographs, study models and photos, all by stereophotographic means and thereby reduce this information to computer data to give a full three-

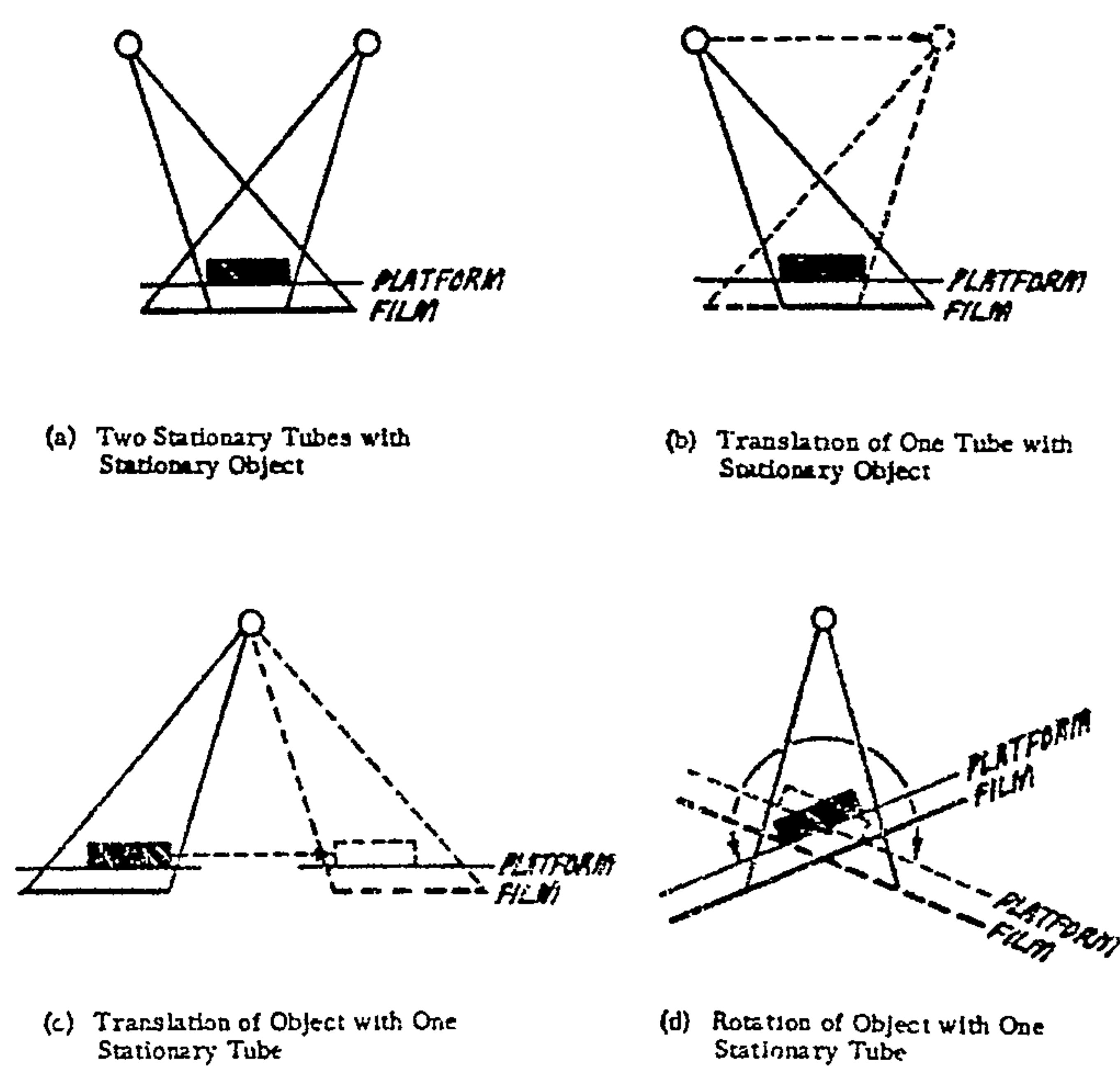


FIG 11      Mc Neil (1966)      X-ray Stereophotogrammetry

Four      basic      configurations      for      exposing  
stereoradiographs

dimensional craniofacial mapping system. This system used an integration of three definite sub-systems :

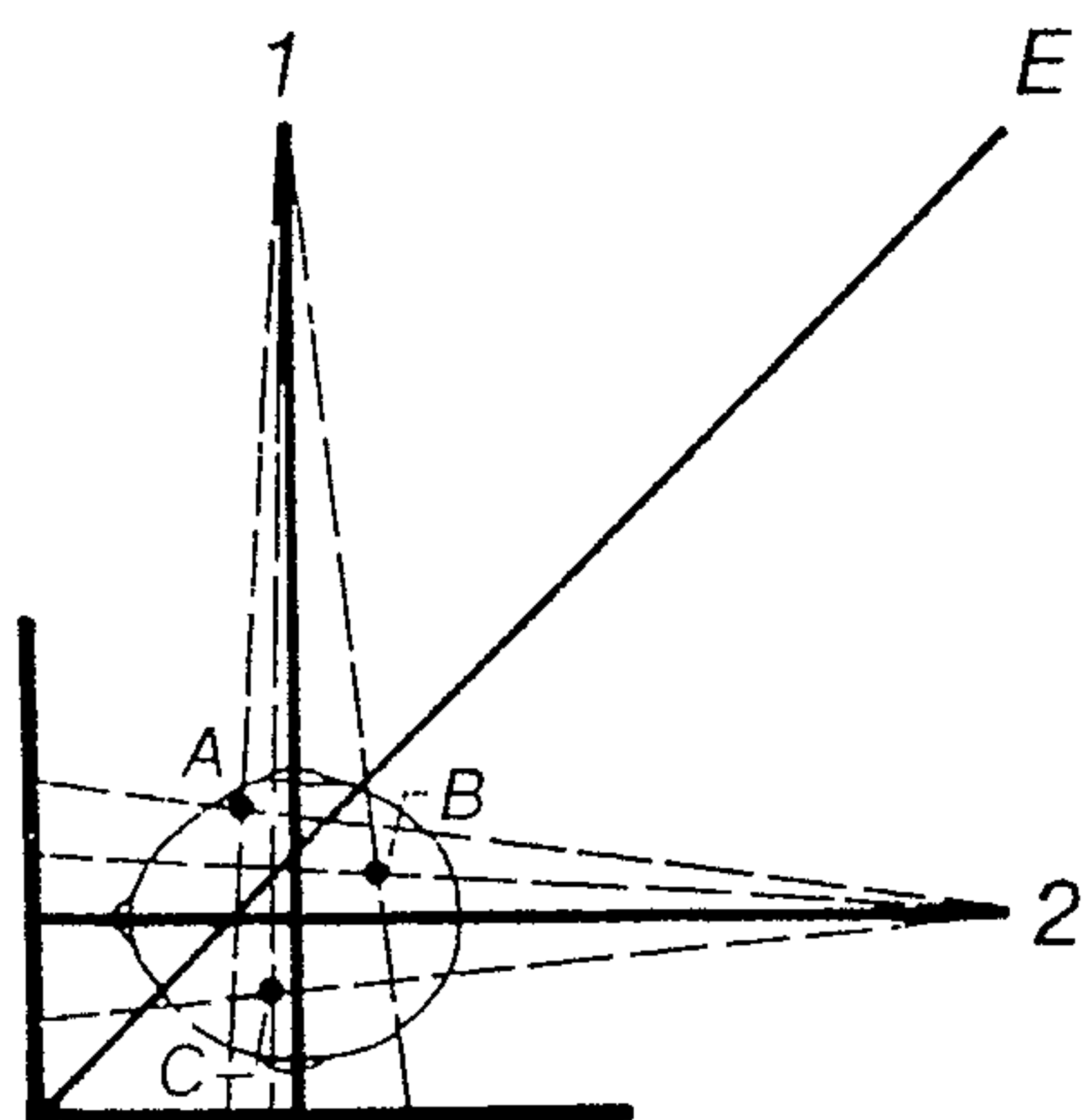
- 1...A stereo x-ray system
- 2...A stereo camera system for the study models
- 3...A stereo camera system for the face

The three systems were tied together by radio-opaque as well as "photographable" markers to act as control points for location and scale.

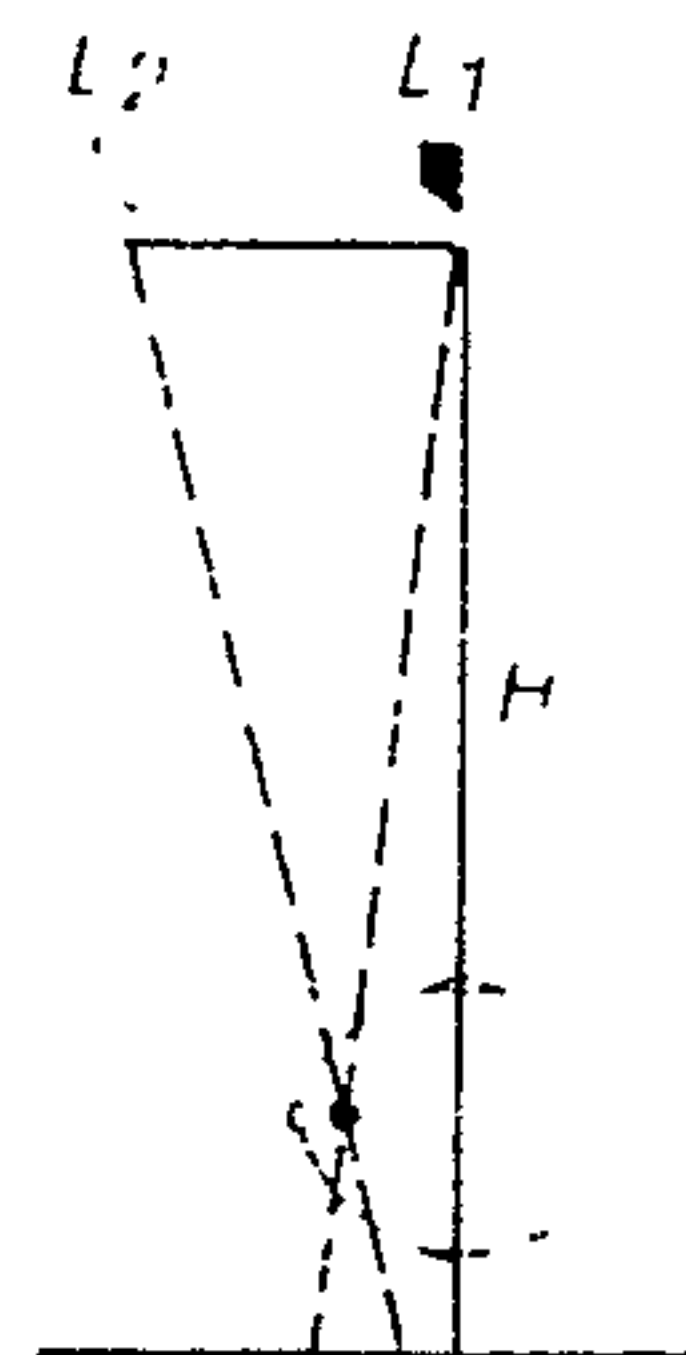
Baumrind (1981) updated the three-dimensional x-ray stereogrammetry from paired co-planar images. He explained the difference between Broadbent's attempts at using biplanar projections and his own coplanar projections, (Fig 12). The biplanar projections do not allow accurate identification of landmarks on both films, whereas coplanar distortions, being much smaller, allows stereophotogrammetric location of the points on both the frontal and lateral views which then can be integrated. This is a highly specialised field of endeavour which involves intricate computer software and hardware as well as a complex and costly physical approach which, to a large extent has been simplified by the use of computed tomography. Computed tomography will be discussed later in this paper.

#### 1.4.2.3 Plotting from photographs

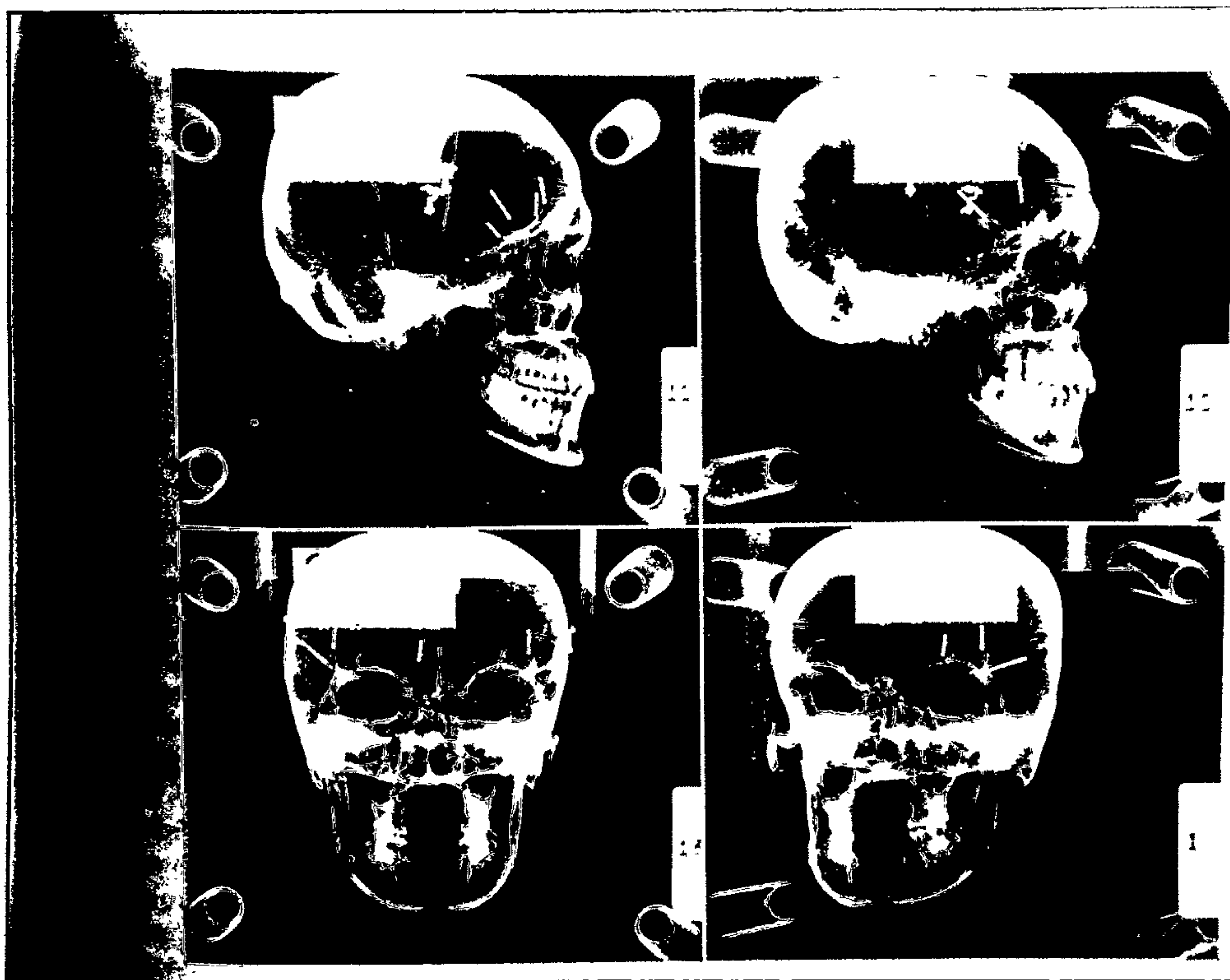
BeGole et.al.(1981) put forward a method of recording dental cast relationships in three-dimensions, using photographs as the basis for digitisation. With this information, the computer then was



a...



b...



c...

FIG 12 Baumrind (1983) 3-D x-ray stereometry

a...Broadbent's "biplanar" method  
 b...Baumrind's "coplanar" method  
 c...Stereographic x-rays used by Baumrind

able to assess descriptive parameters such as Bolton's ratios, mesio-distal relationships, overjet and overbite, curve of Spee and tooth/arch discrepancies. Prior to photography of the casts two orientation lines were marked on the casts with a pencil. These were the dorsal aspect of the incisive papilla and a point on the palatine raphe near the fovea centralis. With the teeth in occlusion, these points were then transferred to the mandibular cast using a device which allows vertical movement and indents the mandibular cast directly below the maxillary cast. It is pointed out that the photographs taken require the occlusal plane to be parallel or perpendicular to the film at all times. Five views are taken; maxillary and mandibular occlusal, left and right occluded and right lateral mandibular unoccluded.

The digitisation involves 118 points. The program corrects for magnification and orients the dental casts to the mid-palatine suture. The program is capable of handling up to five sets of study models of an individual patient, showing pre- and post-treatment changes. This data can also be displayed in a printed or a diagrammatic format, and can be kept as a diagnostic record of the case.

### 1.4.3. Direct Three-dimensional Mapping

This class of three-dimensional imaging processes involves itself with direct imaging from the study models without using a projection step as a separate intermediate phase. These systems in their mapping construction use an integrated build-up of two-dimensional projections, whether by light or radiographic means.

#### 1.4.3.1. The Reflex Optical Plotter

Butcher and Stephens (1981), reported this in a preliminary paper as a new method of intra-oral measurement. It works on the principle of binocular vision, (Fig 13). The observer views the target through a semi-reflecting mirror with binocular vision. A light source is moved to the appropriate position where the target point coincides with the light and is seen as one illuminated point. This position is recorded and the information is transferred from the light source as co-ordinates which are unique in a three-dimensional position.

Measurements were taken directly from the most mesial and distal points of the subject's six lower anterior teeth and were compared with measurements taken from models of the teeth.

The authors thought that while errors were comparable to direct measurement - S.E. of 0.159mm from model and 0.196mm directly from the mouth - further refinement was necessary and they also felt that this technique would lend itself to soft-tissue measurements.



FIG 13 Butcher (1981) The Reflex Metrograph

Takada et.al. (1983) studied the performance of the Reflex Metrograph as it became known. The study was designed to investigate the applicability of the Reflex Metrograph to the three dimensional analysis of dental casts.

Three points on a maxillary dental cast placed in six different positions were used to evaluate the measurement accuracy of the Reflex Metrograph. Because this process involves the alignment of the light source using eye judgement, ten operators were also used to test the possible differences in performance skills.

The authors concluded that digitisation of the study cast could be achieved without direct contact of the cast itself and that orientation of the cast did not affect the outcome. Inexperienced operators were able to determine specific points to an accuracy of  $\pm 0.1\text{mm}$ , with minimal training. When measuring distances, they recommended that operators be checked for inter-operator error by measuring a pooled sample.

This instrument functioned satisfactorily and was simple to use without requiring any intermediate phase, such as photographs. It was also noted that the three-dimensional co-ordinates could be obtained directly without correction.

Richmond and Jones (1985) compared two- and three-dimensional incisor angles from dental study casts and lateral radiographs using the reflex plotter.

Richmond (1987) then described a method of complete cast analysis in three dimensions. He reported that cast plotting took twenty minutes for some 110 points. He also reported that the error

found was less than 0.27 mm with an angular error of less than 0.76%. It was possible to fully describe and store a plotted version of the study models to aid in case analysis.

Jones et al. (1988) studied the dimensional changes of alginate impressions following disinfection regimes using glutaraldehyde.

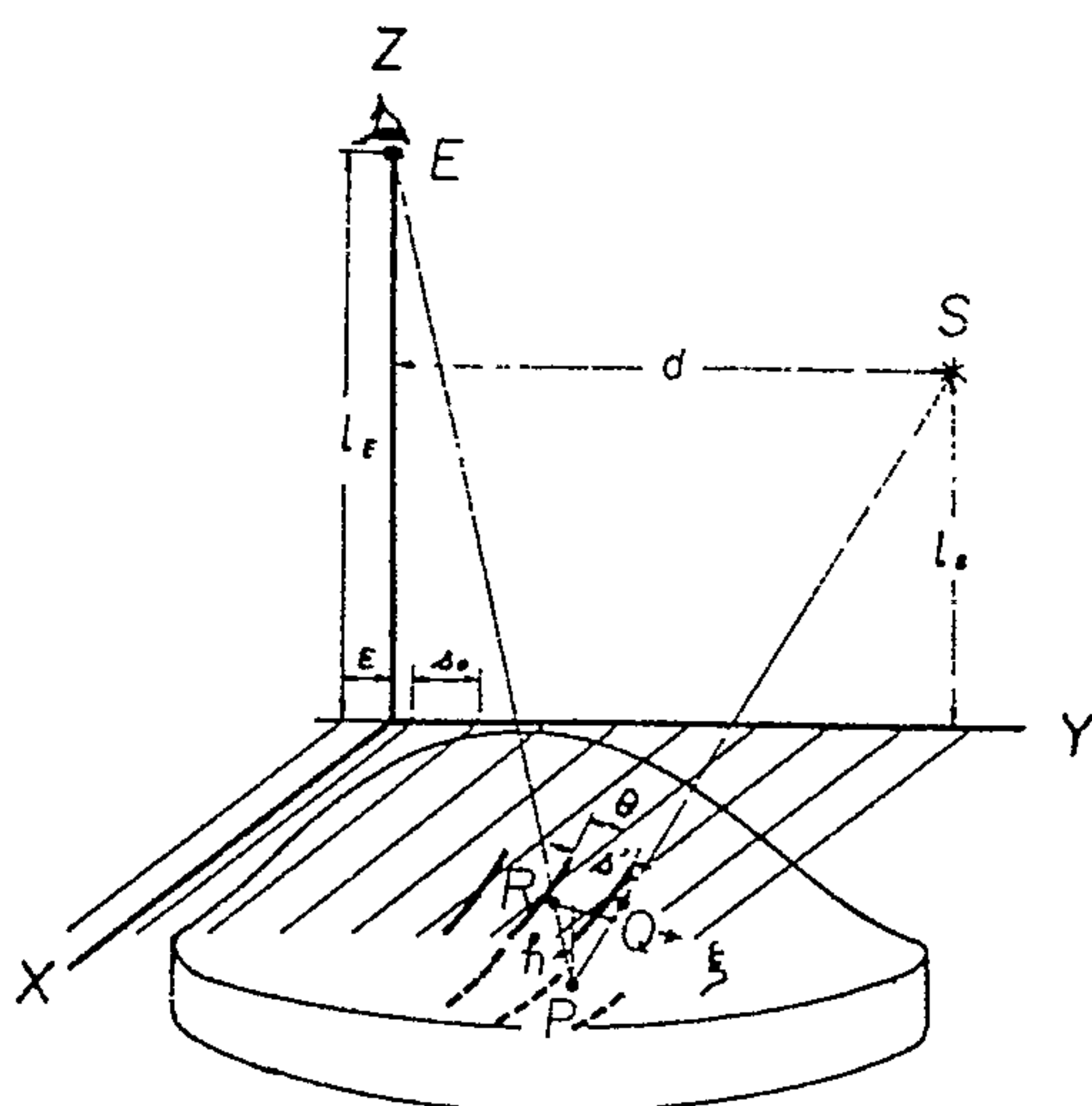
#### 1.4.3.2. Moire Topography

Takasaki (1970) described a method of three-dimensional mapping of an object using contour lines projected onto the body from an equispaced plane grating. This was a simple method of direct mapping not involving the use of stereoscopic methods.

The principle involves the projection of an equispaced plane grating onto a three-dimensional surface, (Fig 14), from a point source (s). The object is viewed from a point (e). The points (s) and (e) lie on the y-axis. The x-axis is along the grating lines, and (e) lies on the z-axis. The heights of (e) and (s) are known as is the line spacing of the grating and the initial phase of the grating.

A point P on the surface of the object can be seen on the grating at R ( $x_r, y_r$ ). The projected contour around P from (s) is also seen as an out-of-phase grating. The amount of distortion can be calculated and this is related to the depth of P from the grating. It is therefore possible to accurately calculate the position of a point on the surface using this method. Photographs can be made and these can later be analysed with the grating.

Takasaki (1973) went on to develop a camera system for large



a...



b...

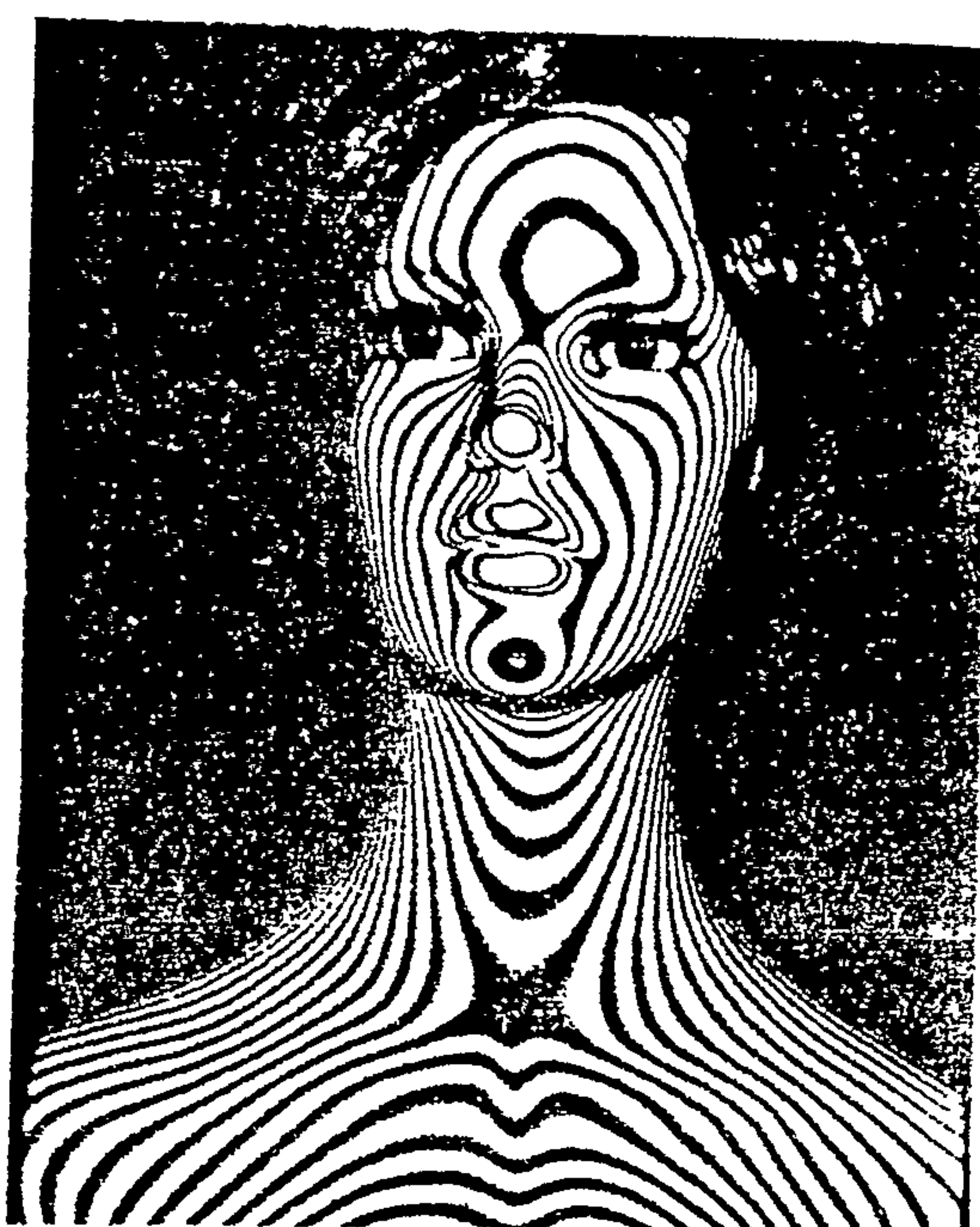


FIG 14 Takasaki (1970) Moiré' Topography

a...Principals of the Moiré' technique  
b...Images formed

objects such as the human body. Nobudo Ohta et al. (1982) and Kenzo Hojo et al. (1982) studied facial growth and form using this technique. Takei et al. (1985) used this method to study dental study casts and individual canines. The reason these ranges of measurements are possible is that the width of the grid scale can be reduced to 0.2mm as used on the maxillary canine. From the results tabled the method has been used to measure lengths in tenths of millimeters. Takasaki (1973) noted that depth accuracy was at a 0.2% level.

Soh (1983) studied the morphological changes in the palate associated with orthodontic treatment using the Moire technique. His findings will be elaborated in chapter 2 dealing with the use of the palatine rugae as reference points in this study.

#### 1.4.2.3. The Travelling Microscope

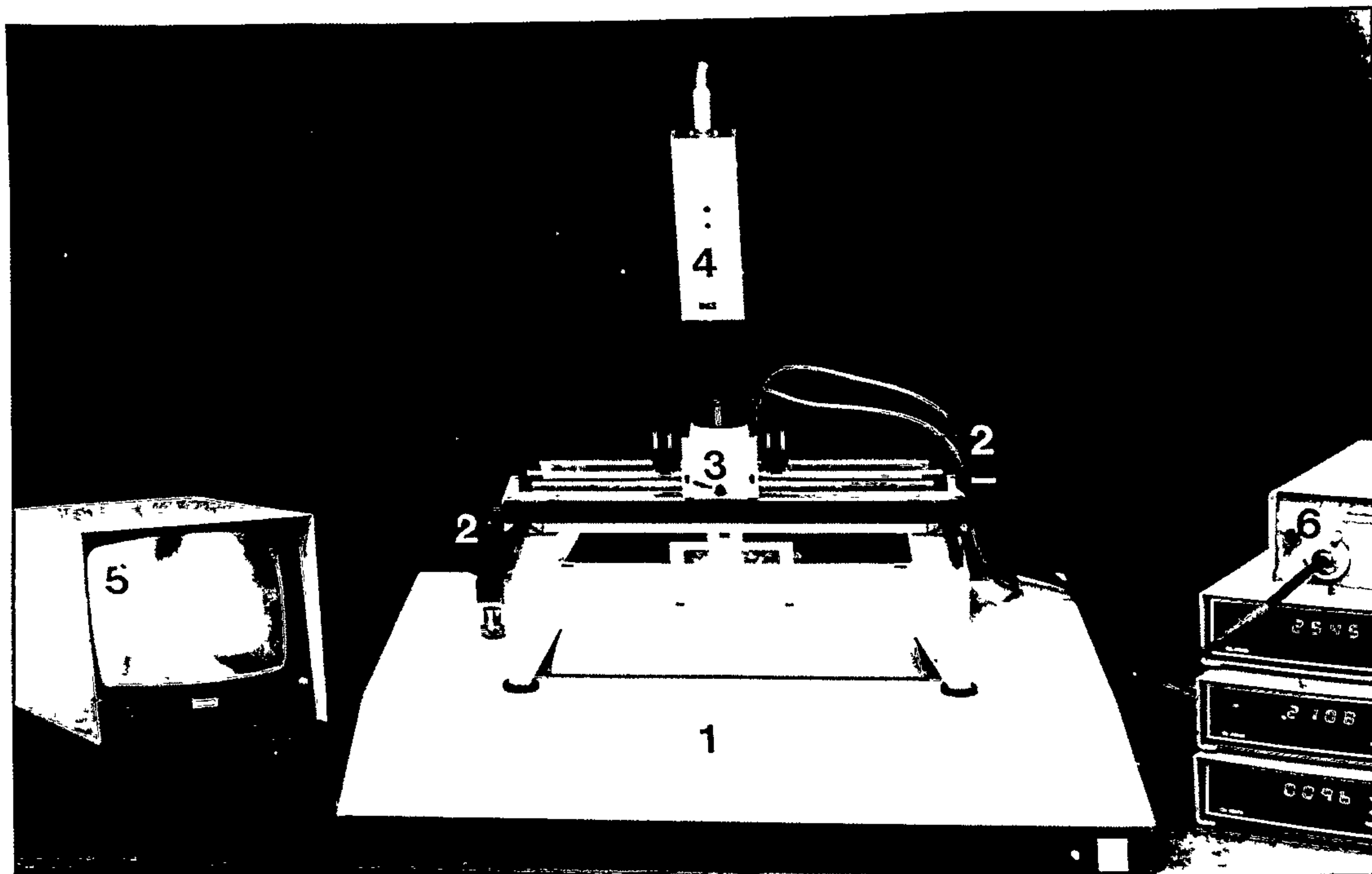
This is a similar instrument to the Reflex Metrograph, in that it measures in three dimensions without the need for contact with the object being measured. As with the comparator, the microscope moves on a slide system to locate the X-Y plane. In this situation however, the microscope has a graticule placed in the system to allow for focusing with the aid of a microimage projected onto the object itself. When the graticule and the micro-image are aligned then the system is in focus, and the depth of the lens movement is noted. This then adds the third dimension. Focusing can also be done subjectively.

Fig 15 shows the apparatus as used by Bhatia and Harrison (1987).

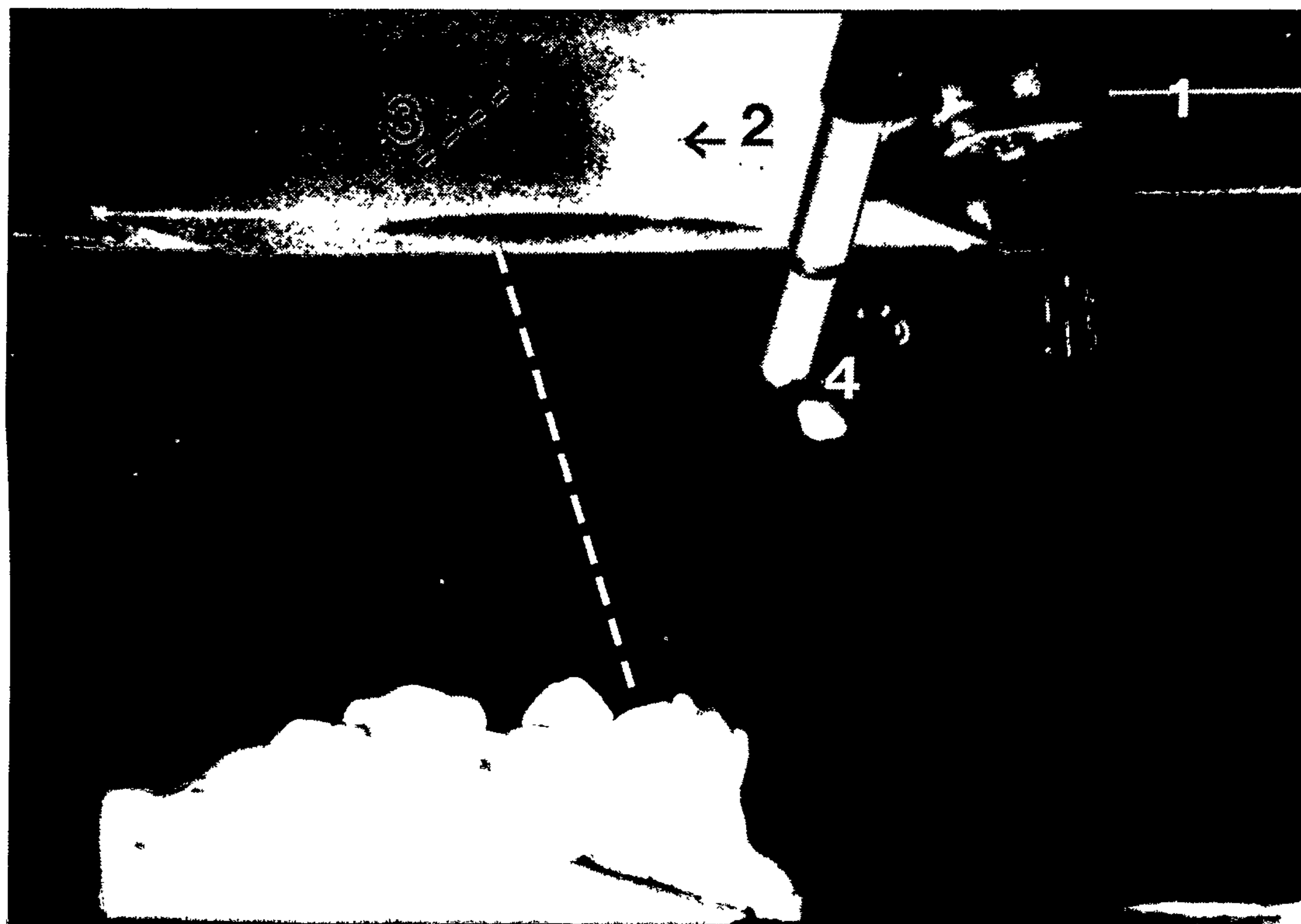
Bhatia and Harrison tested the instrument in the measurement of individual points marked and unmarked, and distances between these points. They found that the errors of replication of marked points for the X,Y and Z co-ordinates were,  $\pm 0.018$ ,  $\pm 0.017$  and  $\pm 0.031$  mm respectively. The errors for the unmarked points X,Y and Z co-ordinates were,  $\pm 0.169$ ,  $\pm 0.199$  and  $\pm 0.24$  mm respectively. The errors from linear measurements from marked and unmarked points were,  $\pm 0.069$  and  $\pm 0.22$  mm respectively. This particular instrument can also use the light table to measure two-dimensional radiographs or photographs.

The Reflex Microscope is a further development of a combined reflex metrograph and travelling microscope. Bhatia and Harrison reported the future development of these instruments were leading to automation and ease of use.

MacLarnon (1989) reported on the performance of all the reflex instruments. There are three new instruments available besides the Reflex Metrograph, these are; the Reflex Microscope, the High Precision Reflex Microscope and the Translating Reflex Microscope. Each is used in different applications related mostly to the size and nature of the object being measured. They all work on the same optical principles as the Reflex Metrograph. The standard deviations involved in calculating distances between two points range from between 0.003 - 0.01mm, for the standard Reflex Microscope. These are extremely precise instruments. The associated computer hardware and software allows these



a...



b.

FIG 15 Bhatia (1987) The Travelling Microscope

a...The apparatus

b...Close-up of focusing instrument

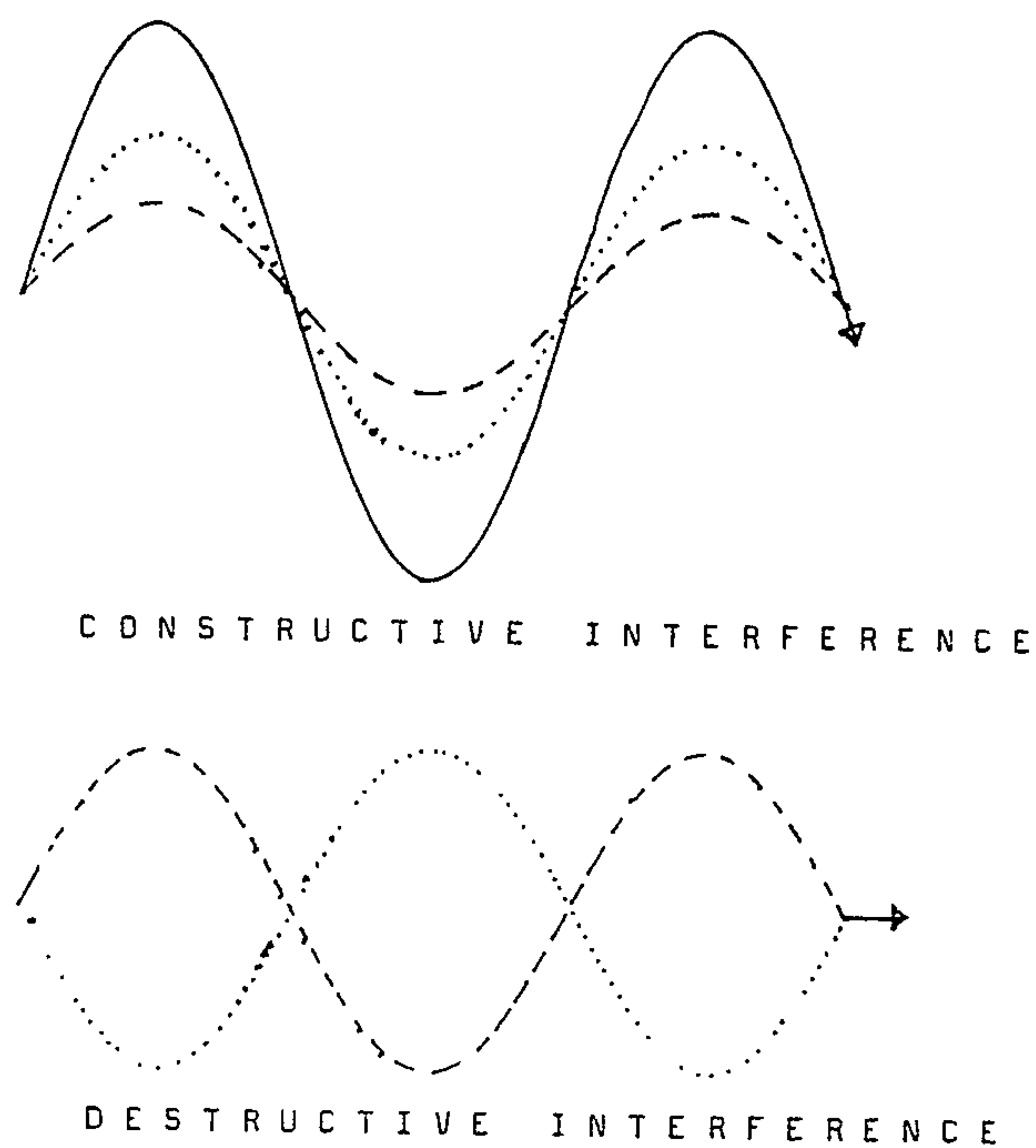
to generate contour maps, calculate areas and project onto specific planes. The instruments can be used to measure many types of objects including fixed objects which cannot be placed on a stage, such as a fossil in a rock. The translating allows measurements to be made by moving the eye piece and not the table on which the object sits.

Adams and Wilding (1988) used the Reflex Microscope to study the wear of composite resins by using comparisons of changes in volume. The reflex instruments can also be used to measure from stereo-photographs or stereo-radiographs.

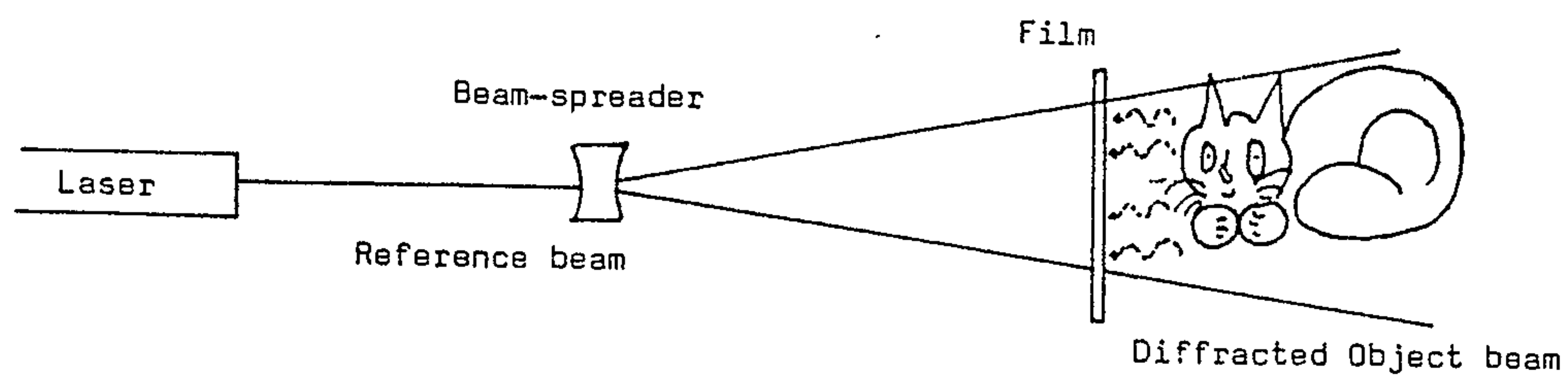
#### 1.4.4. Holography

Holography is a wave-front reconstruction process involving the use of lasers. It was first described by Gabor in 1948 (Keating et al., 1984).

As we know, light is an incoherent mixture of electromagnetic radiation of differing wavelengths and frequencies. From the study of waves we know that when waves converge there is a constructive or a destructive interference pattern generated, (Fig 16a). As light hits an object, an interference pattern unique to that object is generated. In order to attempt to map this pattern coherent light must be used. This is light of the same wavelength and frequency as that found in a laser beam. In essence then, the hologram is produced by two converging laser beams which produce an interference pattern when hitting an object, such as a study model. This pattern is recorded on film



a...



b...

FIG 16      Keating (1984)      Holography

a...Constructive and destructive interference patterns  
 b...Principle of the single beam reflection hologram

as in a photograph. This film can be developed to reproduce this pattern using the laser or using a white light source. As the light projects through the film the same interference pattern is generated and the holographic image appears where the object previously was.

When projecting the reconstructed image it is important to recreate the same conditions as when the object was photographed; otherwise the image will be distorted because the diffraction pattern generated will be different. The type of holographic technique used for this purpose is the single beam reflection technique. The object beam and reference beam are co-axial. The reference beam passes through the film and is reflected back as the diffracted beam to the object, (Fig 16b).

This was the method employed by Keating et al. (1984) in their investigations into a method for the holographic storage of study models to replace the need for the physical storage of the study models. This preliminary study measured the study models using a vernier calliper. The virtual images of the study models were also measured with vernier callipers. The film was sandwiched between two glass plates and placed on a simple stand so that measurements could be taken directly under the film. It was also important to recreate the same conditions as those in which the films were produced, to obtain an accurate reproduction of the study model. Fig 17 shows photographs of three views taken from a holographic image.

The authors found a random error of less than 0.33mm at maximum,



FIG 17      Keating    (1984)      Holographic images of a study model

for both the physical and holographic measurements. They did note that when measuring the depth of the study model the error increased to 0.64mm for the holographic image. This they concluded was due to the reliability in spotting the points to be measured and not the accuracy of the measurement. They too are attempting to combine the reflex metrograph and adapt its use to the measurement of holograms.

Ryden et al. (1982) used holographic images of dental casts and dental casts superimposed on one another to compare changes in position of teeth during treatment. Holography has been used to measure movements directly in the mouth by various authors. Burstone et al. (1982) measured incisor extrusion. Tooth mobility has been measured by Burstone et al. (1978) and Ryden et al. (1982). Williams et al. (1983) have examined the wear of class II restorations using a laser technique.

Buschang et al. (1990) studied the accuracy of measurements made from dental casts compared to those taken from holographic images. They noted that measurements made in the hologram's reference plane were comparable to those from the study casts. Measurements of depth, however, were less accurate. To ensure accuracy a series of holograms was suggested. Parallax was a suggested reason for this inaccuracy.

The high resolution of the interference pattern due to the small wavelength of light makes this method of method of imaging a precise one. The disadvantages of cost, vibration, tissue invasive character and image measurement are being overcome.

#### 1.4.5. CT Scanning

To complete an overview of imaging methods the CT scanner must be included. At this stage of development it is not directly being used to analyse the dentition in terms of study model analysis. It is however being used to directly view the dentition from within. Moss et al. have developed a system which combines surface laser scanning, for facial profile, and computed tomography for the skeletal structures, to simulate the face. This they have developed to aid in orthognathic surgery predictions in conjunction with programs to visualise the facial changes brought about by the proposed skeletal movements.

The technology can also be used to create patterns from which skeletal mould can be milled. It is possible that this technology may be used with dental analysis and replace the need for impressions in the future. Although this is an unlikely thought due to the cost and radiation dose, it represents the combination many of the principles of imaging already described.

#### 1.5. Conclusion

The measurement of study models has evolved throughout the years from a simple linear measurement, to the present attempts to extrapolate information in three dimensions.

This evolution has been made possible with the advent of digitisation, advanced engineering methods and computer technology. In the future, with the use of CT scanning or NMR, it

may be possible to realise Simon's objectives of 1924. His attempts to relate each portion of the face and dentition to each other portion, to assess the relative influence of each, was very far-sighted at the time.

The difficulty in relating the teeth to the cranium stems from the difficulty in finding reproducible reference planes, which can be measured as accurately as the study models themselves. This can be seen in the many methods described to position the study models in such a way as to relate the maxillary to the mandibular dentitions, without compromising accuracy of detail, and the use of the palatal rugae, (see Chapter 2), to attempt to relate change to the rest of the facial structures.

Three dimensional mapping of study models eliminates the need for projection in order to measure distances or areas. There is also the capacity to measure volume. Relative changes in tooth position can also be measured in longitudinal samples.

To use this information however, it is still necessary to use a point or plane of reference from which to measure the change. In orthodontic terms, one wishes to measure the contribution of change from each part to assess the effect of each. Thus the palatal rugae, although providing better accuracy with some three-dimensional measuring devices, still only relate the changes of the dentition to the palate and not the rest of the face.

It is therefore possible that a two-dimensional radiographic study model imaging system may be able to deliver the required

information with equal reproducibility and accuracy and less cost. This would then make it an accessible research tool to dentists, most of whom would have the basic equipment already at hand.

## CHAPTER 2

USE OF THE PALATINE RUGAE AND THE FUNCTIONAL MAXILLARY  
OCCLUSAL PLANE AS REFERENCE POINTS AND PLANES2.1        The Palatine Rugae

Winslow in 1753 (Peavy and Kendrick 1967), wrote about the rugae and Allen (1889) suggested relating the rugae to the teeth. Lysell (1955) measured and classified the rugae and studied their growth.

Friel (1949), Sillman (1951), Sved (1955) and Moorrees (1959), amongst others, all noted that during the development of the dentition and mesial migration of the teeth, the palatine rugae seemed to remain stable.

Carrea in 1937 (Peavy and Kendrick 1967), stated that the rugae patterns were formed in the twelfth to fourteenth week in utero and that they remained unchangeable throughout life regardless of tooth loss or orthodontic treatment. Hausser in 1951 (Peavy and Kendrick 1967), felt that sagittal tooth movement could be related to the rugae.

Two questions must now be asked:

1...How stable are the rugae? and

2...Are the rugae affected by orthodontic treatment?

### 2.1.1 Stability of the Palatine Rugae

In Lysell's (1955) study on the palatine rugae and incisive papilla, his primary objective was to describe and classify the rugae, and use this information to assess heredity and the possible use of the rugae patterns as a viable identification method.

Lysell stated that, in general, rugae are unchanged throughout life and could therefore be used as a method of identification. Nevertheless, he felt that this system would be too cumbersome and would never match the reliability of fingerprints.

Lebret (1962) studied the growth changes of the palate using the symmetrograph designed by Korkhaus (1930). His sample came from serial dental casts of 184 North American children of European stock. Of these only 30 {13boys 17girls} children's series of dental casts were acceptable due to the presence of malocclusions, tooth loss or poor casts.

Each series consisted of 5 casts ranging from 6 to 18 years of age. The 3 intermediate casts were chosen at different developmental levels:

- \* eruption of the permanent incisors and first permanent molars
- \* eruption of the premolars
- \* eruption of the permanent canines and second molars.

The initial casts were oriented in the horizontal plane by the occlusal plane and in the sagittal plane by drawing the median

raphe on the initial casts from 2 posterior points on the palate. Each subsequent cast in the series was oriented in the horizontal by using the median palatal contour line. This had already been shown by Korkhaus (1930) to be largely unaffected by growth changes.

The transverse orientation was accomplished by using a line drawn on the palate at the gingival level of all the teeth. The relative lateral tip could later be assessed by distance measurements from perpendicular projections from the median palatal contour line. This would allow for accurate orientation of the subsequent casts.

To determine the stability of the rugae, he then picked a point R on the most clearly defined ruga of the series and projected this point in a perpendicular to the median palatal line. He then measured the distance from R' to a point A required for his growth study. Three other points were randomly selected on the rugae (X,Y&Z) and the distances X'A, Y'A, Z'A and R'A were measured. Lebet found that these distances "were almost constant" for the entire series especially for points on the rugae close to the median palatal line.

His study also confirmed Korkhaus' results that the top of the palatal vault is essentially constant except for an increment in breadth increase at the apex in 75% of the series.

The mid-sagittal palatal outline was found to extend both forwards and downward and backwards of reference point A. This is a similar finding to Hellman's (1927) cross-sectional study of

skulls. Lebet in 1964, using this method, studied maxillary tooth migration relative to the rugae.

From Lebet's literature there were no figures available as to how constant "almost constant" was.

Peavy and Kendrick (1967) studied the effects of tooth movement on the palatine rugae by relating the pre-treatment positions of the primary rugae, as classified by Lysell (1955), to the teeth in zones. Measurements were done by symmetrograph and post-treatment zone changes were noted.

Their results showed that there was indeed movement of the rugae with treatment, especially the lateral aspects. The medial aspects remained stable.

They felt that the median projections of the rugae could be very useful in orienting casts to the mid-sagittal plane. They felt however that there was limited use for the rugae to determine amount and direction of tooth movement. They came to this conclusion because the measured changes were less than their error.

Van der Linden (1978) studied the changes in the position of posterior teeth in relation to the rugae points by means of the Optacom (1972). These changes were studied using annually collected casts of 65 children ranging from 6-16 years old. As he was only looking at changes through the erupting dentition of the children, he delineated three stages according to dental

development only, irrespective of age and sex. This allowed an evaluation of changes separating the deciduous, intermediate and permanent dentitions.

In this study Van der Linden noted that little or no change takes place in the length of the individual rugae and inter-rugae distances as projected onto the functional occlusal plane and calculated in a sagittal direction.

The measured change is near zero, with a 0.41mm maximum increase in length. No cases showed any decrease and only fifteen out of forty-two showed any increase.

#### 2.1.2 Rugae and orthodontic treatment

As previously mentioned, Peavy and Kendrick (1967) noted the changes of the palatine rugae points following orthodontic treatment. This they noted was confined to the lateral projections while the medial projections remained stable.

Van der Linden (1978) also studied six orthodontically treated cases and came to the same conclusions as Peavy and Kendrick. He also noted that if orthodontic treatment changes the occlusal plane relative to the palatal plane, then for every three degrees decrease in the angle there is a corresponding 1mm more dorsal projection of the molar onto the occlusal plane relative to the medial rugae points.

It is important to note that this change is a result of dental

movement relative to the palate and its significance will be discussed in the following section on the validity of the functional maxillary occlusal plane as a horizontal reference plane.

Soh (1983) studied the morphological changes in the palate associated with orthodontic treatment using the Moire technique. His method of levelling the maxillary casts to the occlusal plane involved the use of a plaster block. The plaster block was levelled with the occlusal plane and the study model was then oriented so that the moire pattern used the block as a base plane during projection.

Soh studied 29 adult female patients with maxillary premolar extractions and edgewise appliance placed. The mean age was 18 years. The palatine suture was designated the Y-axis and the X-axis was designated as the perpendicular at the deepest portion of the palatal vault. The moire pattern was set at 1 mm intervals. The areas and distances of each stripe were measured before and after orthodontic treatment. Changes in shape, area breadth and length were noted. Fig 18 shows the Moire pattern.

Soh concluded that :

- 1) No changes occurred in the posterior part of the palate
- 2) No changes occurred in the palatal vault
- 3) Changes were noted in the anterior segment of the palate.

These were most noticeable in the canine region and barely perceptible in the bicuspid region.

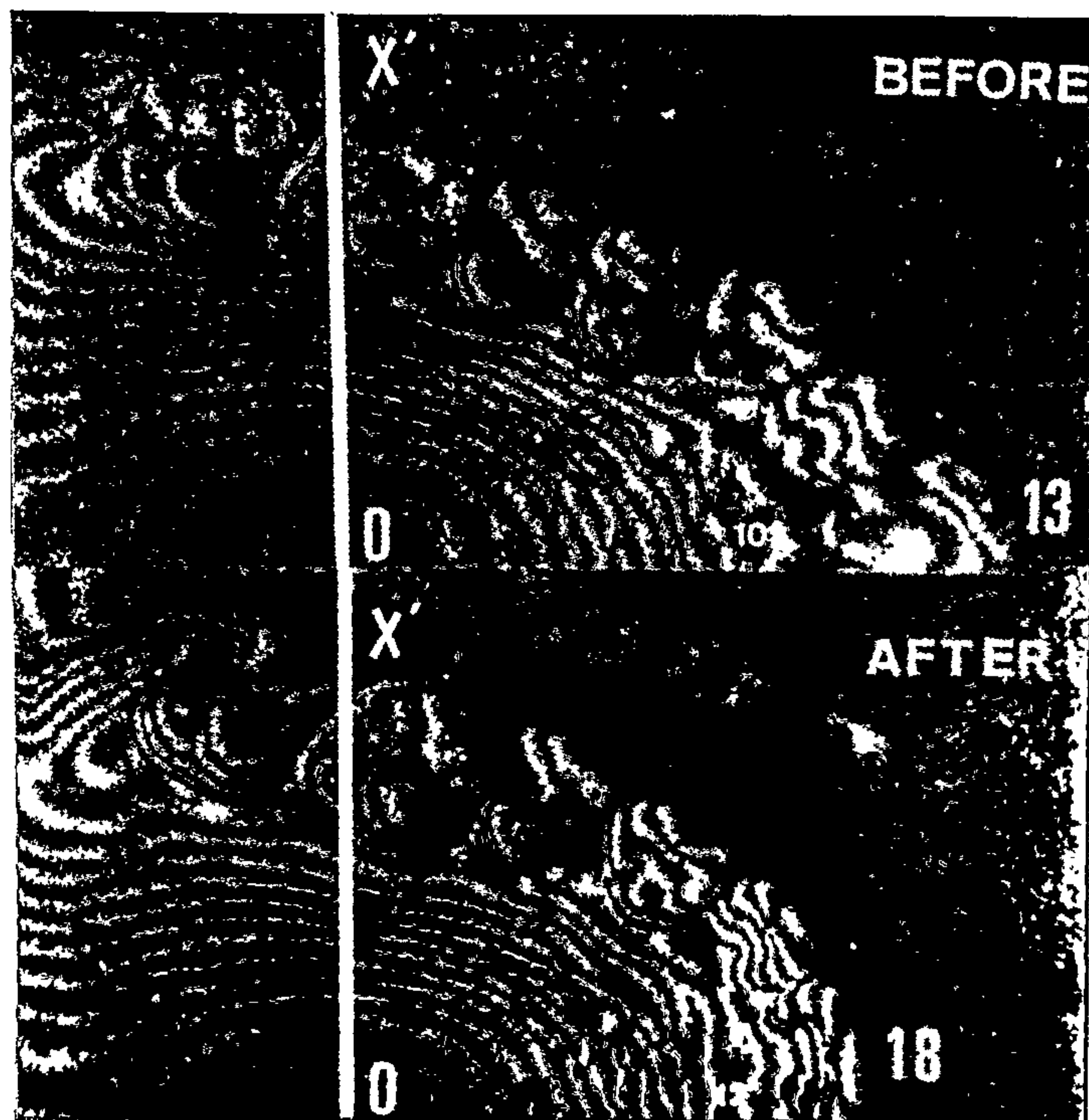
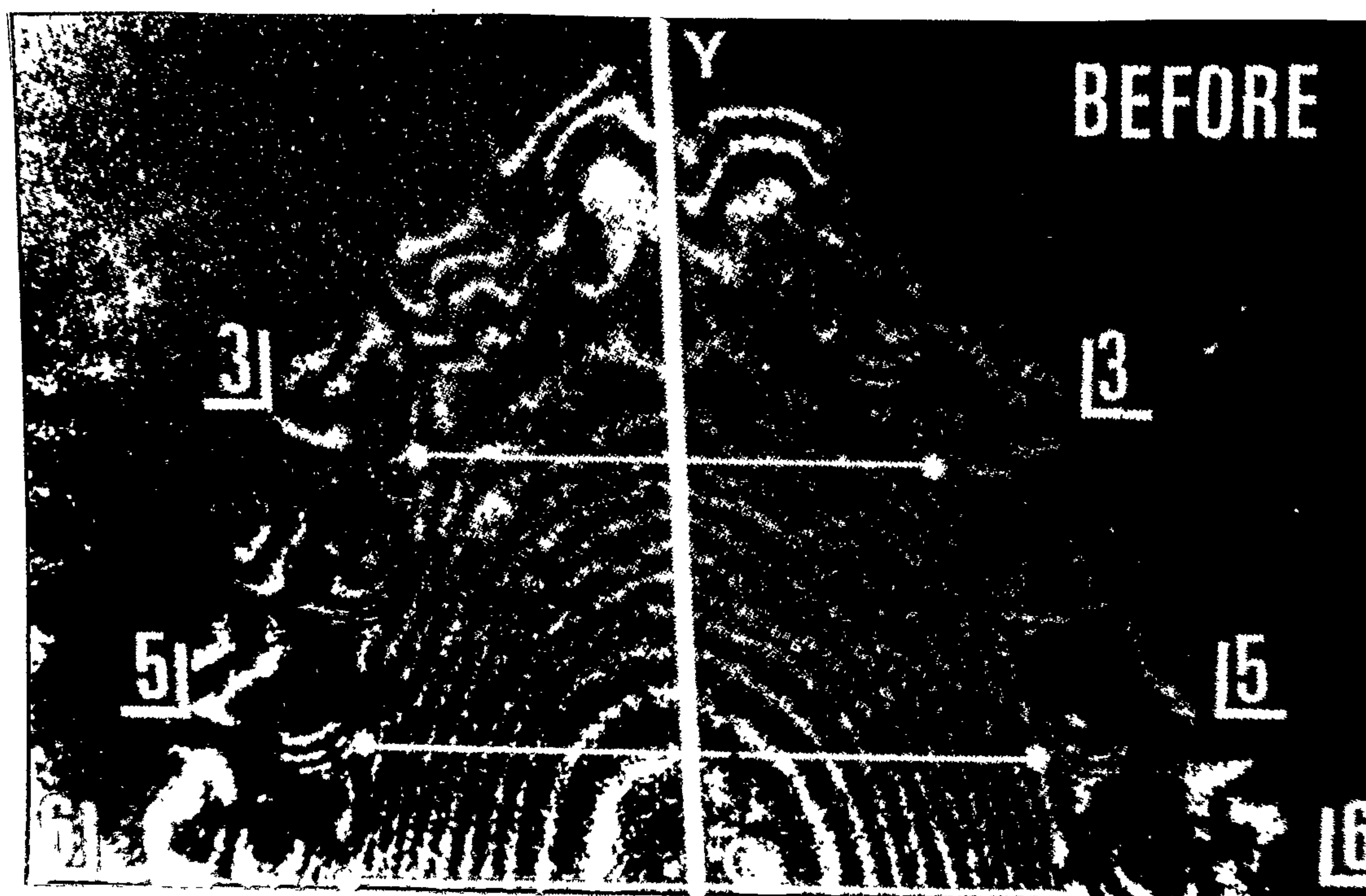


FIG 18      Soh (1983)      Moire' patterns of the palate before and after treatment

These findings would support the literature that the dimensions of the palate are stable in the region of the vault and the median projection of the palatine rugae.

### 2.1.3 Discussion

The information presented demonstrates that the dimensions of the medial projections of the palatine rugae are stable enough from about the age of six to use as valid reference points from which to measure longitudinal changes in tooth position.

The palatal reference points are used to determine the mid-sagittal plane and an origin point on that plane, being the perpendicular projection of the most prominent common median rugae point to all the maxillary casts.

## 2.2 The Functional Maxillary Occlusal Plane

The functional maxillary occlusal plane has been chosen as the horizontal plane of reference onto which all points are projected. The reason for this choice is that it is the most commonly used reference plane in many of the imaging methods previously described. Physically, it is the easiest plane to assess when trimming the study models.

Johnston (1985) describes his pitch-fork diagram to analyse cephalometrically, the effects of treatment and growth and each

component's contribution to an overall analysis of C1 II treatments. His reference plane is the functional maxillary occlusal plane. His reason behind this choice is that treatment results are ultimately expressed in the mouth and the functional occlusal plane is where these changes can be observed.

Changes therefore can be related to the functional occlusal plane and comparisons can be drawn between treatments or treatment analysis can be performed.

Changes in the cant of the occlusal plane will affect the projected lengths from the palate as described by van der Linden (1978), and seen in Fig 19. On average a decrease of  $3^\circ$  in the occlusal plane, will result in a distal displacement of 1mm of the tooth in relation to a projected palatine ruga point. This may alter measurements during case analysis.

The significance of this change will depend on the reliability of the two dimensional radiographic study model imaging process. Should the imaging process be found to be reliable and allow for significant accuracy to measure tooth movement, it would be possible then, with the aid of cephalometric radiographs, to factor the change of the cant of the occlusal plane on a case-by-case basis.

As pointed out in Chapter 1, the same problem still remains, and that is being able to relate the changes of the dentition to the cranial base without distortion.

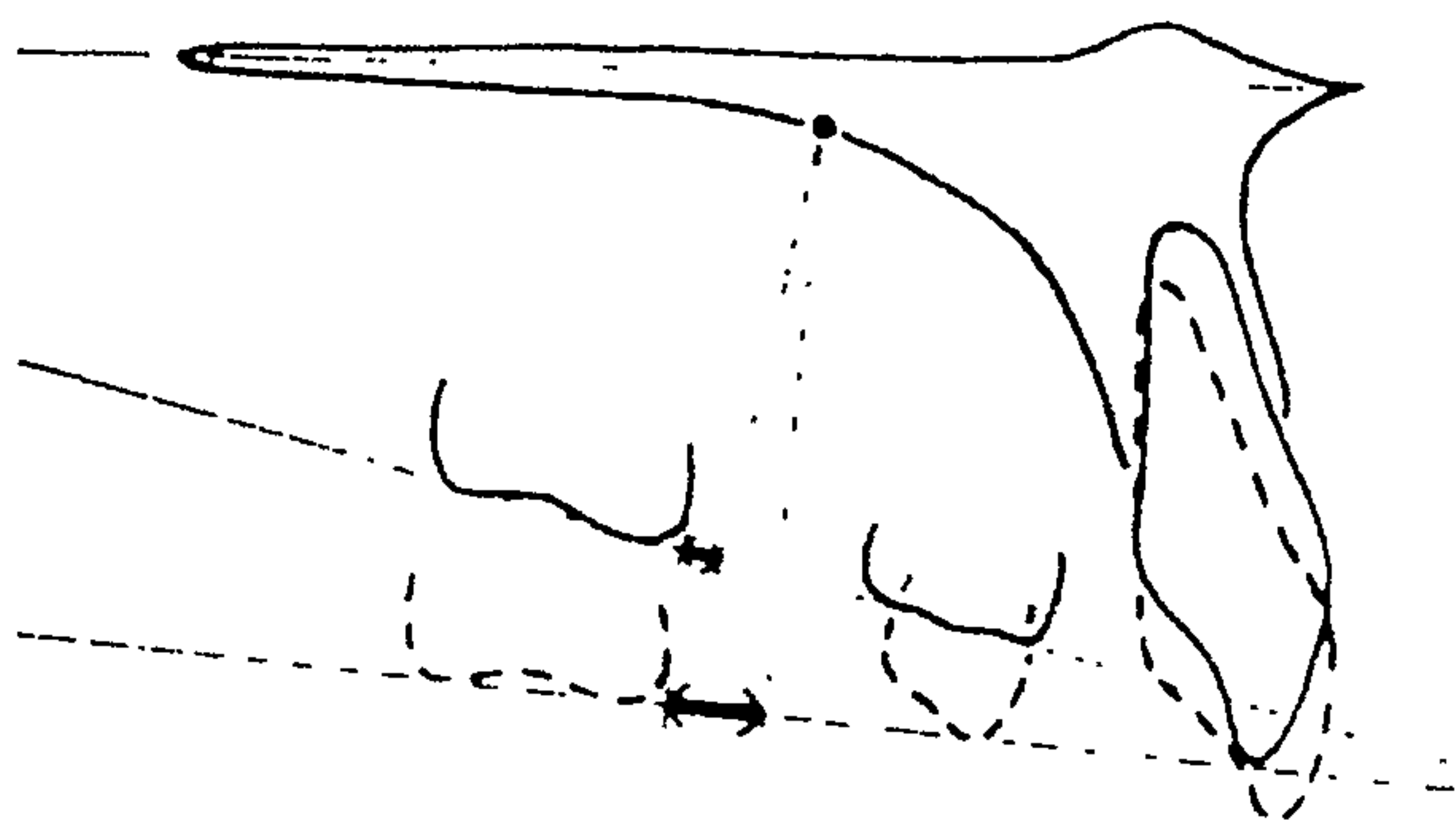


FIG 19 Van der Linden (1978) canting of the occlusal plane

### 2.3 Conclusion

The literature indicates that the medial aspects of the palatine rugae appear to provide the necessary stability for longitudinal investigations. The stability of the posterior part of the palate also enables the establishment of a stable mid-palatal reference line.

The functional maxillary occlusal plane, with known limitations,

may be used as the plane of projection.

Should the method show adequate consistency and accuracy then a method of integrating this information with a lateral cephalometric radiographic evaluation of relative skeletal changes may be considered at a later time.

## CHAPTER 3

### A DESCRIPTION OF THE IMAGING PROCESS

#### 3.1. Duplicating the study models

For the purpose of testing the reliability of the imaging process, it was necessary to duplicate one set of study models ten times and use them as the test models. The collected data would then be analysed in order to ascertain the overall consistency and accuracy of this method.

To minimise the effects of duplicating error, duplication was achieved by using reversible hydrocolloid impression material and the stone casts were poured with pattern-stone B, Investo Manufacturing Co. Sydney.

The hydrocolloid, Nobiloid, was heated and kept at 60° C as recommended by the manufacturer, Nobilium, and all the models were poured within forty-five minutes of the duplicating hydrocolloid being poured.

The stone was mixed in the proportions recommended by the manufacturer, 45:100 w:p by weight. Each mix was mixed in a vacuum mixer for 15 sec. and all models were removed from the duplicating hydrocolloid within one hour of being poured.

In this way it was hoped to minimise any duplication error.

### 3.2. Trimming the study models

The most critical part of the physical preparation of the study models is in their trimming. It is critical to have the functional maxillary occlusal plane parallel to the film plane and perpendicular to the x-ray source. It is also critical to have all other base planes perpendicular to the occlusal plane. To achieve this specific steps must be followed, to ensure that any biases in a particular model trimmer are followed through every series of longitudinal casts.

The trimming process can best be described step by step.:

#### Step 1

Use the same model trimmer for all models.

No model trimmer delivers an exact measurement in the angulation of the base to the trimmed surface, and this varies with each model trimmer.

It is important then to carry the same distortion through all the models being analysed to discount its effect.

#### Step 2

Trim each cast following the same sequence.

Because of the inherent inaccuracy in each trimmer varying the approach in trimming the models will change the inclination of the sides relative to each other, causing trimming distortions. These distortions would cause changes in the angulation of the

maxillary and mandibular bases, which would be expressed as errors in the length measurements, once projected onto the x-ray.

### Step 3

Trim the base of the maxillary model parallel to the maxillary functional plane.

The only way this can be done accurately enough is to use a jig, (Fig 20), with a platform parallel to the trimming wheel to ensure that the maxillary model can be oriented on the trimmer in the required position. It may require that the incisors overhang the jig used to locate the model in deep bite cases, or do not contact the platform in open bite cases. The orientation of the model is to be assessed on a case-by-case basis as previously noted.

### Step 4

Occlude the study models and trim the backs perpendicular to the assessed midline with the *maxillary* model base on the trimming table, (Fig 21). This can be done by eye as only the angle of the back of the models to the maxillary base is critical. This angle should be 90°.

### Step 5

With the *maxillary* model base on the trimmer table, trim the remaining sides as required. The symmetry and length of the sides are not critical, only their orientation to the occlusal plane.



FIG 20 Step 3

Trimming the base of the maxillary model to the functional occlusal plane



FIG 21      Step 4

Trimming the back of the occluded study models

These surfaces will be used to superimpose the maxillary radiographic image onto the mandibular radiographic image to transfer the marked maxillary midline and origin reference points.

#### Step 6

Turn the occluded models onto the trimmed back and trim the *mandibular* model base so that it is parallel to the maxillary base, (Fig 22). The jig is used here to locate the maxillary base in the correct relationship and ensure that the maxillary and mandibular bases are parallel.

#### Step 7

Should further trimming be required, as in final smooth trimming, it is essential that this be carried out in the above manner, to maintain the same relationships between the models. It is also important that during the trimming process the models not be pushed against the trimming wheel before being removed so as to ensure that the wheel is not deflected and that the angles are true.

### 3.3. Marking the study models

All points to be used must be marked initially with a sharpened HB pencil. All points are then marked for radiographic purposes using brass ligature wire 0.5 mm diameter cut into sections less

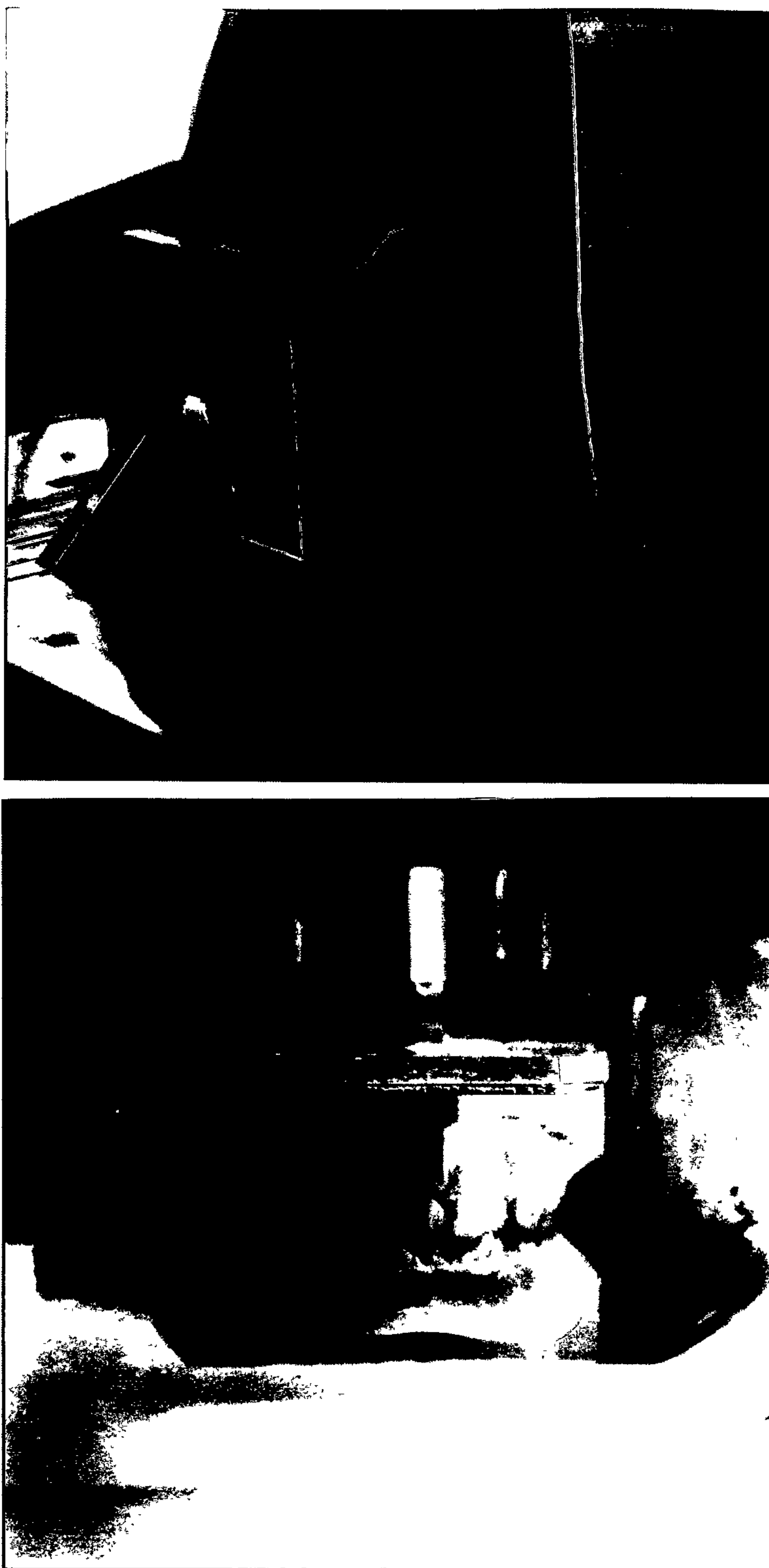


FIG 22      Step 6

Trimming the mandibular base parallel to the functional occlusal plane

than 1 mm long. These are placed onto the pencil markings using model seal as a fixing medium. The markers and model seal can be removed following radiography. Fig 23, shows a fully marked set of study models.

### 3.3.1. Marking the maxillary palatal reference line and origin point

This line is marked by examining the maxillary models in each case and identifying the most clearly definable point on the median raphe near the posterior part of the hard palate and a second point near the top of the palatal vault.

The origin point is a point on a medial projection of the palatine rugae, specifically the most clearly identifiable point in that region of the palate common to all the maxillary casts in the series. The origin point may coincide with the second point described when marking the palatal midline, but may not include the incisive papilla region as it has been shown to be unstable as previously discussed.

### 3.3.2. Marking the teeth

For the purpose of this testing procedure it was decided that in order to detect the changes in the cant of the occlusal plane, four points be chosen, one in each corner of the arch, to give maximum length in any direction.

The points chosen on the maxillary arch were the left and right canine cusp tips, and the points where the buccal groove of the



FIG 23      A fully marked set of study models

first permanent left and right molars cross onto the occlusal surfaces.

The points chosen on the mandibular arch were the left and right canine cusp tips and the points where the buccal groove of the left and right first permanent molars crossed onto the occlusal surface.

### 3.3.3. Marking the transfer points

Three locating transfer points are marked on the maxillary and mandibular dentitions. The points are the distal corner of the right maxillary incisal edge and the contact points between the maxillary first left and right molars and their approximations to the second premolars. The corresponding points on the mandibular arch are marked directly below these maxillary markers to facilitate superimposition and transference of the maxillary reference points to the mandibular arch.

### 3.4. Radiographing the study models

Once trimmed and marked, a study model is placed onto a loaded lateral cephalometric cassette. Sheet lead is used to mask the unused portion of the film. Each model is placed onto the film and radiographed. The whole required series is taken so that the final film has on it the six images of the three sets of study models. Each set of study models is identified by number.

Fig 24, shows the radiographic apparatus in use.



FIG 24 The x-ray set-up showing the x-ray source, plumb-line and study models on the x-ray cassette before being exposed

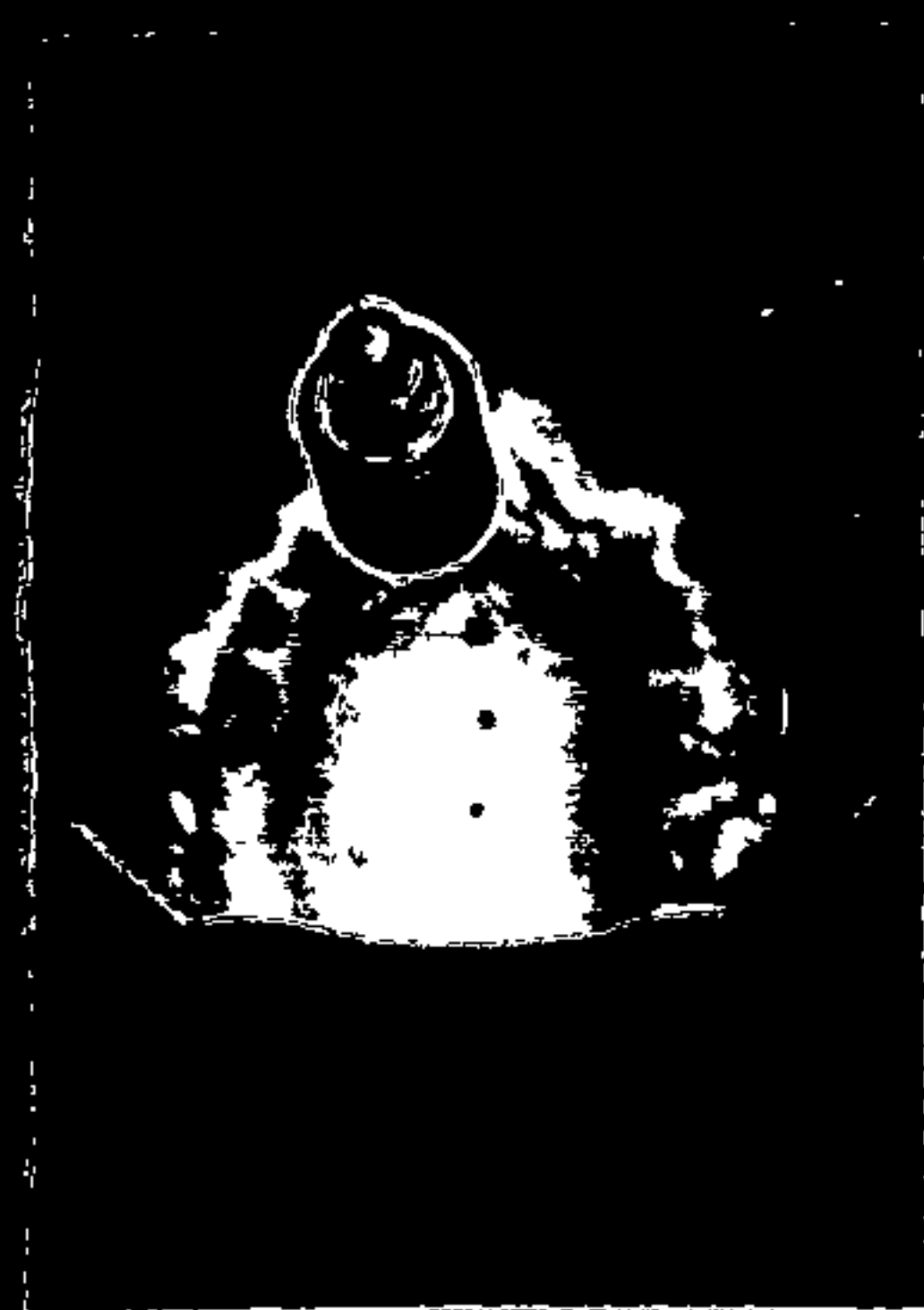
The cassette is placed on a horizontal surface such as the floor. The x-ray tube is located 1.5m above the floor and centred over each model by means of a plumb line. Following each exposure the cassette is moved so as to centre the new study model under the plumb line.

A second series of radiographs will be taken with the central beam of the x-ray positioned in the centre of the cephalometric cassette and three sets of study models positioned on the cassette. Measurements between the two methods will be compared to determine if any significant errors are present due to projection angles. These errors will be discussed later in the thesis. Fig 25 shows the two methods of radiography employed. Fig 26 shows examples of the radiographs from each method.

### 3.5. Transfer of the reference points from the maxilla to the mandible

This step involves the use of tracing paper onto which the maxillary reference points and locating points are traced. This is then turned over and placed over the corresponding mandibular cast. The locating points are then matched and the models are in occlusion. At this point the tracing paper is fixed to the mandibular x-ray with adhesive tape. This will allow digitisation of the corresponding mandibular points to use the maxillary reference points also. All distances measured will therefore be related back to the origin point and functional maxillary

a...

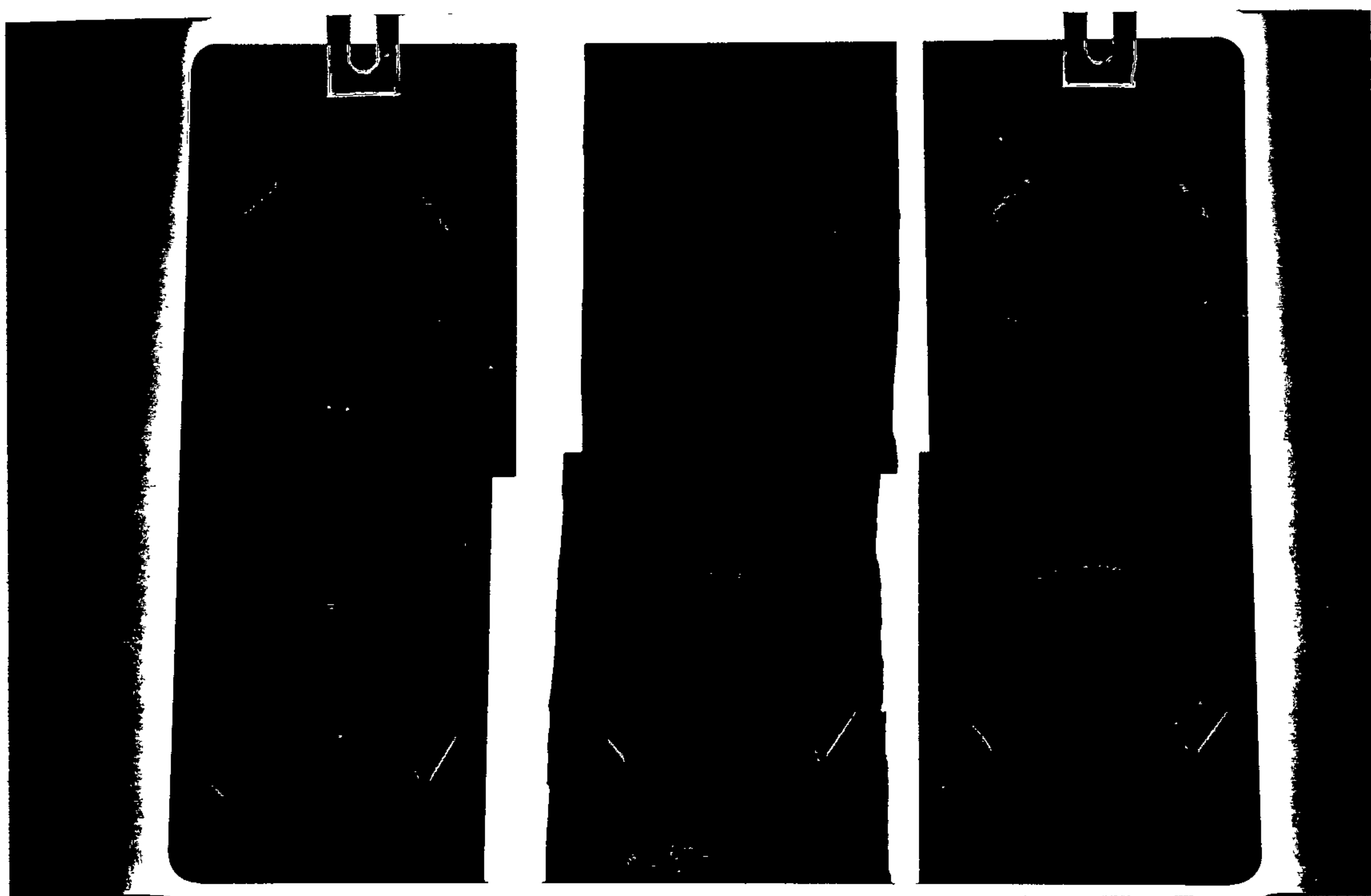


b...



FIG 25 Radiographic method

a...Individual exposures using the lead shield  
b...Single exposure method



a...



b...

FIG 26 Radiographic method (cont'd)

a...Individual exposure radiograph

b...Single exposure radiograph

occlusal plane.

As part of the test design, the corners of the study models will also be used as locating points in an attempt to assess the need for locating markers.

### 3.6. Digitising the study models

To facilitate the process of data processing and handling, a software program has been developed which will measure the lengths required to test the method, (see Appendix II). Fig 27 shows radiographic image, the points to be digitised and the subsequent lengths to be measured.

A Hipad digitiser was used and the software was written on an IBM compatible NEC IV computer.

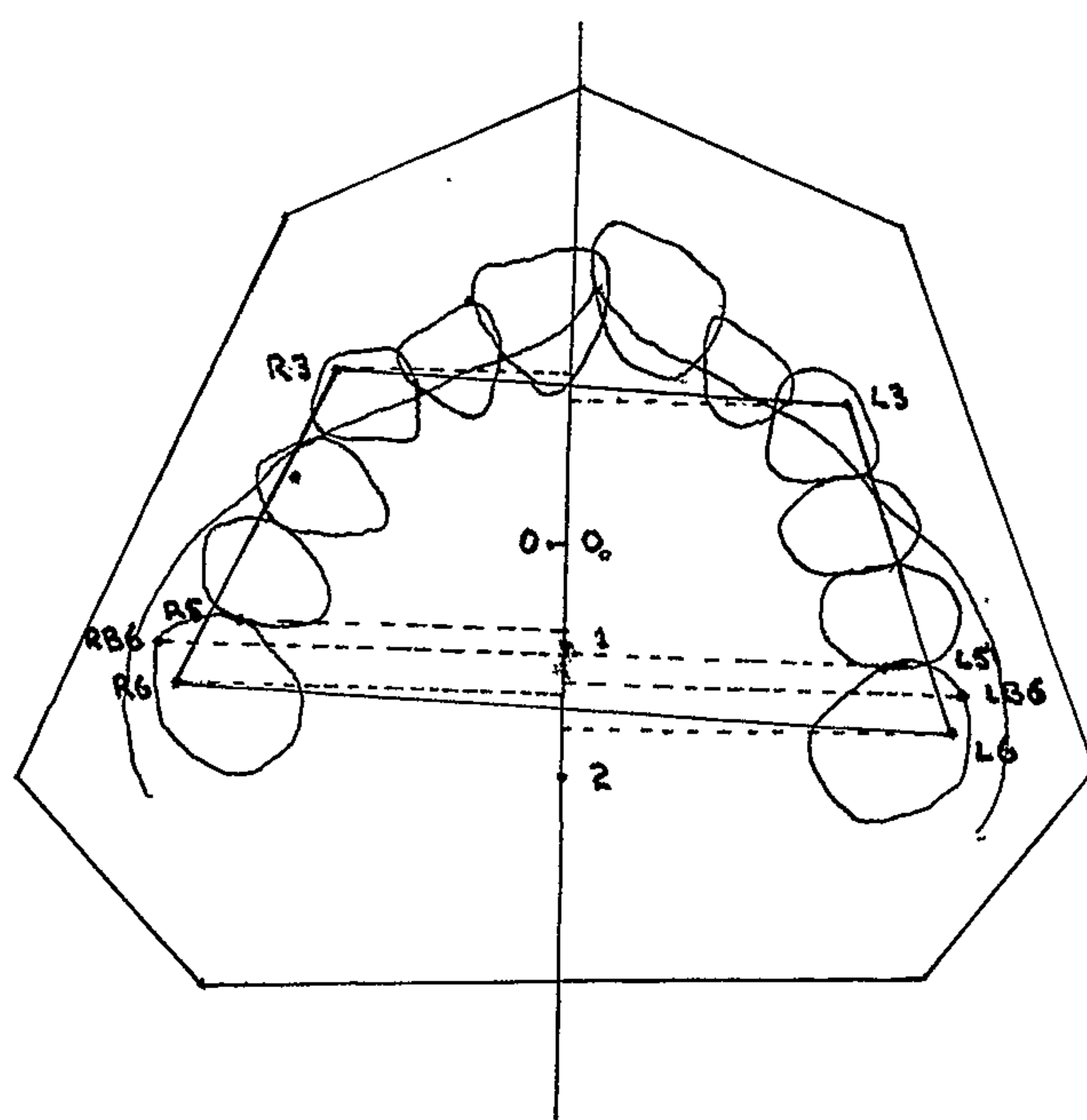
#### 3.6.1. Points used in digitisation

In sequence, as digitised :

- 1 - Anterior palatal reference point
- 2 - Posterior reference point
- 0 - Origin point
- L6 - Left side first permanent molar buccal groove, marked
- L3 - Left side canine tip, marked
- R3 - Right side canine tip, marked
- R6 - Right side canine tip, marked
- R6 - Right side first permanent molar buccal groove, marked
- L5 - Left side mid-contact point between the first permanent



a...



b...

FIG 27 The radiographic image for digitisation

a...A maxillary study model radiograph  
 b...Diagrammatic representation of the points and lines used in the analysis

molar and the second bicuspid, unmarked

R5 - Right side mid-contact point between the first permanent molar and the second bicuspid, unmarked

LB6- Most buccal point on the left side first permanent molar unmarked

RB6- Most buccal point on the right side first permanent molar unmarked

1 & 2 - define the mid-palatine reference line.

0 - defines the most prominent median ruga point common to all maxillary casts in a series. 1 and 0 may coincide.

All points are projected, perpendicular to and, onto the mid-palatine reference line.

The distance of all digitised points from their corresponding projected points are recorded.

The distance of each projected point from the projected origin point is also recorded.

### 3.7. Measurements used in the analysis

The purpose of this analysis is to determine the reproducibility and accuracy of the two dimensional radiographic study model imaging process. To this end, the data collected and the measurements made are designed to show variation.

The lengths; L6-L3, L3-R3, R3-R6 & R6-L6 are compared to the physical measurements taken from the models. Significant differences between the two groups may be due to incorrect magnification factor compensation, digitising error or an error in the manipulation of the study models.

The lengths of the perpendicular projections from the digitised points to the mid-palatal reference line will show the reliability of the marking of the mid-palatal reference line. When applied to the mandibular arch the reliability of the superimposition method can also be tested. These measurements also test the accuracy of measurements in the transverse direction.

The distance of each projected point on the mid-palatal line to the projected origin point, tests the accuracy of measurement in the antero-posterior direction.

### 3.8 Analysis of data

#### 3.8.1 Measurements to be analysed

To evaluate the reliability of the method, it is not necessary to analyse all the measurements taken. A representative set of 8 measurements was chosen, (Fig 28) :

L6-L3, L3-R3, R3-R6 and R6-L6 were chosen to assess the effect of

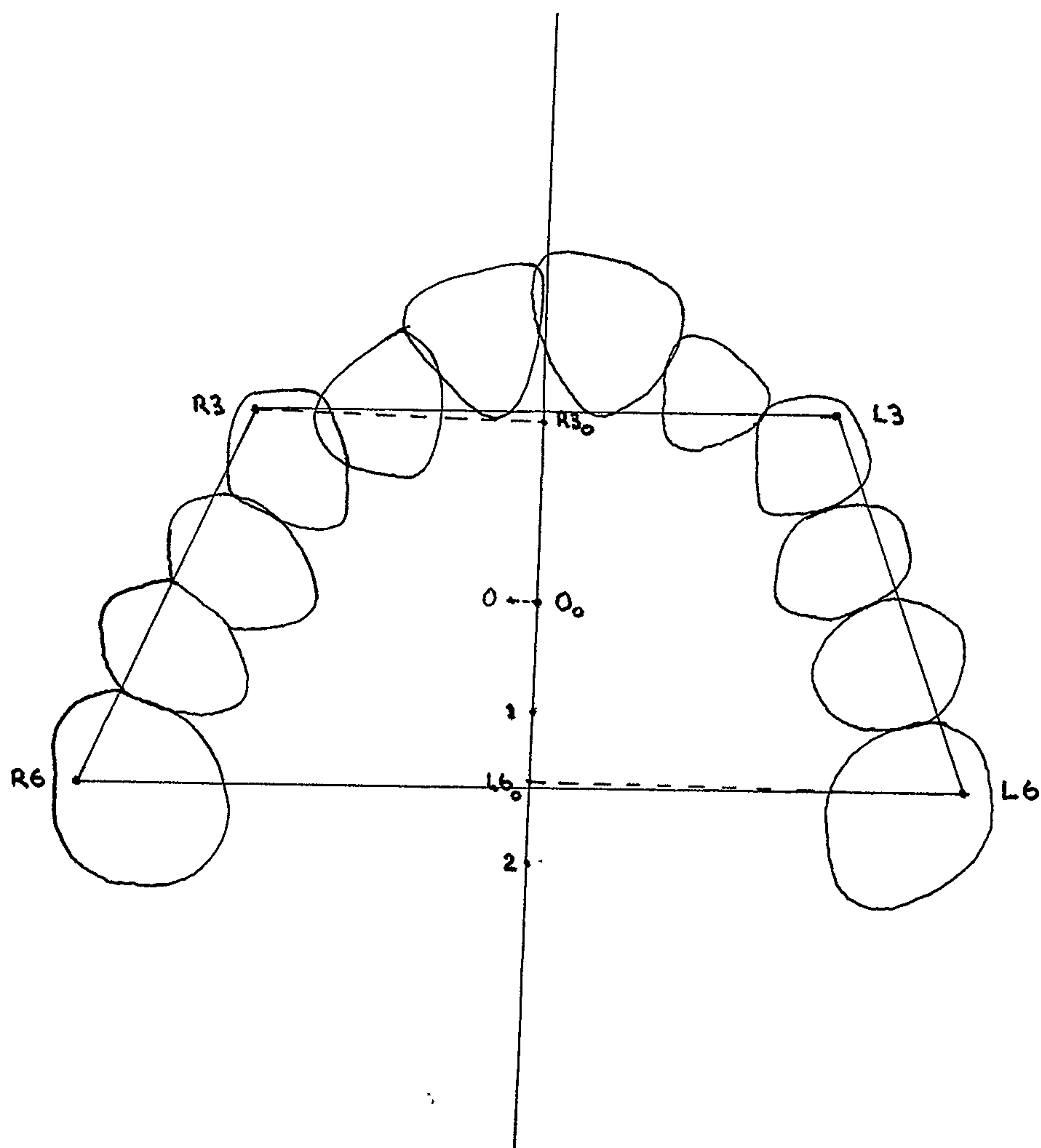


FIG 28 Diagrammatic representation showing the lengths used in the analysis of the method.

projection on any changes in the cant of the occlusal plane due to trimming variation. These lengths could also be used to assess the accuracy of the magnification factor calculated.

R3-R3o, R3o-Oo, Oo-L6o and L6o-L6 were chosen to test the consistency of projected measurements involving the mid-sagittal reference line in both the transverse and antero-posterior dimensions.

On the successful completion of the analysis of these measurements, further measurements would be analysed to evaluate the possibility of using measurements derived from unmarked points or using the bases of the study models as templates for the superimposition of the study models.

This later part of the analysis would evolve as a response to the results obtained.

### 3.8.2 Statistical analysis to be used

The analysis involves repeat measurements and a number of models. It is important to know that the repeat measurements show no statistical differences between them, thus ensuring a representative measurement of the length being measured.

It is also important to know the variation found between the models and to assess any significant difference between them.

The Analysis of Variance is a powerful statistical tool allowing simultaneous evaluation of inter-measurement and inter-model differences.

Software was written to allow quick handling of the data and simultaneous evaluation of the eight chosen length measurements (see Appendix I).

This facilitates the adaptability of the analysis to respond to need for changes in the design of the analysis should they be required, or should some of the measurements need to be repeated. Following an assessment of the reliability of the methods involved in the study, it then becomes necessary to compare the actual measurements with the radiographic measurements. These can be compared using the Student's  $t$  - Test, (see Appendix X).

## CHAPTER 4

## EXPERIMENTAL DESIGN

## 4.0 Aims

- 1 Investigate trimming error
- 2 Investigate radiographic projection error
- 3 Investigate magnification error
- 4 Investigate marking error
- 5 Duplicating error
- 6 Measuring directly from the radiograph: Is it possible?
- 7 Mx/md transfer: Is it possible directly from the radiograph?

4.1 Trimming error

The method calls for accurate trimming of study models to avoid projection variation as the teeth and palatal reference points are on different planes and will give false readings of tooth movements.

This error can be tested in two ways :

## 1) By calculation

It is possible to calculate mathematically the differences involved with changes in the cant of the model base

## 2) By experiment

A series of study models can be marked and radiographed. The

collected data can be compared to the calculated variation, and the consistency and accuracy of the trimming method can be assessed. This depends of course, on the reproducibility of the measurements for the method.

#### 4.2. Radiographic projection error

As the radiographic source is from a central point, then one expects to see some variation of measurements from study models measured on different parts of the x-ray film. How much does this projection error affect the overall measurements if six casts are expected to be placed on the x-ray film at any one time?

This projection error, a parallax effect, can be calculated mathematically for differing heights of the x-ray source from the study model and differing distances of the study models from the central beam of the x-ray.

#### 4.3 Magnification error

This is related to the study model base thickness. How do these variations in thickness affect the overall measurements due to magnification and when do they become significant?

This error is calculated mathematically and factored into the software as a percentage, to adjust the raw data from the expected magnification.

#### 4.4        Marking error

Marking error will be determined by physical measurement of the distances between the points on all the study models. This incorporates duplicating error as well. The measurements will be done with slide callipers. Each distance will be measured twice on two separate occasions. An acceptable range of measurements will be determined and those falling outside this range will be remarked and remeasured. Should they not fall into the acceptable range a second time the model will be discarded and a replacement model will be used.

This will ensure that any measurement variation found from digitisation will be due to the method.

#### 4.5        Duplicating error

The duplicating error is the systematic error involved in the manipulation of the hydrocolloid and dental stone. The method of duplicating has been described previously and the manufacturer's instructions were followed. A systematic error has been estimated for the study. This is described in Chapter 5. The estimated percentage error involved is less than 1%.

4.6            Measuring directly from the radiograph : Is it possible ?

This may be seen as a possibility considering the amount of contrast and clarity of definition available from the radiograph. A series of measurements will be taken directly from the radiographs and the errors involved compared to those taken from marked distances.

4.7            Mx/Md transfer

The reference points on the maxillary cast must be traced on a sheet of tracing paper and transferred across to the mandibular cast. The locating points are used for this.

The consistency of this method will be seen by examining the measured mandibular distances relative to the origin point. A series of repeat measurements may be made in order to isolate this error.

4.8            Mx/Md transfer: Is it possible directly from the radiograph?

The transfer of the maxillary reference points and lines used locating points marked at points of or near occlusal contact where direct positioning is possible to avoid the problems of magnification. If the trimming of the study models is consistent

and the projection and magnification errors are constant, it is possible that the reference points can be transferred using the base perimeters of the study models as the locating lines.

To test whether the study model bases can be used, a second transfer tracing will be made using a tracing of the base of the study model as the reference base. A second set of mandibular measurements will be collected and compared to the set collected using the locating points described.

## CHAPTER 5

## DETERMINATION OF ERRORS

5.0 General

There are three broad sources of error which must be considered in this study in order to determine the possible clinical application of this two dimensional radiographic study model imaging process and analysis :

## Group 1)

Errors involved in the general handling of impression materials and dental stone used for the collection of study models, in a clinical environment.

## Group 2)

Errors of the method involved in the set up and testing of the study model analysis proposed.

## Group 3)

Errors in the physical measuring of the study models and digitisation of the radiographs.

Group 1) errors which cannot be controlled within the bounds of this study will be examined, and their relevance to the overall limitations of this type of analysis will be discussed.

Group 2) and 3) errors can and must be identified in order to ascertain the amount and nature of the errors involved in the proposed method, and differentiate these errors from the errors due to measurement. These are the errors which can be minimised, compensated for, or eliminated, by the method used.

The experimental aims as we have seen, are to identify and deal with this second group of errors by setting up an experiment which allows direct comparison of the measurements taken from the actual study models with those taken from the radiographs.

The aims do go further, in that they also include a comparison of different radiographic and superimposition techniques. The success of the experiment hinges on the way in which the errors are managed.

The eventual clinical relevance of the two dimensional radiographic study model imaging process and analysis is also dependent on the nature and source of the errors.

### 5.1 Group 1) Errors

This group of errors arises from the manipulation of impression material, mostly alginate and dental gypsum products, mostly type I or II dental stones. As we are measuring linear measurements, and the ultimate clinical use of this analysis is to measure linear change over a period of time using a series of dental casts, then it is important to determine the degree of linear variation possible in the study models.

### 5.1.1. Errors in manipulation of impression material

The impression material generally used to obtain study models is alginate. This discussion will be restricted to the manipulation of alginates.

Miller (1975), investigated the dimensional change of 12 different alginate materials. The materials were mixed to manufacturers instructions and linear measurements were made, using a microscope, to determine the dimensional change of the alginate materials at intervals from 10 minutes to 24 hours following mixing. The alginate was poured into a rectangular cylinder, 19x1.5x1 cm and remained stored in moist air. Miller found that shrinkages of up to 0.44% at one hour, and up to 1.28% at 24 hours occurred.

Hosoda et al. (1961), investigated the dimensional changes of stone dies poured in three different alginate materials. The dies were cylindrical in shape and inner and outer measurements were made. The dies, poured from dental stone, were compared to the original dies and dimensional linear changes ranging from -0.17-+0.65% were found.

These two studies serve to point out the fact that there is a percentage linear change with the use of any alginate material. This linear change can be up to the order of 1% if the material is left in moist air for 24 hours.

Since the rising concern about Hepatitis B and Acquired Immune Deficiency Syndrome, there has been a greater awareness to the

possibility of cross-infection when handling impressions. As a result methods of disinfection are being employed to reduce this risk.

Herrera et al. in (1986) evaluated the effect, on the linear dimensions, of a 30 minute immersion of full arch alginate, polysulphide rubber base, vinyl polysiloxane and polyether dental impressions in selected broad spectrum disinfectants. These were compared to control impressions immersed in distilled water and impressions left in the air at room temperature. The alginate controls in the air were wrapped in moist paper and poured immediately. They measured inter-canine and inter-molar widths as well as buccal segment lengths. They discovered no significant differences between any of the solutions used with the exception of the affects on the alginate materials, but restricted to the buccal segment lengths ( $p < 0.05$ ). This difference occurred in two out of three of the solutions used.

Durr et al. (1987), compared the dimensional stability of alginate impressions after a ten minute immersion in 1% sodium hypochlorite or 2% potentiated glutaraldehyde solutions, with control group impressions not immersed and a master cast. They used a dental stone with a 0.05% expansion. Even with a low setting expansion stone they noted a statistical difference between the master cast and all the impressions, controls included.

Both these studies concluded that, although there was some variation due to immersion of the impressions in different

disinfecting solutions, these differences would not affect the resultant casts when used in clinical applications.

Jones et al. (1988), investigated the dimensional stability of alginate impressions following disinfection by varying regimes employing 2.2% glutaraldehyde. They used five different regimes and a control group of impressions dipped in water. The regimes ranged from a dip in the glutaraldehyde and left for 10 mins. in air before casting, through 5min., 10min., 20min. and 30 min. soaks before casting. The impressions were taken from a master acrylic set of study models. Using the reflex plotter they were able to measure the casts linearly and overjet and overbite. The linear measurements involved intercanine, intermolar and molar-canine measurements.

Again they found no clinical significance in the results. The working models cast from the different impressions would be clinically all acceptable. They did, however, find marked statistically significant differences between regimes. This they determined was due to the low error tolerance in the instrument. They concluded that, should subsequent study models be measured with a Reflex Metrograph, the regime should be limited to at most a 10 min. soak in the 2.2% glutaraldehyde. They also noted that caution was required using long term serial studies.

Phillips (1973) showed the dimensional stability of eight different alginates. The linear dimensions were measured in air and water over a period of 260 mins. All materials maintained

their original dimensions within 0.1% for the first 60 mins. Only one material varied more than 0.2% over the time.

Phillips also notes sources of distortion other than those found in the material itself. These distortions are due to movement of the tray during setting, premature or improper removal after setting, delayed removal after setting and delayed pouring after removal.

#### 5.1.1.1 Discussion

These studies all serve to illustrate the linear dimensional stability of alginate used in controlled environments.

The dental surgery is not a controlled environment and alginate is not always mixed with such accurate precision. This will lead to further variation in the dimensional stability of the casts.

It is important to then calculate an estimate of the variation allowable and still maintain clinical significance. In view of the variability of the materials used and to allow for some misuse an estimated 0.4% variation will be acceptable. 0.2% is allowed for manipulation of the material, while doubling this range should allow for some unforeseen situations.

An allowable range of 0.4% over 25mm translates to a range of  $\pm 0.05\text{mm}$ . Over 50mm it is  $\pm 0.1\text{mm}$ . These figures are small and should not interfere with the clinical significance of measurements made in a study.

### 5.1.2. Errors in manipulation of dental stone

The behaviour of dental stone also factors in the dimensional stability of the resultant study models. Phillips (1973) describes dental plaster and types I & II dental stones.

In general, setting expansion of plaster and dental stone is affected by the water/powder ratio used, the mixing time and temperature:

- \* Increase w/p ratio decreases setting expansion
- \* Increase mixing time increases setting expansion
- \* Both changes decrease strength

Phillips notes that dental plaster setting expansion ranges from 0.24% - 0.51% depending on the water/powder ratio and the mixing time. Phillips also notes that Type I dental stones, such as Pattern Stone B, have setting expansions ranging from 0.09% - 0.18%. Type II dental stones, mostly investment stones, show a range of setting expansions from 0.08 - 0.10%.

Lautenschlager and Corbin (1969) investigated the expansion on a dental stone. This was a Type I dental stone, Coecal Buff Dental Stone, Coe Laboratories, Inc. They found that varying the w/p ratio from 0.25 - 0.60 gave a range of setting expansion of 0.202 to 0.165. The instrument they used to investigate the expansion was a Strain Gauge Extensometer, accurate to  $\pm 0.00005$ ".

Kakuta et al.(1989) evaluated the setting expansion of dental stone poured into hydrophilic and hydrophobic silicone impressions. They noted that there was less expansion evident

when the stone was poured into the hydrophobic silicone impression material. This would support the finding that increasing the w/p ratio decreases the expansion of the material. They also noted that the range of setting expansion when poured into both types of impression materials was 0.2 to 0.35%.

#### 5.1.2.1 Discussion

From the above information it is important to identify the type of stone or plaster being used in a study. Dental plasters expand approximately twice that of Type I dental stones and four times that of Type II dental stones.

Again these situations described are those found in a controlled environment, which the clinic or laboratory is not always. As we know, dimensional stability of our study models is of a lesser concern than the strength of these models. The result is that one often decreases the water/powder ratio to increase the strength. Some practitioners may also add a pinch of salt or stone dust to help the setting time. These factors all influence the expansion of the setting stone.

In order to determine the systematic variation allowable in the manipulation of the dental stone a figure must be chosen. This author has chosen a value of 0.3% as an average value for the setting expansion of all types of dental gypsum products to be used. If this value is doubled to allow for "modification" of the mixing technique, an allowable systematic variation of 0.6% is reached.

### 5.1.3. Summary

The error involved in obtaining a study model is dependent on the materials used, the way in which they are used and the environment in which they are used.

From the literature, and allowing for some latitude in material handling, a variation of the order of 1% (0.4+0.6) has been chosen as an acceptable systematic error in the preparation of study models. This translates into  $\pm 0.05$  mm. error in tooth length measurements and  $\pm 0.25$  mm in arch width measurements.

Jones et al. (1988), questioned the use of serial casts for comparative measurement because of this dimensional variation, especially when using an instrument such as the Reflex Metrograph with a low error tolerance. The Reflex Metrograph measures to within  $\pm 0.1$  mm plotting individual points, and  $\pm 0.3$  mm when measuring distances.

Because the error involved in the manipulation of the impression material and dental stone exceeds the error tolerance of the instrument, any measurements made on serial sets of study models would show up significant statistical differences if analysis of variances was performed comparing the study models, which would theoretically make the comparison invalid.

This problem can be overcome by allowing a certain amount of error, for example 1% calculated above, in the manipulation of the materials. If that is the case then changes found when analysing serial casts must exceed the allowable error in order to become significant.

## 5.2      Group 2) Errors

These errors deal with the experimental design and how the radiographic and digitisation methods affect the measurement of predetermined lengths. As discussed in Chapter 4 the errors and their investigation will now be examined.

### 5.2.1.      Magnification error

If we examine Fig 29, we can see that the magnification error X, due to the projection of an x-ray through a point C, at a distance Y from the central beam, with an object of height Z above the projection plane and the x-ray source a height A above the projection plane, can be expressed by the formula :

$$X = \frac{Y \times A}{A - Z} - Y$$

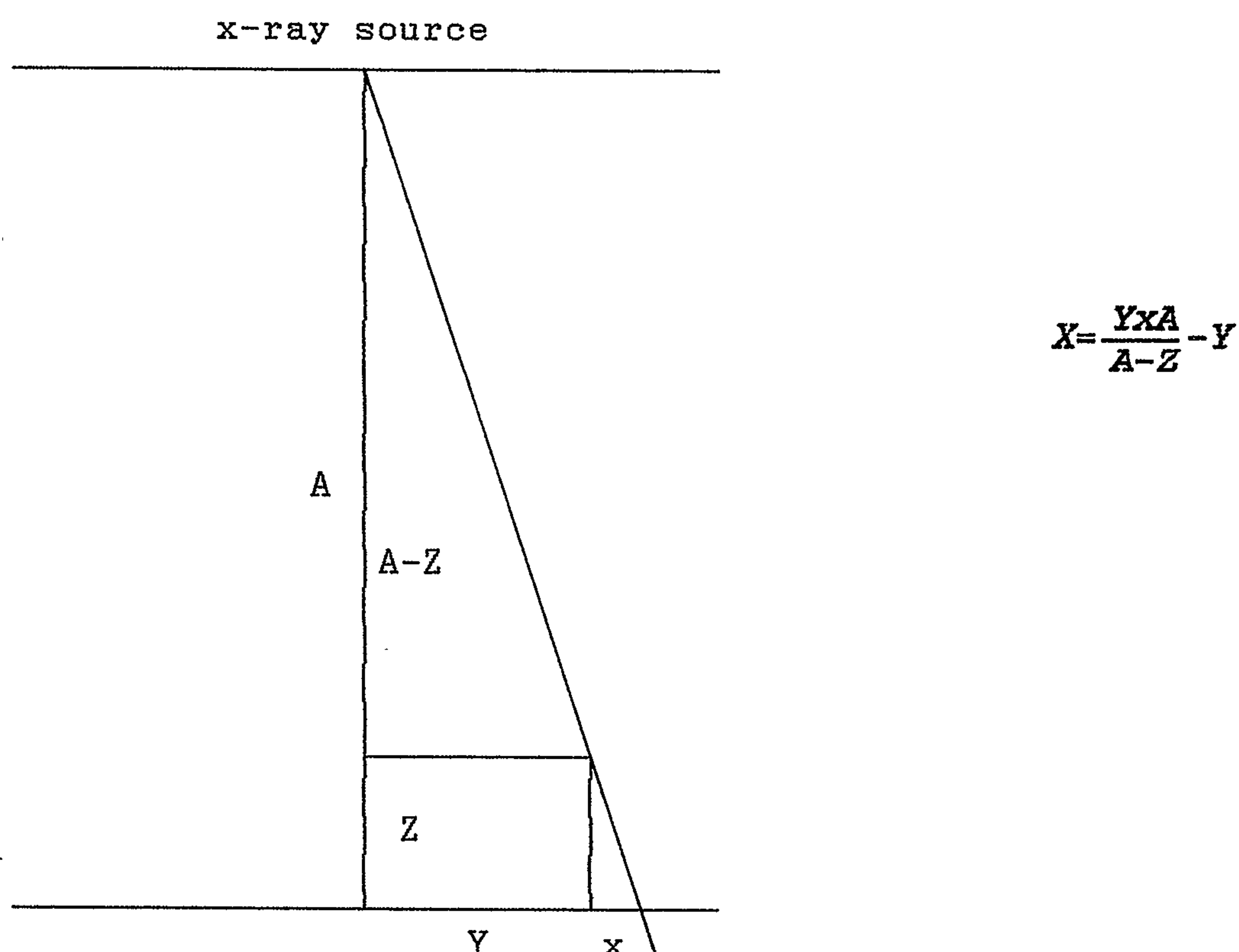


FIG 29 Determination of Magnification Error

The degree of magnification is determined by the height of the x-ray source above the film (A), the height of the object above the film (Z) and the distance of the point through which the projected ray passes from the central beam (Y).

Table (1) shows a range of A and Z values and the corresponding magnification errors expressed as a percentage of (Y), the distance of a point (C) from the central beam.

From table (1), it is possible to calculate an expected range of magnification errors for differing experimental design situations, to account for any particular x-ray source-to-film

distance and typical study model heights.

How does the magnification error change if there is a small amount of discrepancy such as may be found during the trimming of the study models?

From Table (1), it can be seen that a difference of 5mm in study model height will give a range of percentage magnification errors depending on the experimental design set-up :

- \* Using the most favourable set-up to minimise magnification error, with a source-to-film distance of 2500mm and a model height range of 20-25mm, the percentage magnification error over this range is 0.2%.

- \* Using the most unfavourable set-up, with a source-to-film distance of 500mm and a model height range of 40-45mm, the percentage magnification error over this range is 1.17%.

In designing the experiment, a compromise must be struck between minimising the effects of magnification and the practicality of setting up the apparatus. In view of this it has been decided to use a source-to-film distance of 1500mm and an average model height of 40mm. An acceptable model height trimming range between 38-42mm has also been chosen. Using these parameters, the expected percentage magnification factor is 2.74 %.

The percentage magnification error over the allowable model height range is 0.28%

In practical terms this translates to a magnification correction factor of the order of 1mm and an error range of the order of

TABLE 1

PERCENTAGE MAGNIFICATION ERROR TABLE  
 expressed as a % of the distance of the point through  
 which the projected ray passes from the central beam (Y)

|                                                                        |    | A mm      Source distance from film |      |      |      |      |
|------------------------------------------------------------------------|----|-------------------------------------|------|------|------|------|
|                                                                        |    | 500                                 | 1000 | 1500 | 2000 | 2500 |
| Zmm<br><br><br><br><br><br><br>Model<br><br><br><br><br><br><br>Height | 20 | 4.17                                | 2.04 | 1.35 | 1.01 | 0.81 |
|                                                                        | 25 | 5.26                                | 2.56 | 1.69 | 1.27 | 1.01 |
|                                                                        | 30 | 6.38                                | 3.09 | 2.04 | 1.52 | 1.21 |
|                                                                        | 31 | 6.61                                | 3.20 | 2.11 | 1.57 | 1.26 |
|                                                                        | 32 | 6.84                                | 3.31 | 2.18 | 1.63 | 1.30 |
|                                                                        | 33 | 7.07                                | 3.41 | 2.25 | 1.68 | 1.34 |
|                                                                        | 34 | 7.30                                | 3.52 | 2.32 | 1.73 | 1.38 |
|                                                                        | 35 | 7.53                                | 3.63 | 2.39 | 1.78 | 1.42 |
|                                                                        | 36 | 7.76                                | 3.73 | 2.46 | 1.83 | 1.46 |
|                                                                        | 37 | 7.99                                | 3.84 | 2.53 | 1.88 | 1.50 |
|                                                                        | 38 | 8.23                                | 3.95 | 2.60 | 1.94 | 1.54 |
|                                                                        | 39 | 8.46                                | 4.06 | 2.67 | 1.99 | 1.58 |
|                                                                        | 40 | 8.70                                | 4.17 | 2.74 | 2.04 | 1.63 |
|                                                                        | 41 | 8.93                                | 4.28 | 2.81 | 2.09 | 1.67 |
|                                                                        | 42 | 9.17                                | 4.38 | 2.88 | 2.15 | 1.71 |
|                                                                        | 43 | 9.41                                | 4.49 | 2.95 | 2.20 | 1.75 |
|                                                                        | 44 | 9.65                                | 4.60 | 3.02 | 2.25 | 1.79 |
|                                                                        | 45 | 9.89                                | 4.71 | 3.09 | 2.30 | 1.83 |

0.1mm, provided the central ray is located over the origin point of the study model.

#### 5.2.2. Calculation of projection error

Let us now consider the effect of projection error. This is a form of parallax error. Magnification error considers the situation where the study model is located directly under the central ray, (Fig 30, pos(a)).

What is the effect of parallax in the situation where the model is located at the periphery of the ceph x-ray cassette?, and does this alter the relationship between the study models when comparing tooth movements, and between the pairs of study models when attempting to superimpose maxillary and mandibular casts?

Let us consider the examples depicted in Fig 30. Does each of these projected images differ from each other, and by what degree?

In order to determine the answers, one must look at the overall length of, and relative position of, each reference point in both situations.

Position (a):

The study model is situated beneath the central ray, in the centre of the cephalometric film.

In this case the lengths ab and bc are equal. There has been a symmetrical increase in length due to magnification.

Note that B and B1 are both in the same line under the central ray. There is no change in the projected position b.

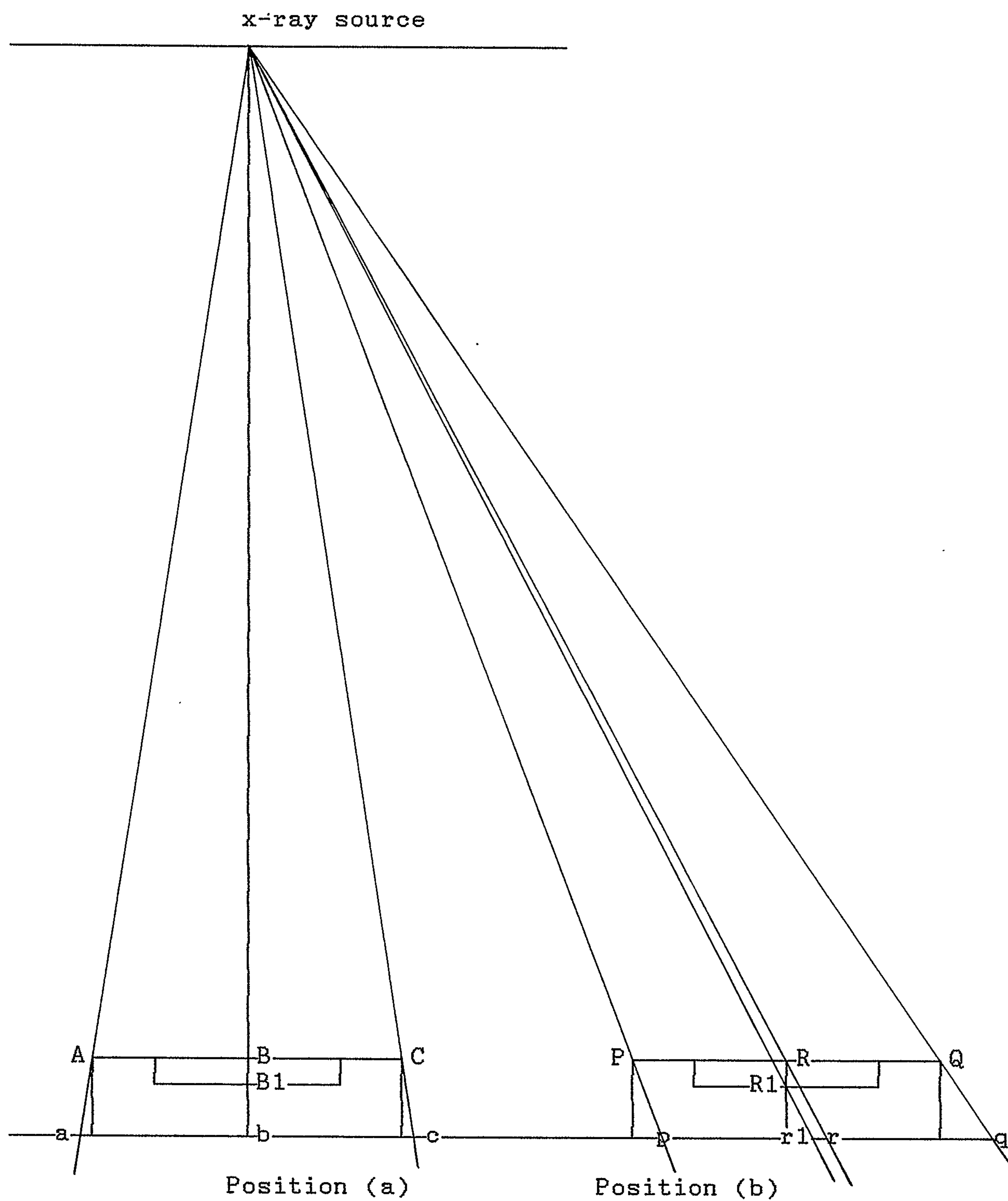


FIG 30 Calculation of Projection Error

Position (b):

The study model is situated at the distance from the central beam situated at the centre of the cephalometric film. Do the projected lengths differ?

If length  $AC = PQ$  then,

Length  $AB = BC = PR = RQ$  also,

Length  $ac = pq$  and,

Length  $ab = bc = pr = rq$  therefore,

Length  $pr_1 < pr$  ;  $r_1q > rq$

If all lengths to be measured lie in the same plane then there is no difference in the relative lengths of their projected lines.

If there is a difference, as in a palatal origin point  $R_1$ , then a difference occurs. This difference is critical because the palatal reference points must be stable throughout a series. The distortion represented by the length  $r-r_1$  can be termed the projection error. Is it significant?

Let us set up a typical experimental situation using a study model 40mm high, the x-ray source 1500mm above the film and estimate that the origin point is 15mm below the occlusal plane.

The origin point  $R_1$  is centered 130mm from the central beam.

The resultant projection error is calculated to be 1.36mm. The projected origin point has moved 1.36mm from its central position.

This is an error which is dependent on the position of the study model on the cephalometric film. It is variable and cannot be

accounted for in a mathematical correction. It can be avoided altogether if the central ray is kept centred over the origin point of each study model.

In the situation where tooth movements are being compared, it means that orientation of the study models is essential. A cast placed near the periphery of the x-ray film, showing this distortion, may increase or decrease the measured change. This may also be compounded or negated if two study models are at either end of the film, depending on their orientation.

Where the maxillary and mandibular models are being superimposed, the distortion is carried over onto the mandibular registration with the mandibular registration point being in an incorrect position.

#### 5.2.2.1. Discussion

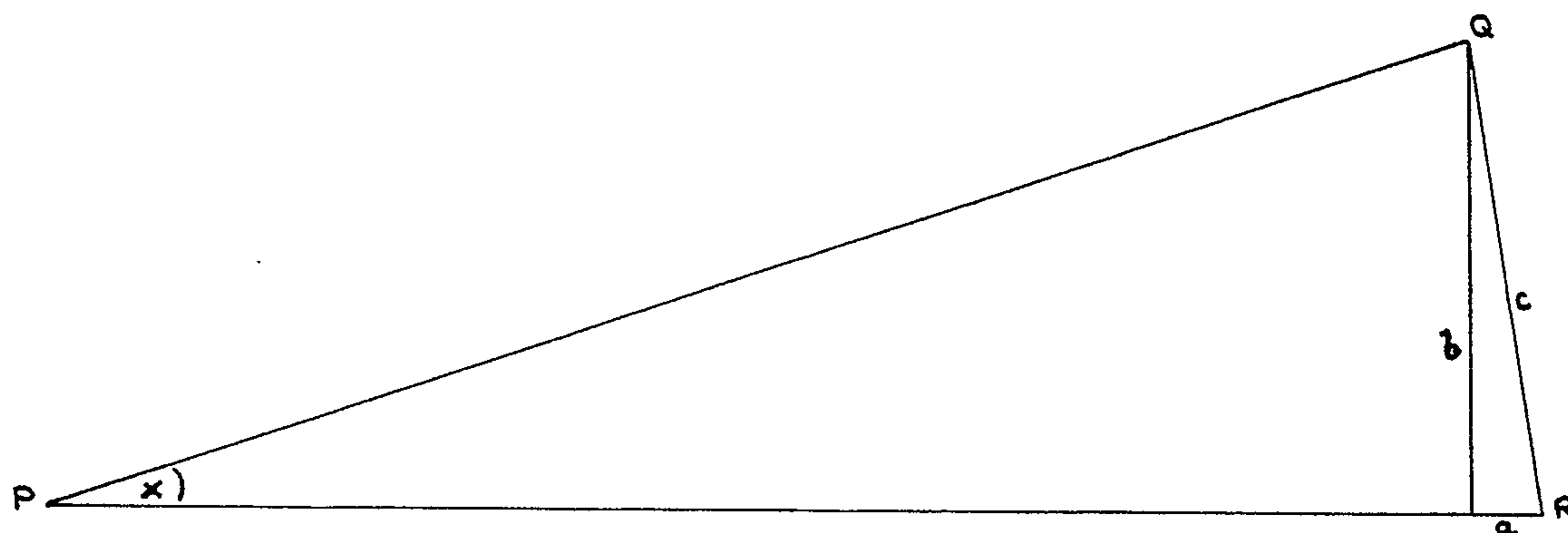
Magnification error, as can be seen can be adjusted for in the mathematical calculations as it is a percentage value and relates to all points not in the vertical line of the central ray and is the same for all points the same height above the film plane.

Projection error is magnification error related to the distortion caused by the difference in height between the occlusal plane and the palatal registration point. This can be an error of approximately 1% which cannot be mathematically accounted for because of its variable nature and its dependence on the

orientation of the study models. It can be overcome if each model origin point is centred under the central ray.

### 5.2.3. Calculation of trimming error

Variation in the cant of the occlusal plane affects the positions of the reference points used in both vertical and horizontal planes. How do these changes affect the percentage magnification factor? Let us consider the situation in Fig 31:



$X$  = degrees away from parallel with the occlusal plane

$PQ = PR = 100$  units (for calculation purposes)

$c = 2(\sin X/2 \times 100)$

$a = \cos(90-X/2)c$

$b = \sin(90-X/2)c$

$Q$  - represents the new position of a point from  $R$  when tilted through an angle  $X$  degrees.

$a$  - represents the horizontal component of change in length.

$b$  - represents the vertical component of change in length.

FIG 31 Calculation of trimming error

This horizontal and vertical linear change for a given  $X^\circ$  tilt can be expressed as a percentage of any length PR. These values are calculated in Table 2.

TABLE 2                      % HORIZONTAL AND VERTICAL LINEAR CHANGE  
FOR CHANGE IN ANGULATION X

| $X^\circ$ | (a)horiz | (b)vert |
|-----------|----------|---------|
| 1         | 0.03     | 1.74    |
| 2         | 0.12     | 3.49    |
| 3         | 0.27     | 5.23    |
| 4         | 0.48     | 6.97    |
| 5         | 0.72     | 8.69    |

The percentage horizontal change as depicted by the length (a) over a  $5^\circ$  tilt remains under 1% of the overall length. The resultant percentage magnification error at the film will be less than 1% of the known percentage magnification factor. This error will be of the order of less than one thousandth of a millimetre.

The vertical component (b) is more noticeable and a  $5^\circ$  tilt can produce a height difference of 7mm at the outside. If one looks at Table 1, and the choice of experimental set-up, a vertical

variation will produce a percentage magnification error of up to 0.42%.

This is unlikely to occur as a 7mm height difference can be spotted by eye. A 3mm difference may not be spotted and will show a 0.15% error. This may be tolerated.

#### 5.2.3.1. Model trimmer bias

Each model trimmer is set at a different angle and very few grinding wheels are exactly set at right angles to the model plate. Pressure due to trimming deflects the spinning wheel also. It is therefore essential that each model be trimmed on the same model trimmer using the same method to ensure that any model trimmer bias is carried through the whole series of casts and therefore discounted as affecting the analysis of the cases.

#### 5.2.3.2. Discussion

Through analysis of the errors encountered, it can be seen that an occlusal plane change due to incorrect trimming, may not significantly affect the projected image dimensions. From the previous analysis of projection error, however, a vertical change will have a greater effect at the periphery of the x-ray film. This could be avoided by ensuring that the central ray passes through the palatine reference point.

## CHAPTER 6

THE EXPERIMENT, IT'S INITIAL PROBLEMS  
AND SUBSEQUENT MODIFICATIONS6.0 Introduction

Certain aspects of the study caused some difficulties which had to be taken into consideration when interpreting the results. The experiment also had to be modified, as did some of the aims as the study progressed.

In order to explain how the experiment evolved, there will be some analysis of the data, mostly confined to interpretation of the analysis of variance tests performed. More detailed analysis of the data will follow in Chapter 7.

6.1 Duplication of study models

Great care was taken to ensure that the study models were duplicated in the prescribed manner to ensure the least amount of distortion in the resultant models.

Towards the end of the duplications, which numbered some 15 sets of models after the unsuitable ones were discarded, it was observed that the original set of models had begun to "melt". This became quite obvious when all the models were placed side by side. There was a marked loss of detail, which made marking a

difficult task.

## 6.2 Trimming the study models

Trimming of the study models was quite straight forward once the technique was mastered and followed as described. Some difficulty was encountered when a set of study models was over-trimmed. It became wise to trim the models to the mark under trimming pressure and then releasing the pressure. A rebound was observed. Trimming then continued using light pressure and release until the model rested at the mark.

It was easy to observe the bias of the trimmer and the essence of repeating the method to the letter, as there is a good deal of flex in the trimming wheel used.

## 6.3 Marking the study models

The study models were marked as previously described. This process became quicker with practice, and it was necessary to compare all the points to each other to ensure the same reference positions were chosen when locating the marker on the point. This variation became obvious when the models lay side by side. Some of the markers were repositioned.

The markers were also easily brushed off. This became a problem so that when all markers were replaced the entire set was sprayed with hairspray which acted as a strong bonding material to fix

the markers into position. This aided the transportation of the models.

#### 6.4 Measuring the study models.

The marked study models were measured using a sliding caliper with a resolution of 0.05 mm. It was decided to use this approach because measuring the models first would not ensure that the markers were correctly positioned. The mid-point of each marker was estimated and the lengths were measured. Variation was encountered because it was not possible to place the calliper on the markers as they would easily be dislodged.

It was necessary to repeat the measurements as an analysis of variance of the first set of repeat measurements showed a statistically significant difference between the measurements.

The second set of measurements showed that the repeat measurements did not statistically differ significantly from each other, and therefore, the results could be seen as a representative set of data, (Appendix III).

It showed that measurement technique requires practice.

#### 6.5 Radiography

The radiographic technique had to be tested for contrast and definition to obtain a radiograph of adequate quality.

The final settings used were; 10 mA., 75 kV and 0.3 sec.

The film used was Fugi 100 HG.

The x-ray source was 1.5 m. from the cassette.

The x-ray unit used was made by General Electric with a variable kV and mA settings.

It took some time to obtain an adequate radiograph, and lower kV values are less inclined to burn out the contrast. It is also possible to use a glove filled with water to absorb some radiation as it leaves the tube as a filter. The film, settings and x-ray study model distance are all highly individual and dependent on each clinical situation. Time must be spent to obtain adequate detail and a usable image.

To further enhance the image quality, different films could also be tested. As it happened there were two types of film available, the other was found to show a much grainier image. This could become an expensive process if specialised film is used.

A series of 25x30 cm x-ray cassettes were used as test and experimental radiographs, these were:

1. A series of six individual exposures of a single maxillary study model (model N° 2).
2. A series of twenty individual exposures, one each of each of the ten sets of maxillary and mandibular study models.
3. A series of single exposure films using a number of the sets of study models on each cassette.
4. An attempt at radiographing a single maxillary model, with the tube almost contacting the occlusal surface was made.

## 6.6 Digitization and analysis

### 6.6.1 Test 1

The x-ray film was placed on the digitizing pad and secured with adhesive tape. The marker points on each image were then digitised four times. These measurements were then analyzed statistically using the analysis of variance. This analysis allows one to detect a significant difference, should it occur between the individual measurements and also between the radiographic images themselves.

One would expect to find a consistency of both the measurement and image in the situation using the same maxillary cast. The variability would then be attributable to the digitisation of an image, and could thus be distinguished from other sources of variability.

It was found that most of the measurements and the images showed significant differences between them. This was unsatisfactory and a second test was conducted. The x-ray was repositioned on the digitizer in a different orientation to the first test.

This time many of the repeat measurements for individual images showed no significant differences between them, but the images still showed a significant difference between them. A third test was conducted and the x-ray was again repositioned in a different position to the previous test. The same occurred. The results for test 1 can be found in Appendix IV. This time, however, different repeat measurements showed a significant difference between them,

while others showed no significant difference between them. The inability to obtain consistent repeat measurements of the inter-marker lengths over three separate test runs indicated that there was variability over the digitising pad.

An explanation of these results :

The first set of data was not consistent enough and showed that the digitization technique was poor, or unpracticed.

This improved over the next two test runs as could be seen by the improvement in the consistency between the measurements.

Even with this improvement it was still not possible to achieve consistency of measurement within the inter-marker group of length measurements.

It was possible to achieve some repeat measurement consistency. This varied between different measurements chosen each time the images were digitised. The images were also positioned differently for each set of repeat measurements. There were 6 images of the same model. Variation between the images should not affect the repeat measurement consistency. Was the digitisation method so variable? Unlikely, as it was possible to achieve measurement consistency on occasions.

The only other possibility is that there was some variation in the digitizing pad depending upon where the image was positioned on it, as well as the variation found in radiographing each time and variation in the digitization technique.

### 6.6.2 Tests 2 and 3

The variability over the digitizing pad must be tested and assessed before meaningful results can be obtained using the radiographs.

In order to minimise variability it was decided to use a square of graph paper as a template to mimic the digitization of the study model radiographs.

The choice of a square of graph paper eliminated the variability of the marker sizes themselves and the grid system allowed accurate positioning of the cross-hairs of the cursor. Initially the intersecting points were marked by a fine-tip black felt pen. This made positioning of the pointer difficult as the marked point did not always correlate with the exact centre of the grid line. It was decided to circle the point and use the intersecting graph lines as the guides for the pointer. Fig 32 shows the two different marking methods.

Similar points to those used on the study models were used for digitisation and similar lines were chosen to analyse the test, (Fig33).

One test was run with the square fixed on the digitizing pad throughout the whole test, twenty-four digitizations were recorded. For convenience, the same analysis was used and in this situation it was found that there was no significant difference between the measurements across or down the groups, (Appendix V). As hoped, consistency of measurement was achieved. This would be used as a comparison for measurements taken at different

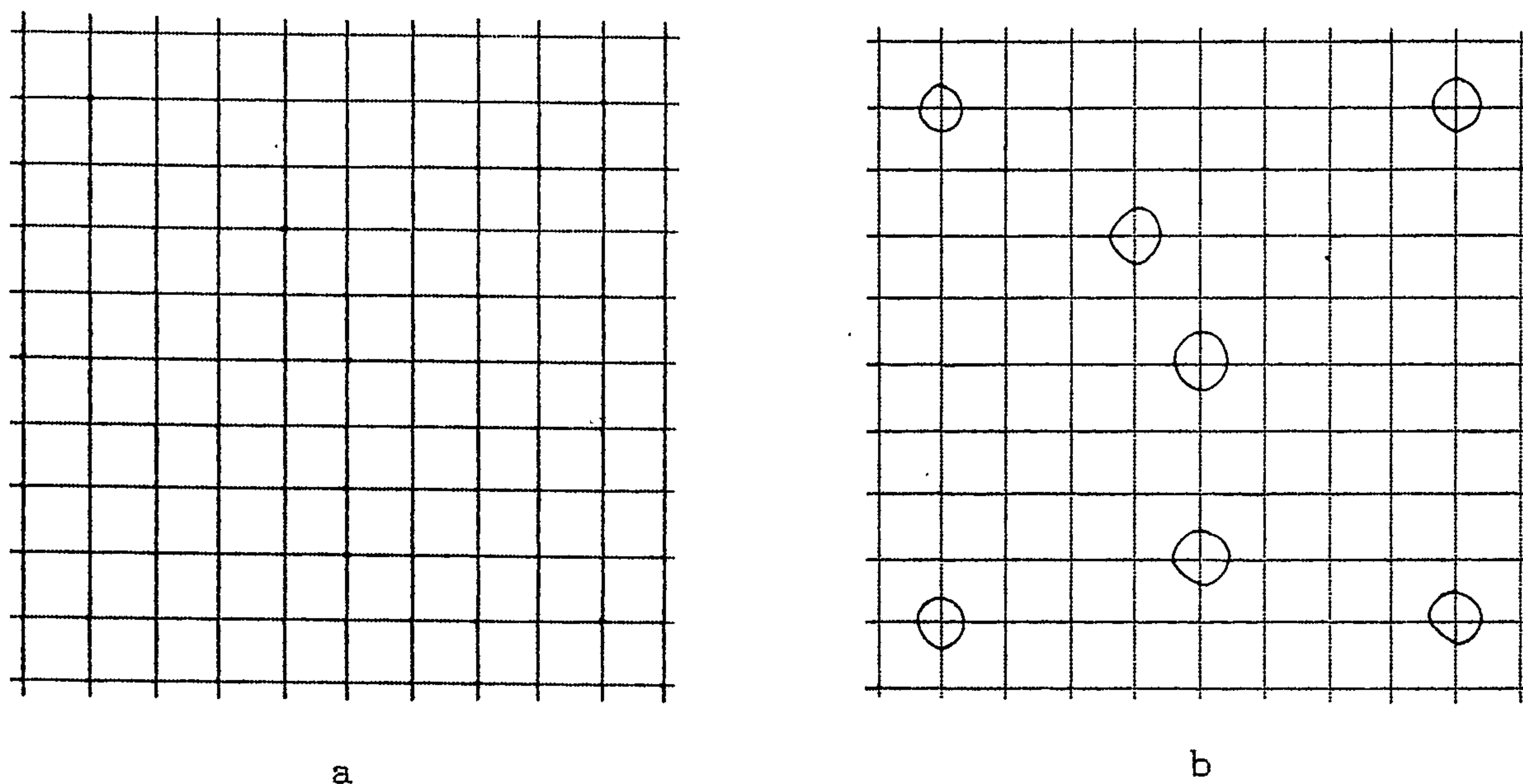


FIG 32

Test graph paper showing the marked points (a)  
and the marked circles (b)

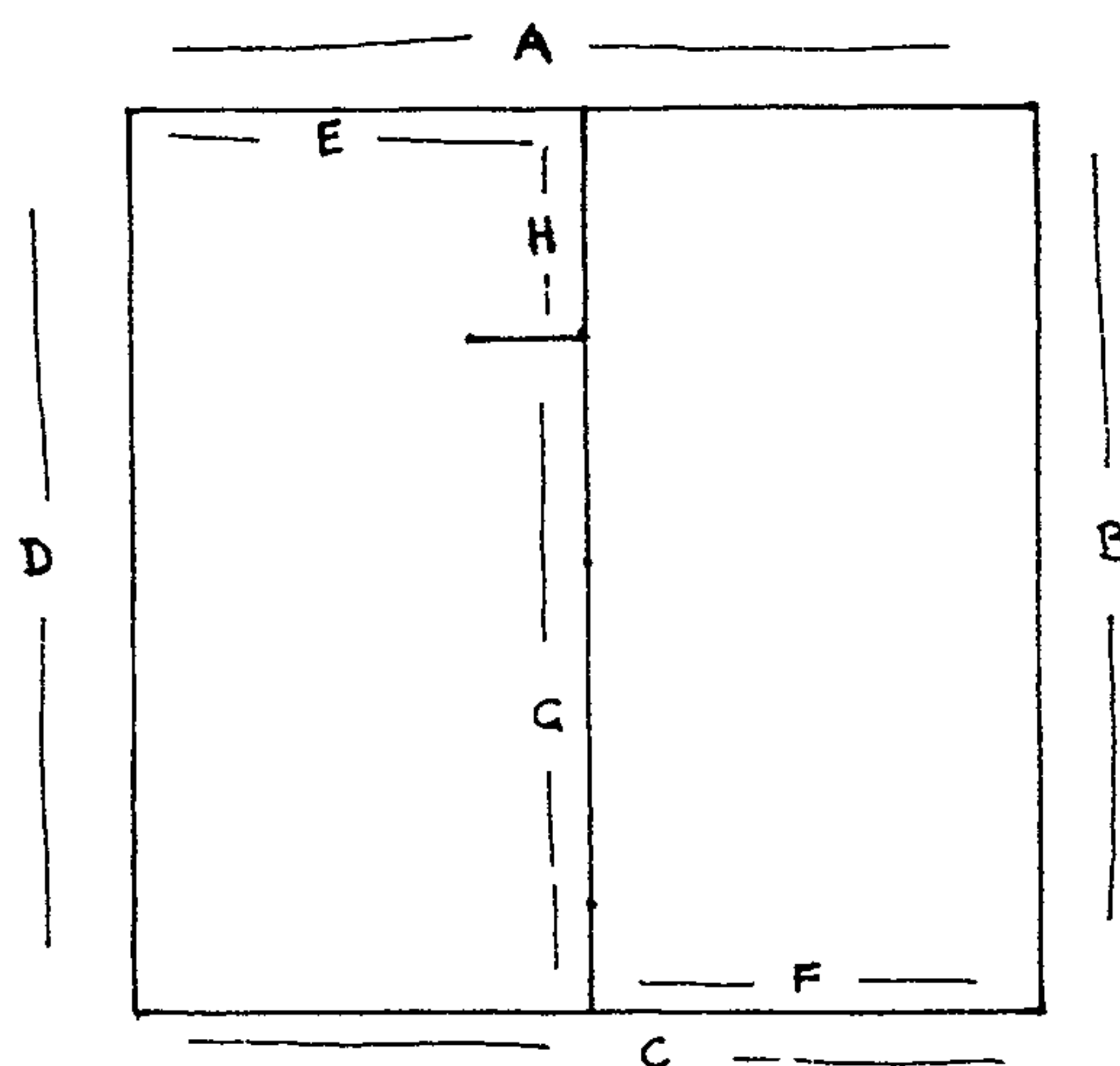


FIG 33

Diagram of the lines used in the analysis of the  
test squares of graph paper

positions on the digitizing pad.

A second set of digitized records was collected using the same square of graph paper as a template. This time 4 measurements were made in each of 6 locations on the digitising pad. The results of the analysis of variance, (Appendix VI), demonstrated that the measurements were consistent throughout the repeats, but showed a statistically significant difference between the locations. In essence the analysis interpreted that at each location a different piece of paper was being measured.

Analysis of the lengths involving the points projected onto the simulated mid-sagittal reference line of the graph paper showed that, due to the geometry and calculations involved in determining the projection of the digitized points and the pad itself, the orientation of the mid-sagittal plane was limited to a range of positions.

If the mid-sagittal plane is co-incident with either axis of the digitizing pad, then there is no difference of the x or y co-ordinates and the zero value prevents the calculation of the projected lengths.

If on the other hand the axis of the mid-sagittal plane is  $45^\circ$  then the gradient factor become the same and their difference becomes zero also.

The simplest solution was to position each radiographic image at the same position with the same axial inclination each time.

### 6.6.3 Tests 4 and 5

The maxillary and mandibular radiographs were then cut into individual images and thus digitized. This was to ensure that the images lay flat on the digitising pad.

The maxillary transfer points were used as described. Mandibular model number 4 had lost its left mandibular transfer point.

When using the transfer points it became clear that the study model bases would not be suitable for use as transfer points due to the variation in model trimmer bias and subsequent radiographic projection. Fig 34 shows the difference between the locating points and the posterior border of the study model when the acetate template is in placed over the mandibular model.

The results for Tests 4 & 5 can be found in Appendices VII & VIII respectively.

### 6.6.4 Test 6

The last series to be digitized was a selection of three maxillary models which were differing distances from the central ray when the radiographs were taken with multiple models. These will be compared to their counterpart models which were individually radiographed. A simple superimposition of the occlusal points and the palatal locating points shows the range of variation evident due to projection. This is demonstrated in Fig 35.

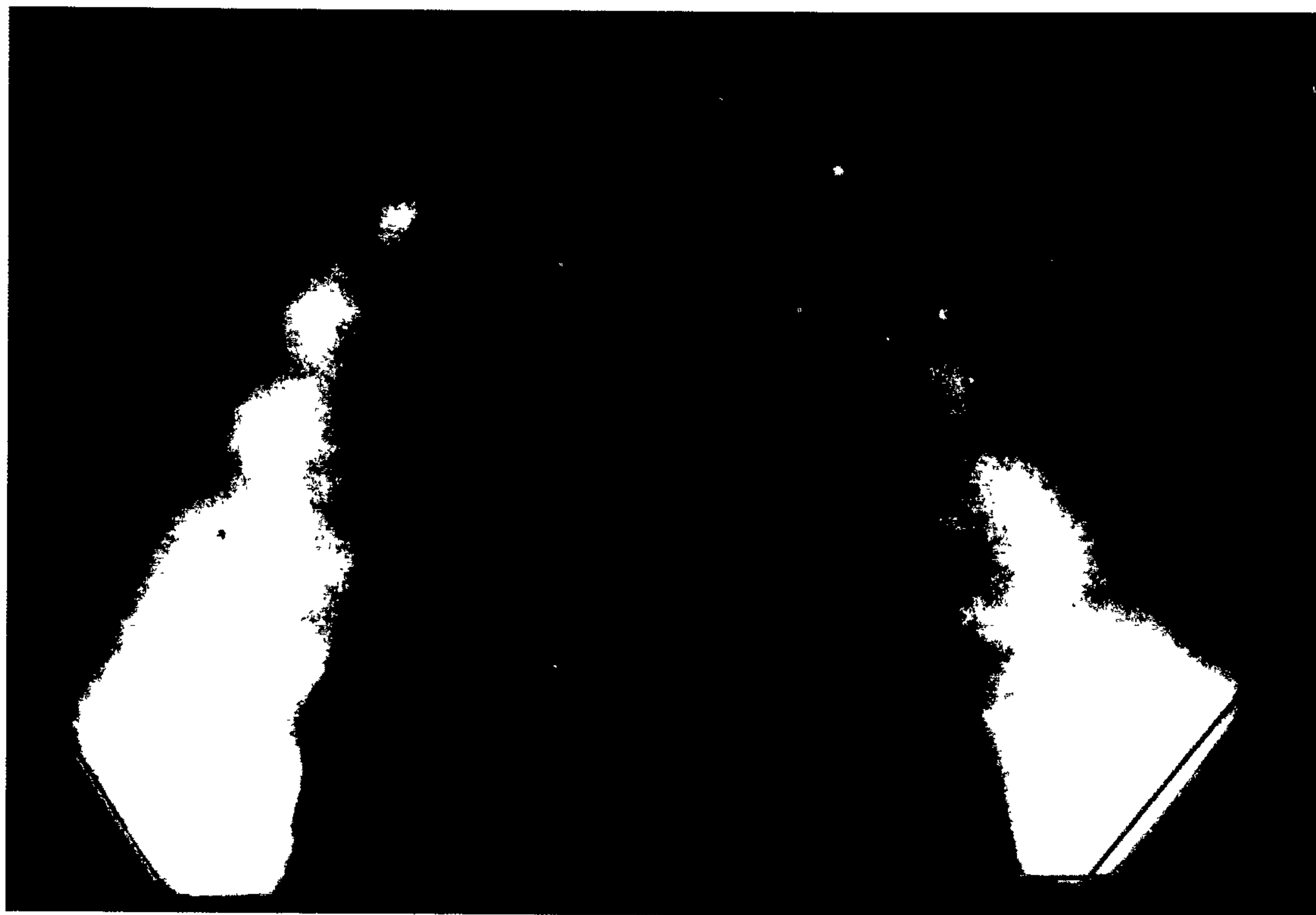


FIG 34 Tracing showing the difference between the model base peripheries when superimposed

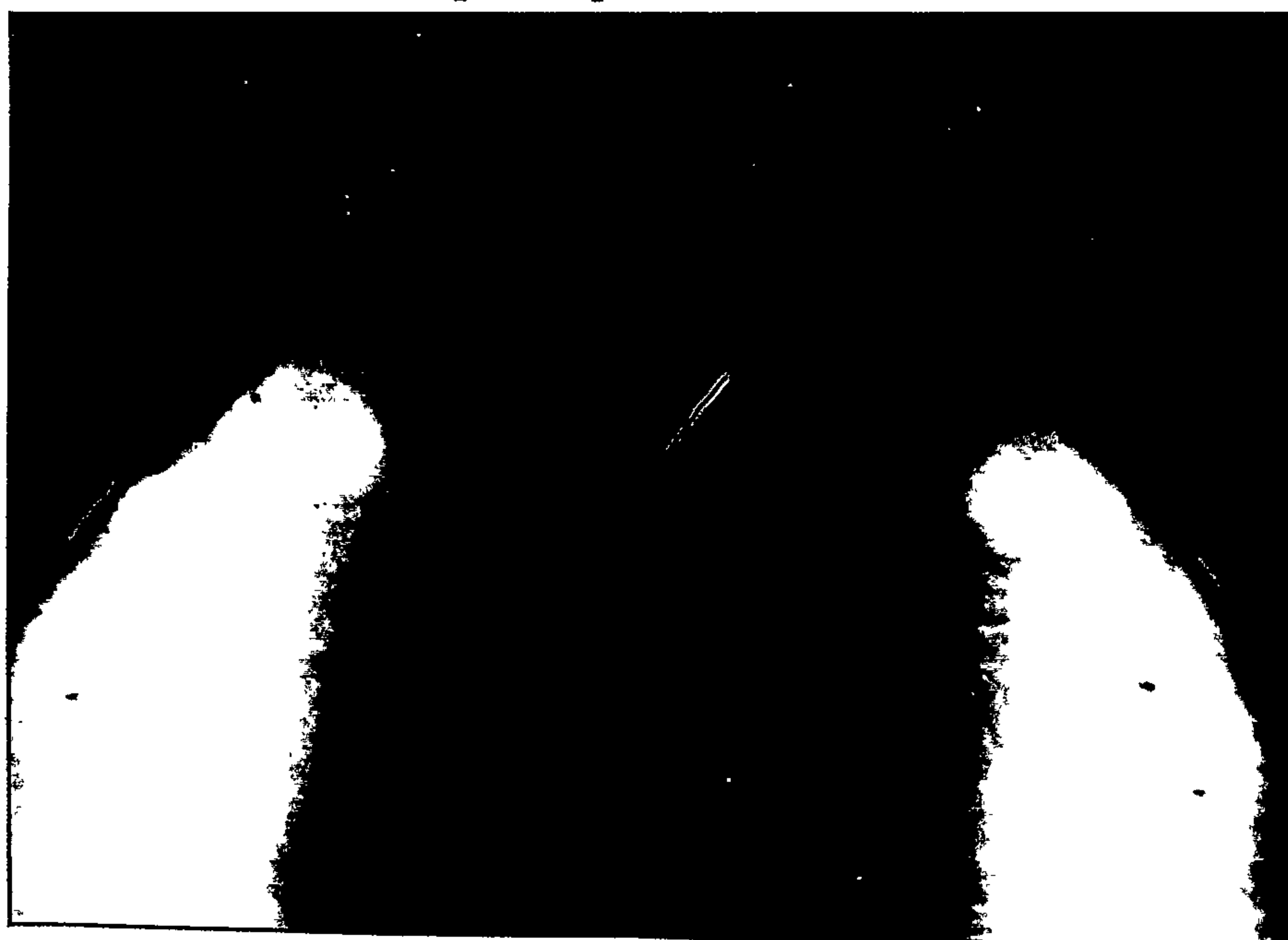


FIG 35 Superimposition showing the difference in origin point positions when superimposing onto different radiographs of the same model, using both radiographic techniques

6.6.5      Test 7

To test the degree of consistency of the digitized data when digitizing a study model, and not a test piece of graph paper, it was decided to digitize a single radiographic image of maxillary model N° 2 24 times, (Appendix IX).

## CHAPTER 7

## ANALYSIS OF THE RESULTS

7.0 Introduction

10 duplicate sets of study models were made from a single set of study models. These were marked, measured and radiographed. The marked points showing on the radiographs were digitised a number of times and lengths were chosen to allow comparison between the study model measurements and the radiographic length measurements. These will be called the "radiographic inter-marker" length measurements (R.I.M's), as they involve direct inter-marker length calculations. They all lie in the same horizontal plane. This group of lengths determines the consistency of measurement and variability of the models or radiographic images. It also shows the accuracy of the predetermined magnification factor used in the calculations.

A second group of lengths was chosen to demonstrate the reliability of the mid-palatine reference line and the origin point to act as references as a basis for longitudinal investigations. These lengths involve the projection of the marker points onto the mid-palatal reference line and these will be called the "mid-palatal projection" length measurements, (M.P.P's).

The analysis of the results will be structured so as to examine the radiographic inter-marker length measurements and the mid-palatal projection length measurements separately. Analysis will follow the testing procedures performed.

The length measurements will be compared using the Coefficient of Variation (C). This expression is a percentage ratio of the standard deviation of a measurement, related to the mean value for the measurement. It is therefore independent of the magnitude of the length being measured. This then allows an assessment of the relative variability of each length measurement.

## 7.1 Analysis of tests

### 7.1.1 Physical measurement of the models

4 sets of measurements for each length were made, using 10 sets of maxillary and mandibular duplicated study models.

The analysis of variance demonstrated no significant differences between measurements. There was, however, a significant difference between the models, as explained in Chapter 6.

This indicates that the means of the study model measurements are representative of the actual lengths, (See Appendix III).

7.1.2 Test 1

6 radiographic images of a single maxillary study model, (Model No2) each digitised 4 times.

## Trial 1

No results were kept as they were so inconsistent

## Trial 2

R.I.M's\* : C's\*  $\leq$  0.97 (0.41 - 0.97)

M.P.P's\* : C's  $\geq$  1.31 (1.31 - 3.76)

## Trial 3

R.I.M's : C's  $\leq$  0.79 (0.39 - 0.79)

M.P.P's : C's  $\geq$  0.91 (0.91 - 3.43)

The inconsistencies in the collected data do not allow these figures to be critically assessed. They do, however, indicate that the coefficients of variation of the radiographic inter-marker length measurements are less than those of the mid-palatal projection length measurements.

Chapter 6 showed that an evaluation of the statistical analysis led to the design of Tests 2 and 3.

R.I.M's = radiographic inter-marker length measurements

M.P.P's = mid-palatal projection length measurements

C = coefficients of variation

### 7.1.3 Test 2

A 40mm square of graph paper fixed in one position, digitised 24 times.

R.I.M's : C's  $\leq$  0.52 (0.35 - 0.52)

M.P.P'S : C's  $\geq$  1.02 (1.02 - 4.29)

All measurements except two mid-palatal projection length measurements showed no significant differences between them. The affected lengths were E and F. These lengths represent the transverse consistency of the mid-palatal reference line. The coefficients of variation of these lines were also the greatest, 3.20 and 4.29 respectively.

These results would indicate that the mid-palatal projection length measurements are more variable than the radiographic inter-marker length measurements.

### 7.1.4 Test 3

The same square of paper used in Test 2 digitised 4 times in each of 6 different locations on the digitising pad.

R.I.M's : C's  $\leq$  0.65 (0.45 - 0.65)

M.P.P's : C's  $\geq$  2.85 (2.85 - 12.66)

All but 2 of the lengths showed no significant differences between them. The affected lengths were C and G. All the lengths showed significant differences between locations.

In spite of the statistically significant differences seen in lengths C and G, a similar pattern to Test 2 has emerged.

The coefficients of variation of the radiographic inter-marker length measurements are less than those of the mid-palatal projection length measurements.

Lengths E and F again displayed the greatest variability. It appears that the determining the mid-palatal reference line is variable. It would be better if the marker points were further apart to minimise this variability. In the study model situation this is not possible because the most unstable region for superimposition is in the anterior region, involving the incisive papilla, (Chapter 2).

#### 7.1.5 Test 4

10 maxillary model radiographs, each digitised 4 times, all positioned in the same area in a similar orientation.

R.I.M's : C's  $\leq$  0.93 (0.41 - 0.93)

M.P.P's : C's  $\geq$  3.23 (3.23 -21.37)

One of the lengths measured exhibited significant statistical differences between the measurements. As expected from the results of physically measuring the models, the analysis of variance between the model radiographs showed a significant difference in all the lengths.

Again the mid-palatal projection length measurements appear to show greater variability than the radiographic inter-marker

length measurements.

The mid-palatal projection length measurements measured along the mid-palatal reference line demonstrated greater variability in this case.

#### 7.1.6 Test 5

10 mandibular model radiographs, each digitised 4 times, all positioned in the same area in a similar orientation.

R.I.M's : C's  $\leq$  6.22 (0.82 - 6.22)

M.P.P's : C's  $\geq$  3.80 (3.80 - 23.93)

All measurements showed no statistically significant differences between them.

The range of variability, as indicated by the coefficients of variation of the radiographic inter-marker length measurements, shows that there may have been some difficulty in digitising. Previous attempts have shown a greater degree of consistency. These results do show that in spite of the variability of the digitisation, the mid-palatal projection length measurements showed no significant differences between the measurements. This tells us that the superimposition method does have a degree of consistency.

Similar patterns to the maxillary results emerged, however. The radiographic inter-marker length measurements demonstrated less variability than the mid-palatal projection length measurements.

The mid-palatal projection length measurements measured along the mid-palatal reference line demonstrated the greatest variability.

Following the analysis of the results, the radiographs were re-examined. They were of poorer clarity, making it more difficult to identify the radiographic markers. The markers themselves appeared to vary more in size and shape. Fig 35 shows an example of a clear radiographic image and a poor one.

It was reasoned, therefore, that the radiographs themselves were the source of this high degree of variability.

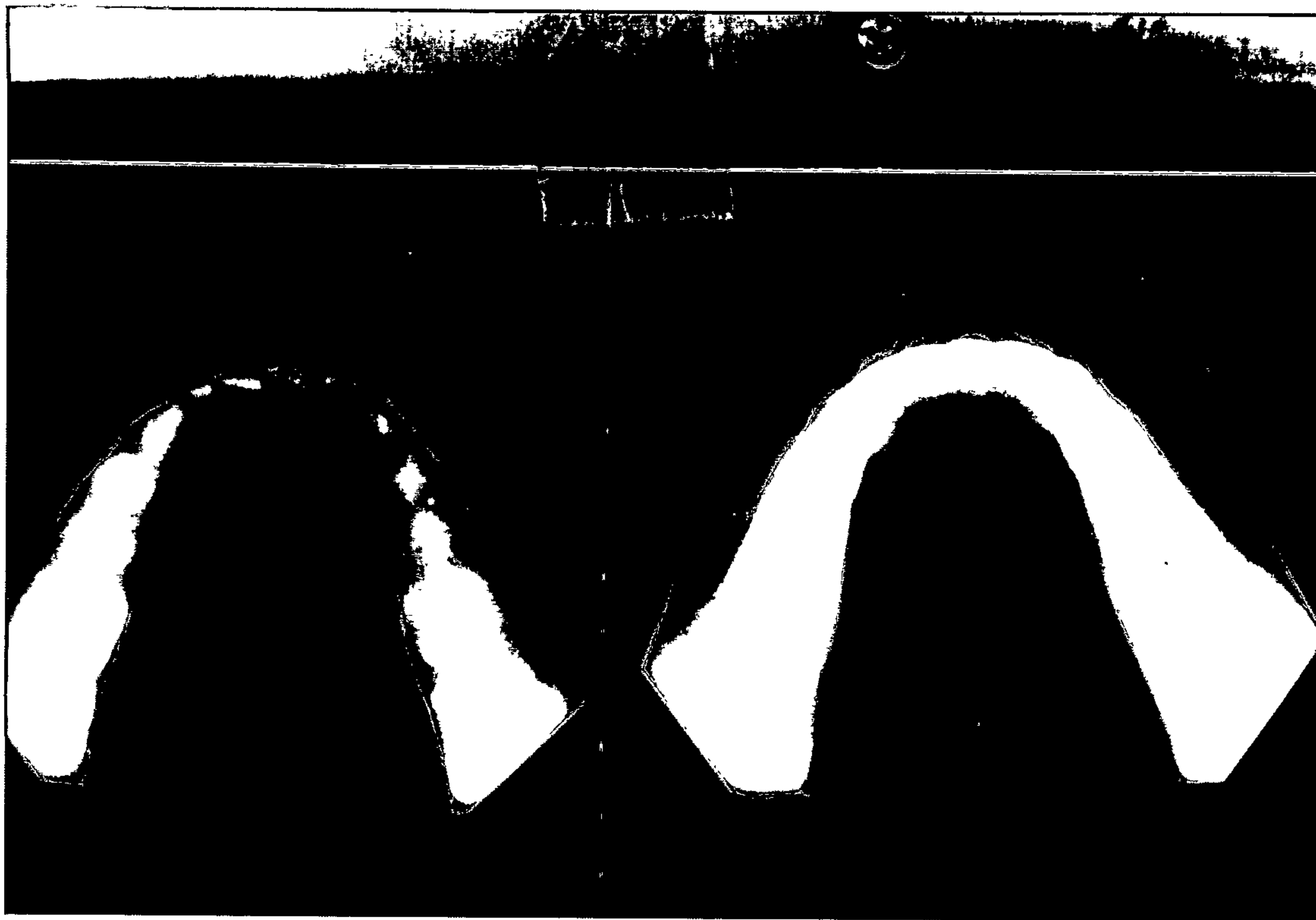


FIG 36 Comparison of a clear and a poor radiographic image

7.1.7 Test 7

A single maxillary model radiographic image was digitised 24 times, in the same position and orientation as all other maxillary and mandibular model images.

R.I.M's : C's  $\leq$  0.68 (0.37 - 0.68)

M.P.P's : C's  $\geq$  0.70 (0.70 - 6.72)

As with the test square of graph paper, the analysis of variance showed no significant differences between the measurements.

The mid-palatal projection length measurements showed greater variability than the radiographic inter-marker length measurements.

The mid-palatal projection length measurements measured along the mid-palatal reference line again showed the greatest variability. A possible explanation is that the mid-palatal projection length measurements, projected onto the mid-palatal reference line, involve the measurement of one marked point and one projected point. The mid-palatal projection length measurements measured along the mid-palatal reference line involve the measurement of two projected points; hence their greater variability.

This differs from the results found using the test graph paper - why? The test graph paper used in Tests 2 and 3, being a square, involved right angle projections which should not cause a change in the recorded lengths on the simulated mid-palatal reference

line. The greatest change came from the variability of the marking of the simulated reference line. This was the only line defined by two points not on the perimeter of the square of graph paper, it was bound to cause the greatest variability.

In the study model situation it can be seen that as all the lines are not geometrically constructed the greatest variability comes from the length measurements formed between two projected points.

## 7.2      Comparison of maxillary physical measurements with maxillary radiographic measurements.

To determine any possible effects of model trimming on the radiographic inter-marker length measurements, it is necessary to compare the actual model lengths and radiographic inter-marker length measurements statistically. To do this the Student's t - test was used to determine if there was any statistical differences between the means of physical measurements and the radiographic measurements, (Appendix X).

Of the four lengths tested only the right canine - molar length demonstrated a statistically significant variability. Without a corresponding change in any of the other lengths, it is probable that the significance is due to measurement error and not trimming distortion.

The results also show that the magnification co-efficient used has not affected the measurements, and can be relied upon.

As a check in future studies, a scale should be placed on the occlusal plane as a test and then onto the cassette. The radiographic images could then be compared.

### 7.3 Discussion

Analysis of the tests shows the following.:

- \* Varying the position of the radiographic image on the digitising pad adversely affects the measurement consistency.

- \* Radiographic inter-marker length measurements show less variability than mid-palatal projection length measurements.

- \* Mid-palatal projection length measurements involving a marked point and a projected point on the mid-palatal reference line show less variability than those involving two projected points measured along the mid-palatal reference line.

- \* The overall range of coefficients of variation of the maxillary radiographic inter-marker length measurements was 0.37 - 0.93. Mandibular measurements were not included due to poor, inconsistent quality of the radiographic images and resultant poor data.

- \* The overall range of coefficients of variation of the maxillary mid-palatal projection length measurements was 0.70 - 21.37.

Mandibular measurements were similarly omitted.

\* The test demonstrating the least amount of variability was Test 2: the square of graph paper fixed in one position on the digitising pad. The radiographic inter-marker length measurements demonstrated a range of coefficients of variation of 0.35 - 0.52.

\* A Student's t-test comparison of the study model lengths and the radiographic inter-marker length measurements, shows that the trimming method is consistent. It also shows that the calculated magnification factor is reliable.

\* The patterns found in tests using a single position on the digitisation pad were also demonstrated in the tests using multiple radiographs and different positions on the digitising pad.

\* Of all the measurements performed, all but one radiographic inter-marker length measurement, demonstrated smaller coefficients of variation than those found amongst the mid-palatal projection length measurements.

#### 7.4 Interpretation of the results

In order to evaluate the experiment and assess its possible usefulness or shortcomings, it is necessary to determine the contribution of the systematic error, method error and

measurement error to the overall variability of the two-dimensional radiographic study model imaging process.

This will be done by examining the radiographic inter-marker length measurements and mid-palatal projection length measurements separately.

The results will be analysed in terms of percentage errors derived from the coefficients of variation :

If we use 10mm as a standard length then a 3% range of error from the "true value" is 0.3mm. This may be expressed as a range of  $\pm 0.15$ mm. If this range represents two standard deviations either side of the mean then it will include  $> 95\%$  of the the total readings. The standard deviation, therefore, is 0.075mm. A 3% error expressed as a coefficient of variation becomes 0.75. Coefficients of variation values 0.25, 0.50, 0.75 and 1.0 represent errors of 1%, 2%, 3% and 4% respectively. An increment of 0.25 represents 1%.

#### 7.4.1 Radiographic inter-marker length measurements

Analysis of the maxillary radiographic inter-marker length measurements will allow us to determine the systematic error involved in the method, as these lengths are related directly to the study models.

We will compare the single test radiograph results with the results from the 10 maxillary test radiographs.

The single test maxillary radiograph recorded coefficients of

variation of between 0.37 and 0.68. This represents an approximate overall percentage error of between 1.5 and 2.5%. The 10 maxillary test radiographs recorded coefficients of variation of between 0.41 and 0.93. This represents an approximate overall percentage error of between 2 and 4%.

From this evidence, it is not unreasonable to assume a combined systematic and marking error of approximately 1.5%. This leaves a measurement error of up to 2%.

If we include the most consistent results given by the stationary test square of graph paper, the coefficients of variation ranged from 0.35 to 0.52. This represents an error range of between 1.5 and 2%. This represents the measurement error using the digitising pad.

Comparing the total error of the stationary test square of graph paper with the single maxillary test x-ray shows a difference of approximately 0.5%. This may be due to the difference in markers used.

This supports the evidence of a measurement error of between 1.5 and 2%.

#### 7.4.2 Mid-palatal projection length measurements

The coefficients of variation of the mid-palatal projection length measurements are in all but one case greater than 1.00.

At best an error of 4% can be expected. This occurred using the single test maxillary radiograph. When including the 10 maxillary

test radiographs the coefficients of variation were as high as 21.37, which represented an error range of over 85%.

## 7.5 Discussion

Interpretation of the results shows that there is a combined systematic and marking error of up to 2%. 0.5% of this combined error may be due to the variability in digitising the radiographic markers used.

The remaining 1.5% error accounts for the marking and the systematic errors as well as the variability found in projecting the radiographic inter-marker length measurements. If the systematic error includes the marking error, and is of the order of 1% as estimated in Chapter 5, then the remaining error due to the method involved in estimating the radiographic inter-marker length measurements is approximately 0.5%. This appears small but not unreasonable as a statistical comparison of the measured study model lengths with the corresponding radiographic inter-marker length measurements indicated that there was little distortion to the radiographic study model image.

Measurement error has been estimated to be between 1.5 and 2%.

The variability in determining the lengths of the radiographic inter-marker length measurements is between 2 and 4%.

The variability of the mid-palatal projection length measurements is greater than 4%.

What does this mean clinically? Is this two-dimensional radiographic study model imaging process a useful research tool? Clinically a 4% variability represents a range of  $\pm 0.5\text{mm}$  over a 25mm length. It is therefore, unreasonable to expect that this method can be used to measure inter-marker length changes of less than 1mm reliably.

How stable are the palatal reference points as longitudinal reference markers? Quite obviously it has been demonstrated that the variability encountered in using the mid-palatal projection length measurements is far greater than preferred for use in research.

This error probably comes from four sources:

- 1...The inherent systematic and marking errors of the method
- 2...The measurement error of the method
- 3...The error of identification of the mid-palatal reference line geometrically. This is demonstrated in Test 2 with the test square of graph paper.
- 4...The inherent nature of the projection error involved in the radiographic interpretation of the three-dimensional study models. This is demonstrated when comparing the range of coefficients of variation of the mid-palatal projection length measurements found in the test using the stationary square of graph paper, with those of the mid-palatal projection length measurements of the single 10 maxillary study models. As expected the variability over the 10 maxillary study models is much

greater.

These sources of error probably combine to give the sometimes very large degree of variability found.

## CHAPTER 8

## CONCLUSIONS

8.0 General

The aim of this thesis was to describe, test and evaluate the reliability of the proposed two dimensional radiographic study model imaging process and analysis, and comment on its overall application as a research tool.

The method involves the following:

- \* Manipulation of the study models
- \* Radiographic imaging of the study models
- \* Digitisation of the images
- \* Analysis of data

Conclusions will be grouped under these headings to determine the contribution of each part to the total outcome.

Comment will then be made on its overall application as a research tool and possible future directions discussed.

8.1 Manipulation of study models8.1.1 Duplicating and marking the study models

An estimated combined systematic error involved in the duplication and marking of the study models of approximately 1%

was calculated. The error involved in marking the study models was not directly tested.

#### 8.1.4 Trimming the study models

Comparison of the physical model measurements with the radiographic inter-marker length measurements showed that trimming error was not significant and did not contribute greatly to the overall error of the method. This may have accounted for 0.5% error.

### 8.2 Radiographic imaging of the study models

#### 8.2.1 Magnification error

Comparison of the study model measurements with the radiographic inter-marker length measurements, showed no significant differences between them. This indicated that the calculated magnification factor was reliable. In future studies a test length could be placed both on the occlusal plane of the study model as well as on the x-ray cassette to do a direct calculation of the magnification.

#### 8.2.2 Projection error

Two methods of radiographing the study models were tested. The first involved the individual radiographing of each study model. The second involved the radiographing of a series of study models, as might be used in a longitudinal analysis of a case.

By calculation, it could be seen that the effect of projection error and the different heights of the occlusal plane and the palatal reference points from the x-ray film, would contribute to a misrepresentation of the palatal reference line and origin points. This would occur in both a longitudinal study and when superimposing the maxillary reference points onto the mandibular study model image.

By calculation it was also noted that lengths measured in the occlusal plane were not affected by the projection error when situated different distances from the central beam.

These calculations were confirmed by simple superimposition of the individual study models onto each other. The non-projected lengths could be superimposed onto one another, while it could be seen that the palatal reference points did not match.

Projection error can simply be minimised by using individually radiographed study models. The possible effect of projection variability was noted, but not directly measured, when analysing the mid-palatal projection length measurements, as these demonstrated a great amount of variability.

### 8.3 Digitising the images

The initial aims of the experiment, as described in Chapter 4, were set out in an attempt to fully explore the possibilities available using the digitising pad and associated software. It

soon became apparent that the digitising pad was one of the main obstacles.

It was found that varying the position of the radiograph on the digitising pad affected the statistical significance of the lengths being measured, to the extent that all measurements had to be made placing each radiograph in the same position. This meant that all the radiographs had to be cut into pieces to be analysed, so as to ensure that the images lay flat on the digitising pad. This presents a storage problem later and nullifies the advantage of having all the information of a case on a single x-ray film.

The focus of the study became finding a situation where the collecting of data could be considered reliable. This involved the use of test squares of graph paper.

Even using these precautions the largest single error is the measurement error found in the digitisation process and was estimated to be between 1.5 and 2%.

It is because of this large measurement error that many of the aims were abandoned, as the simple process of determining the consistency of the radiographic inter-marker length measurements became a difficult goal.

#### 8.4      Analysis of data

Analysis of the data collected using this two dimensional radiographic imaging process shows that:

- \* Varying the position of a radiographic image on the digitising pad adversely affects measurement consistency
- \* Manipulation of the study models accounted for approximately 1.5% of the overall error of the method
- \* Measurement error ranged between 1.5 and 2% of the total error of the method
- \* This two-dimensional radiographic study model imaging process could be used to measure changes between the radiographic inter-marker length measurements, provided these changes were greater than 1mm.
- \* As the two-dimensional radiographic study model imaging process stands, it cannot be used as a research tool using the palatal reference points as reference points for longitudinal studies, as the variability in the determination of the mid-palatal projection length measurements was so great.

## 8.5 Discussion

As an imaging method it can be seen that physically the method shows consistency. A 1.5% systematic error, including marking error, is acceptable. No significant trimming error is present due to changes in the model base cant. Projection error can be minimised by using individual radiographic exposures for each study model. Magnification error can be compensated for in the computer software.

It appears, however, that the measurement variability encountered during digitisation, as the largest singlr source of error, causes the downfall of this imaging method as a research tool. At best the measurement error is 1.5%.

This measurement error combined with the systematic and projection errors, cause the determination of the mid-palatal projection length measurements to show such a great amount of variability that it renders the method unusable in its present form.

The digitising pad also displays some variability in measurements due to the position of the radiograph on the pad. This means that statistically it would be difficult to obtain consistent data.

The key to the success of this two dimensional radiographic study model imaging process and analysis, lay in the possibility of

storing and processing information quickly and efficiently, show longitudinal dental change relative to the palate, and provide a method which could be used to study these changes using differing treatment regimes.

Without the ability to use the palate as reference the method becomes a clumsy and relatively inaccurate method for measuring inter-arch length changes. This could be seen using the mandibular study models as an example. Poor choice of markers and radiographic definitions highlighted the fact. It would be simpler to photograph the models, marked with pen of consistent diameter. Vision is better and there is no need for poor light conditions when digitising.

## 8.6 Future directions

Unless there is an improvement in the measurement error due to the digitisation process and the variability involved in the positioning of an x-ray on the digitising pad, then there is limited future for this method as a research tool. The variability would have to be reduced quite markedly in order to allow the clinical use to the palatal points as longitudinal reference points in a study. Any future testing should aim at reducing this source of error.

It appears logical to use a template made of dental stone or plaster with marker points set into it to simulate the

differences between the occlusal plane and the palatal points. The depth and distances of the points apart would be known so that the source of the differences in the variability due to the different heights above the x-ray film could be tested.

An area to concentrate also on would be assessment of the source and magnitude of digitisation error and how it can be reduced. This would directly improve the physical aspect of digitisation of the points, as well as reducing the variability due to the position on the digitising pad.

It can be seen that avoiding the use of a digitiser gives a much better consistency to the method, such as is found using the travelling microscope or Reflex Metrograph, (Chapter 1), which can measure lengths to a range of approximately  $\pm 0.22\text{mm}$ . Which is approximately half the range achievable using this two-dimensional radiographic study model imaging process to measure the radiographic inter-marker length measurements.

Another aspect for improvement is the quality of the radiographs. These could be improved if using such x-ray film as that used in mammograms, which are used to differentiate soft tissues.

Finally a simpler radio-opaque marking technique would be useful. The material should be radio-opaque, easily removed following measurement, be of a uniform size and density and not be dislodged during transport. The error involved in digitisation

due to the differing markers used was estimated to be approximately 0.5%. A reduction here would significantly reduce the measurement error.

Should these areas show significant improvement then the study could well be repeated, this time using duplicate models from an acrylic master which would not "melt". This would further help to reduce the systematic error.

#### 8.7 Summary

To summarise then, the proposed two-dimensional radiographic study model imaging process is not usable as a research tool, primarily because of its measurement variability, but also because of the compounding effects of the two-dimensional representation of the three-dimensional study model.

As a research tool the method should be reliable, consistent, and easily used. At this point the proposed method does not fit any of these categories and further investigations into measurement improvement are required. With an improvement in measurement reliability it may then be possible to more accurately determine the sources of the errors involved in the measurement of the mid-palatal projection length measurements. Minimising these errors are the key to the method's success as a future research tool.

## BIBLIOGRAPHY

- ADAMS L.P. (1988) Tooth wear measurements using a reflex microscope  
WILDING J.C. J Oral Rehab 15 : 605-613
- ALLEN H. (1888) The palatal rugae in man.  
Proceedings of the academy of natural sciences of Philadelphia  
vol 40 :254-272
- BALLARD M.L. (1944) Asymmetry in tooth size: A factor in the etiologi, diagnosis and treatment of malocclusion  
Angle Orthod 14 : 67-70
- BAUMRIND S. (1983) Three-dimensional x-ray stereometry from paired co-planar images: A progress report.  
MOFFIT H. Am J Orthod 84 : 292-312  
CURRY S.
- BAUMRIND S. (1975) A system for craniofacial mapping through the integration of data from stereo x-ray films and stereo photographs.  
Am Soc Photogrammetry ; Proceedings of the symposium on close-range photogrammetric systems: pp 142-166
- BEGOLE E.A. (1981) A computer system for the analysis of dental casts.  
CLEALL J.F. Angle Orthod 51 : 252-258  
GORN H.C.
- BERKOWITZ S. (1968) Stereophotogrammetry of serial casts of cleft palate.  
PRUZANSKY S. Angle Orthod 38 : 136-149
- BERKOWITZ S. (1971) Stereophotogrammetric analysis of casts of normal and abnormal palates.  
Am J Orthod 60 : 1-18
- BHATIA S.N. (1987) Operational performance of the travelling microscope in the measurement of dental casts  
HARRISON V.B. B J Orthod 14 : 147-153
- BIGGERSTAFF R.H. (1969) Electronic method for the analysis of the human post-canine dentition.  
Am J Phys Anthropol 31 : 325-242

- BJORN H. (1954) A photogrammetric method of  
LUNDQVIST C. measuring the volume of facial  
HJELMSTROM P. swellings  
J Dent Res 33 : 295-308
- BLACK G.V. (1902) Descriptive anatomy of the human  
teeth  
4<sup>th</sup> Edition Philadelphia  
S.S. White Mfg. Co.
- BOLTON W.A. (1958) Disharmony in tooth size and its  
relation to the analysis and  
treatment of malocclusion.  
Angle Orthod 28 : 113-130
- BOLTON W.A. (1962) The clinical application of a  
tooth-size analysis.  
Am J Orthod 48 : 504-529
- BRODIE A.G. (1966) The apical base : A zone of inter-  
action between the intestinal and  
skeletal systems  
Angle Orthod 36 : 136-151
- BURSTONE C.J. (1978) Holographic measurement of tooth  
PRYPUTNIEWICZ R.J. mobility in three dimensions  
BOWLEY W.W. J Perio Res 13 : 283-294
- BURSTONE C.J. (1982) Holographic measurement of incisor  
EVERY T.W. extrusion  
PRYPUTNIEWICZ R.J. Am J Orthod 82 : 1-9
- BUSCHANG P.H. (1990) Holographic storage of dental casts  
CEEN R.F. J Clin Orth 24 : 308-311  
SCHROEDER J.N.
- BUTCHER G.W. (1981) The reflex optical plotter : a  
STEPHENS C.D. preliminary report  
B Dent J 151 : 304
- DURR D.P. (1987) Dimensional stability of alginate  
NOVAK E.V. impressions immersed in  
disinfecting solutions  
J Dent Child Jan/Feb 87 : 45-48
- FRIEL S. (1949) Migration of teeth.  
Dent Record : 74-84
- FURUKAWA A. (1984) A study on tooth marks- on the  
reproducibility and identification  
of tooth marks by means of a three  
dimensional measuring instrument.

- GARN S. (1962) Automation in anthropometry  
Am J Phys Anthropol 20 : 387-388
- GARNER L.D. (1971) Occlusogram: Its application to  
cleft palate rehabilitation  
J Dent Res 50 : 1286-1290
- HABU H. (1986) Three-dimensional measurement of  
stone cast deformation  
Nihon Univ Sch Dent J 28 : 51-60
- HERRERA S.P. (1986) Dimensional stability of dental  
impressions after immersion  
disinfection  
J.A.D.A. 113 : 419-422
- HIRON E.H. (1958) Estimation of the sizes of un-  
erupted cuspid and bicuspid teeth.  
Angle Orthod 28 : 236-240
- HOSODA H. (1961) Distortion of irreversible  
hydrocolloid and mercaptan rubber-  
base materials  
J Pros Dent 11 : 318-333
- HOWES A.E. (1952) Model analysis for treatment  
planning.  
Am J Orthod 38 : 183-207
- HOWES A.E. (1954) A polygon portrayal of coronal and  
basal arch dimensions in the  
horizontal plane.  
Am J Orthod 40 : 811-831
- JONES M.L. (1988) A reflex plotter investigation  
into the dimensional stability of  
alginate following disinfection by  
varying regimes employing 2.2 per  
cent glutaraldehyde  
B J Orthod 15 : 185-192
- JONES M.L. (1986) The performance and use of a 3D  
cast analysis system  
B J Orthod 13 : 54
- JORMAN P.R. (1958) Flexible rubber molds for accurate  
multiple reproduction of plaster  
casts  
J Pros Dent 8 : 100-106

- KAKUTA K. (1989) Setting expansion of dental stone in hydrophilic addition type silicone impression  
Nippon Dent Univ Ann Pub 23 : 61
- OGURA H.  
MIYAGAWA Y.  
KASHIWAGI Y.
- KEATING P.J. (1984) The holographic storage of study models  
B J Orthod 11 : 119-125
- PARKER R.A.  
KEANE D.  
WRIGHT L.
- KORKHAUS G. (1930) A new orthodontic symmetrogaph.  
Int J Orthod 16 : 665-668
- KORKHAUS G. (1959) Present orthodontic thought in Germany.  
Am J Orthod 45 : 881-900
- LAUTENSCHLAGER E.P. (1969) Investigation on the expansion of dental stone  
J Dent Res 48 : 206-210
- LEBRET L. (1962) Growth Changes of the palate.  
J Dent Res 41 : 1391-1404
- LEBRET L. (1964) Physiologic tooth migration.  
J Dent Res 43 : 610-618
- LUNDSTROM A. (1981) Intermaxillary tooth-width ratio analysis.  
Europ J Orthod 3 : 285-287
- LYSELL L. (1955) Plicae palatinae and papilla incisiva in man ;  
A morphologic and genetic study.  
Acta Odont Scand: vol 13 sup 18
- McNEIL G.T. (1966) X-ray stereo photogrammetry  
Photogram Eng Rem Sensing 32 : 993-1004
- MacLARNON A.M. (1989) Applications of the reflex instruments in quantitative morphology  
Folia Primatol 53 : 33-49
- MAHLER D.B. (1953) The volumetric contraction of dental gypsum materials on setting  
J Dent Res 32 : 354-361
- ASGARZADEH M.S.
- MILLER M.W. (1975) Syneresis in alginate impression materials  
Brit Dent J 139 : 425-430

- MOSS J.P. (1988) A computer system for the inter-  
GRINDROD S.R. active planning and prediction of  
LINNEY A.D. maxillofacial surgery  
ARRIDGE S.R. Am J Orthod Dentofac Orthop 94 :  
JAMES D. 469-475
- MOORREES C.F.A. (1959) The dentition of the growing child.  
Cambridge, Mass. Harvard Uni Press.
- MOORREES C.F.A. (1965) Changes in dental arch dimensions  
REED R.B. expressed on the basis of tooth  
eruption as a measure of biologic  
age  
J Dent Res 44 : 129-141
- MUSICH D.R. (1973) A reliable device for measuring  
ACKERMANN L.J. arch perimeter  
Am J Orthod 63 : 366-375
- NEWTON I. (1976) The measurement of palatal surface  
EVANS S. area by photogrammetry  
Photogram Rec 8(47) : 646-651
- OHTA N. (1982) A cross-sectional study of facial  
OKADA M. growth with the moire camera  
SAKUMA K. Bull. Tokyo dent Coll. 23 : 25-35
- PEAVY D.C. (1967) The effects of tooth movement on  
the palatine rugae  
J Pros Dent 18 : 536-542
- PECK S. (1975) Orthodontic aspects of dental  
PECK H. anthropology.  
Angle Orthod 45 : 95-102
- PHILLIPS R.W. (1973) Skinner's: Science of dental  
materials ; 7<sup>th</sup> edition  
W.B. Saunders company
- RICHMOND S. (1985) A comparison of two- and three-  
JONES M.L. dimensional incisor angles  
B J Orthod 12 : 90-96
- RICHMOND S. (1986) The development of a 3D cast  
JONES analysis system  
B J Orthod 13 : 53
- RICHMOND S. (1987) Recording the dental cast in three  
dimensions  
Am J Orthod Dentofac Orthop 92 :  
199-206

- RYDEN H. (1982) Movements of healthy and  
BJELKHAGEN H. periodontally involved teeth  
SODER P.O. measured with laser reflection  
technique  
J Periodontol 53 : 439-445
- RYDEN H. (1982) Tooth position measurements on  
BJELKHAGEN H. dental casts using holographic  
MARTENSSON B. images  
Am J Orthod 81 : 310-313
- SAVARA B.S. (1965) Applications of photogrammetry for  
quantitative study of tooth and  
face morphology.  
Am J Phys Anthropol 23 : 427-434
- SAVARA B.S. (1969) A new data acquisition method for  
measuring dentitions and tests for  
accuracy.  
Am J Phys Anthropol 13 : 315-318
- SELMER-OLSEN R. (1949) The fixation and stability of the  
teeth in the jaws with relation to  
their morphology  
Dent Record 69 : 322-334
- SCHUDY F.F. (1963) Cant of the occlusal plane and the  
axial inclinations of teeth.  
Angle Orthod 33 : 69-82
- SILLMAN J. H. (1964) Dimensional changes of the dental  
arches: Longitudinal study from  
birth to 25 years.  
Am J Orthod 50 : 824-842
- SILLMAN J.H. (1951) Serial study of good occlusion from  
birth to 12 years of age.  
Am J Orthod 37 : 481-507
- SINGH I.J. (1964) A method for making tooth and  
SAVARA B.S. dental arch measurements  
J.A.D.A. 69 : 719-721
- SVED A. (1955) The mesial drift of teeth during  
growth.  
Am J Orthod 41 : 539-553
- TAKADA K. (1983) Operational performance of the  
LOWE A. reflex metrograph and its applica-  
DECOU R. bility to the three-dimensional  
analysis of dental casts.  
Am J Orthod 83 : 195-199

- TAKASAKI H. (1970) Moire topigraphy  
Applied Optics 9 : 1457-1472
- TAKASAKI H. (1973) Moire topography  
Applied Optics 12 : 845-850
- TAKEI T. (1985) Applications of moire topography to  
YOKOSAWA S. forensic odontology  
INNAMI T. Nihon Sch Dent J 27 : 87-104  
MIYAZAWA T.  
KUWANA T.  
TAKAGI M.  
FURUKAWA A.
- VAN DER LINDEN F.P. (1971) Quality control of digitized data  
and inclusion of essential and  
meaningful checkpoints  
J Dent Res 50 : 982
- VAN DER LINDEN F.P. (1972) Three-dimensional analysis of  
BOERSMA H. dental casts by means of the  
ZELDERS T. optocom  
PETERS K.A. J Dent Res 51 : 1100  
RAABEN J.H.
- VAN DER LINDEN F.P. (1972) A new method to determine tooth  
positions and dental arch  
dimensions  
J Dent Res 51 :
- VAN DER LINDEN F.P. (1973) Dimensional and positional changes  
in palatal rugae  
J Dent Res 52 :
- VAN DER LINDEN F.P. (1978) Changes in the position of  
posterior teeth in relation to  
ruga points.  
Am J Orthod 74 : 142-161
- WHITE L.W. (1982) Clinical use of occlusograms  
J Clin Orth 16 : 92-103
- WILLIAMS D.F. (1983) Laser techniques for the evaluation  
CUNNINGHAM J. of wear in class II restorations  
LALOR M.J. J Oral Rehab 10 : 407-414

## APPENDIX I

## STATISTICAL FORMULAE

The formulae used in the statistical analyses presented in this thesis are :

$$\text{NUMBER OF MEASUREMENTS} = n$$

$$\text{DEGREES OF FREEDOM } df = n-1$$

$$\text{STANDARD DEVIATION } S.D. = \sqrt{\frac{\sum X^2 - \frac{(\sum X)^2}{n}}{n-1}}$$

$$\text{STANDARD ERROR OF THE MEAN } S.E. = \frac{S.D.}{\sqrt{n}}$$

$$\text{SUM OF SQUARES } S.S. = \sum_n (X_n - \bar{X})^2$$

$$\text{VARIANCE } VAR = \frac{\sum_n (X_n - \bar{X})^2}{n-1} = \frac{SS}{df}$$

## APPENDIX I (cont'd)

## Student's t-Test

The Student's t-Test in its many forms allows a statistical comparison between two groups. The t-Test is used to compare the means of two samples and to determine if the means come from the same sample group or a different group. The t-Test is employed in this study to compare the measurements of the study models and the radiographic images, see Appendix X.

## Analysis Of Variance

When more than two groups are compared or when repeat measurements are made then the Analysis of Variance is a much more powerful statistical tool. Instead of comparing each measurement with one other using a t-Test, it is possible to evaluate the statistical differences of means of groups multiple measurements, and between the samples being measured simultaneously, using the Analysis of Variance.

The study required the comparison of 10 sets of study models over a series of measurements. This form of study was ideally suited to statistical analysis using the Analysis of Variance. Following is a sample of the software written to analyse the lengths used in this study simultaneously. It shows the data processing and the sequence of calculations required:

## APPENDIX I (cont'd)

SEPARATED DATA

| Year | 1       | 2       | 3      | 4       |
|------|---------|---------|--------|---------|
| 1947 | 27,794  | 27,74   | 31,730 | 38,031M |
| 1948 | 37,729  | 37,72   | 37,719 | 27,430A |
|      | 37,771  | 34,025  | 37,476 | 37,434  |
|      | 38,596  | 37,72   | 37,616 | 37,603A |
|      | 37,787A | 37,498A | 37,427 | 37,4012 |
| 1949 |         | 0       | 0      | 0       |
| 1950 | 0       | 0       | 0      | 0       |
| 1951 | 0       | 0       | 0      | 0       |
| 1952 | 0       | 0       | 0      | 0       |
| 1953 | 0       | 0       | 0      | 0       |
| 1954 | 0       | 0       | 0      | 0       |
| 1955 | 0       | 0       | 0      | 0       |
| 1956 | 0       | 0       | 0      | 0       |
| 1957 | 0       | 0       | 0      | 0       |
| 1958 | 0       | 0       | 0      | 0       |
| 1959 | 0       | 0       | 0      | 0       |
| 1960 | 0       | 0       | 0      | 0       |
| 1961 | 0       | 0       | 0      | 0       |
| 1962 | 0       | 0       | 0      | 0       |
| 1963 | 0       | 0       | 0      | 0       |
| 1964 | 0       | 0       | 0      | 0       |
| 1965 | 0       | 0       | 0      | 0       |
| 1966 | 0       | 0       | 0      | 0       |
| 1967 | 0       | 0       | 0      | 0       |
| 1968 | 0       | 0       | 0      | 0       |
| 1969 | 0       | 0       | 0      | 0       |
| 1970 | 0       | 0       | 0      | 0       |
| 1971 | 0       | 0       | 0      | 0       |
| 1972 | 0       | 0       | 0      | 0       |
| 1973 | 0       | 0       | 0      | 0       |
| 1974 | 0       | 0       | 0      | 0       |
| 1975 | 0       | 0       | 0      | 0       |
| 1976 | 0       | 0       | 0      | 0       |
| 1977 | 0       | 0       | 0      | 0       |
| 1978 | 0       | 0       | 0      | 0       |
| 1979 | 0       | 0       | 0      | 0       |
| 1980 | 0       | 0       | 0      | 0       |
| 1981 | 0       | 0       | 0      | 0       |
| 1982 | 0       | 0       | 0      | 0       |
| 1983 | 0       | 0       | 0      | 0       |
| 1984 | 0       | 0       | 0      | 0       |
| 1985 | 0       | 0       | 0      | 0       |
| 1986 | 0       | 0       | 0      | 0       |
| 1987 | 0       | 0       | 0      | 0       |
| 1988 | 0       | 0       | 0      | 0       |
| 1989 | 0       | 0       | 0      | 0       |
| 1990 | 0       | 0       | 0      | 0       |
| 1991 | 0       | 0       | 0      | 0       |
| 1992 | 0       | 0       | 0      | 0       |
| 1993 | 0       | 0       | 0      | 0       |
| 1994 | 0       | 0       | 0      | 0       |
| 1995 | 0       | 0       | 0      | 0       |
| 1996 | 0       | 0       | 0      | 0       |
| 1997 | 0       | 0       | 0      | 0       |
| 1998 | 0       | 0       | 0      | 0       |
| 1999 | 0       | 0       | 0      | 0       |
| 2000 | 0       | 0       | 0      | 0       |
| 2001 | 0       | 0       | 0      | 0       |
| 2002 | 0       | 0       | 0      | 0       |
| 2003 | 0       | 0       | 0      | 0       |
| 2004 | 0       | 0       | 0      | 0       |
| 2005 | 0       | 0       | 0      | 0       |
| 2006 | 0       | 0       | 0      | 0       |
| 2007 | 0       | 0       | 0      | 0       |
| 2008 | 0       | 0       | 0      | 0       |
| 2009 | 0       | 0       | 0      | 0       |
| 2010 | 0       | 0       | 0      | 0       |
| 2011 | 0       | 0       | 0      | 0       |
| 2012 | 0       | 0       | 0      | 0       |
| 2013 | 0       | 0       | 0      | 0       |
| 2014 | 0       | 0       | 0      | 0       |
| 2015 | 0       | 0       | 0      | 0       |
| 2016 | 0       | 0       | 0      | 0       |
| 2017 | 0       | 0       | 0      | 0       |
| 2018 | 0       | 0       | 0      | 0       |
| 2019 | 0       | 0       | 0      | 0       |
| 2020 | 0       | 0       | 0      | 0       |
| 2021 | 0       | 0       | 0      | 0       |
| 2022 | 0       | 0       | 0      | 0       |
| 2023 | 0       | 0       | 0      | 0       |
| 2024 | 0       | 0       | 0      | 0       |
| 2025 | 0       | 0       | 0      | 0       |
| 2026 | 0       | 0       | 0      | 0       |
| 2027 | 0       | 0       | 0      | 0       |
| 2028 | 0       | 0       | 0      | 0       |
| 2029 | 0       | 0       | 0      | 0       |
| 2030 | 0       | 0       | 0      | 0       |
| 2031 | 0       | 0       | 0      | 0       |
| 2032 | 0       | 0       | 0      | 0       |
| 2033 | 0       | 0       | 0      | 0       |
| 2034 | 0       | 0       | 0      | 0       |
| 2035 | 0       | 0       | 0      | 0       |
| 2036 | 0       | 0       | 0      | 0       |
| 2037 | 0       | 0       | 0      | 0       |
| 2038 | 0       | 0       | 0      | 0       |
| 2039 | 0       | 0       | 0      | 0       |
| 2040 | 0       | 0       | 0      | 0       |
| 2041 | 0       | 0       | 0      | 0       |
| 2042 | 0       | 0       | 0      | 0       |
| 2043 | 0       | 0       | 0      | 0       |
| 2044 | 0       | 0       | 0      | 0       |
| 2045 | 0       | 0       | 0      | 0       |
| 2046 | 0       | 0       | 0      | 0       |
| 2047 | 0       | 0       | 0      | 0       |
| 2048 | 0       | 0       | 0      | 0       |
| 2049 | 0       | 0       | 0      | 0       |
| 2050 | 0       | 0       | 0      | 0       |
| 2051 | 0       | 0       | 0      | 0       |
| 2052 | 0       | 0       | 0      | 0       |
| 2053 | 0       | 0       | 0      | 0       |
| 2054 | 0       | 0       | 0      | 0       |
| 2055 | 0       | 0       | 0      | 0       |
| 2056 | 0       | 0       | 0      | 0       |
| 2057 | 0       | 0       | 0      | 0       |
| 2058 | 0       | 0       | 0      | 0       |
| 2059 | 0       | 0       | 0      | 0       |
| 2060 | 0       | 0       | 0      | 0       |
| 2061 | 0       | 0       | 0      | 0       |
| 2062 | 0       | 0       | 0      | 0       |
| 2063 | 0       | 0       | 0      | 0       |
| 2064 | 0       | 0       | 0      | 0       |
| 2065 | 0       | 0       | 0      | 0       |
| 2066 | 0       | 0       | 0      | 0       |
| 2067 | 0       | 0       | 0      | 0       |
| 2068 | 0       | 0       | 0      | 0       |
| 2069 | 0       | 0       | 0      | 0       |
| 2070 | 0       | 0       | 0      | 0       |
| 2071 | 0       | 0       | 0      | 0       |
| 2072 | 0       | 0       | 0      | 0       |
| 2073 | 0       | 0       | 0      | 0       |
| 2074 | 0       | 0       | 0      | 0       |
| 2075 | 0       | 0       | 0      | 0       |
| 2076 | 0       | 0       | 0      | 0       |
| 2077 | 0       | 0       | 0      | 0       |
| 2078 | 0       | 0       | 0      | 0       |
| 2079 | 0       | 0       | 0      | 0       |
| 2080 | 0       | 0       | 0      | 0       |
| 2081 | 0       | 0       | 0      | 0       |
| 2082 | 0       | 0       | 0      | 0       |
| 2083 | 0       | 0       | 0      | 0       |
| 2084 | 0       | 0       | 0      | 0       |
| 2085 | 0       | 0       | 0      | 0       |
| 2086 | 0       | 0       | 0      | 0       |
| 2087 | 0       | 0       | 0      | 0       |
| 2088 | 0       | 0       | 0      | 0       |
| 2089 | 0       | 0       | 0      | 0       |
| 2090 | 0       | 0       | 0      | 0       |
| 2091 | 0       | 0       | 0      | 0       |
| 2092 | 0       | 0       | 0      | 0       |
| 2093 | 0       | 0       | 0      | 0       |
| 2094 | 0       | 0       | 0      | 0       |
| 2095 | 0       | 0       | 0      | 0       |
| 2096 | 0       | 0       | 0      | 0       |
| 2097 | 0       | 0       | 0      | 0       |
| 2098 | 0       | 0       | 0      | 0       |
| 2099 | 0       | 0       | 0      | 0       |
| 2100 | 0       | 0       | 0      | 0       |

## Sorting Data Files

[illegible][illegible]

|         |         |         |         |
|---------|---------|---------|---------|
| 29.3619 | 23.0834 | 24.8908 | 25.1239 |
| 23.183  | 24.8321 | 24.8737 | 25.0449 |

# CALCULATIONS AND STATISTICAL ANALYSIS

## A.N.O.V.A

[illegible]

## APPENDIX II

| RAW PAD DATAINDEX |             | MID-PALATAL PROJECTION |        |             |             |  |
|-------------------|-------------|------------------------|--------|-------------|-------------|--|
| Points            |             | XCOORD                 | YCOORD |             |             |  |
|                   | 3 anterior  | ERR                    | ERR    |             |             |  |
|                   | 3 posterior | ERR                    | ERR    | projected x | projected y |  |
| DIGITISER         | 3 origin    | ERR                    | ERR    | ERR         | ERR         |  |
| WINDOW            | 3 L6        | ERR                    | ERR    | ERR         | ERR         |  |
|                   | 3 L3        | ERR                    | ERR    | ERR         | ERR         |  |
|                   | 3 R3        | ERR                    | ERR    | ERR         | ERR         |  |
|                   | 3 R6        | ERR                    | ERR    | ERR         | ERR         |  |
|                   | 3 L5        | ERR                    | ERR    | ERR         | ERR         |  |
|                   | 3 R5        | ERR                    | ERR    | ERR         | ERR         |  |
|                   | 3 LB6       | ERR                    | ERR    | ERR         | ERR         |  |
|                   | 3 RB6       | ERR                    | ERR    | ERR         | ERR         |  |
|                   | 3           | ERR                    | ERR    |             |             |  |
| MMMMMMMMMMCOMM>   |             | ERR                    | ERR    |             |             |  |
|                   |             | ERR                    | ERR    |             |             |  |
|                   |             | ERR                    | ERR    |             |             |  |
|                   |             | ERR                    | ERR    |             |             |  |

| LENGTH      | STORED DATA<br>FILE | MAGNIFICATION<br>ADJUSTMENT |
|-------------|---------------------|-----------------------------|
| L3-R3 :-    | ERR                 | ERR                         |
| R3-R6 :-    | ERR                 | ERR                         |
| R6-L6 :-    | ERR                 | ERR                         |
| L6-L3 :-    | ERR                 | ERR                         |
| L6-L6o :-   | ERR                 | ERR                         |
| L3-L3o :-   | ERR                 | ERR                         |
| R3-R3o :-   | ERR                 | ERR                         |
| R6-R6o :-   | ERR                 | ERR                         |
| L5-L5o :-   | ERR                 | ERR                         |
| R5-R5o :-   | ERR                 | ERR                         |
| LB6-LB6o :- | ERR                 | ERR                         |
| RB6-RB6o :- | ERR                 | ERR                         |
| L6o-0o :-   | ERR                 | ERR                         |
| L3o-0o :-   | ERR                 | ERR                         |
| R3o-0o :-   | ERR                 | ERR                         |
| R6o-0o :-   | ERR                 | ERR                         |
| L5o-0o :-   | ERR                 | ERR                         |
| R5o-0o :-   | ERR                 | ERR                         |
| LB6o-0o :-  | ERR                 | ERR                         |
| RB6o-0o :-  | ERR                 | ERR                         |

# APPENDIX III

## PHYSICAL MODEL MEASUREMENT MAXILLA

## PHYSICAL MODEL MEASUREMENT MANDIBLE

|        | Mx L3-6 | Source       | SS     | df | MS     | F      | P       |
|--------|---------|--------------|--------|----|--------|--------|---------|
| MEAN:- | 25.41   | Total        | 0.7724 | 39 |        |        |         |
| S.D.:- | 0.14    | Models       | 0.4618 | 9  | 0.0513 | 5.5991 | -----   |
| S.E.:- | 0.04    | Measurements | 0.0632 | 3  | 0.0211 | 2.2983 | 20>p>10 |
| VAR:-  | 0.18    | Error        | 0.2474 | 27 | 0.0092 |        |         |

|        | Md L3-6 | Source       | SS     | df | MS     | F       | P       |
|--------|---------|--------------|--------|----|--------|---------|---------|
| MEAN:- | 24.4    | Total        | 0.7489 | 39 |        |         |         |
| S.D.:- | 0.14    | Models       | 0.5663 | 9  | 0.0629 | 11.4841 | -----   |
| S.E.:- | 0.04    | Measurements | 0.0327 | 3  | 0.0109 | 1.9886  | 20>p>10 |
| VAR:-  | 0.23    | Error        | 0.1479 | 27 | 0.0055 |         |         |

|        | Mx 3-3 | Source       | SS     | df | MS     | F      | P       |
|--------|--------|--------------|--------|----|--------|--------|---------|
| MEAN:- | 38.09  | Total        | 0.8324 | 39 |        |        |         |
| S.D.:- | 0.14   | Models       | 0.4608 | 9  | 0.0512 | 4.6259 | -----   |
| S.E.:- | 0.05   | Measurements | 0.0732 | 3  | 0.0244 | 2.2053 | 20>p>10 |
| VAR:-  | 0.18   | Error        | 0.2987 | 27 | 0.0111 |        |         |

|        | Md 3-3 | Source       | SS     | df | MS     | F      | P     |
|--------|--------|--------------|--------|----|--------|--------|-------|
| MEAN:- | 27.16  | Total        | 0.6774 | 39 |        |        |       |
| S.D.:- | 0.13   | Models       | 0.2958 | 9  | 0.0328 | 2.6258 | ----- |
| S.E.:- | 0.04   | Measurements | 0.0442 | 3  | 0.0147 | 1.1777 | p>20  |
| VAR:-  | 0.12   | Error        | 0.3377 | 27 | 0.0125 |        |       |

|        | Mx R3-6 | Source       | SS     | df | MS     | F      | P     |
|--------|---------|--------------|--------|----|--------|--------|-------|
| MEAN:- | 25.95   | Total        | 1.0300 | 39 |        |        |       |
| S.D.:- | 0.16    | Models       | 0.4563 | 9  | 0.0507 | 2.5813 | ----- |
| S.E.:- | 0.05    | Measurements | 0.0435 | 3  | 0.0145 | 1.3544 | p>20  |
| VAR:-  | 0.18    | Error        | 0.5303 | 27 | 0.0196 |        |       |

|        | Md R3-6 | Source       | SS     | df | MS     | F      | P     |
|--------|---------|--------------|--------|----|--------|--------|-------|
| MEAN:- | 24.76   | Total        | 0.6009 | 39 |        |        |       |
| S.D.:- | 0.12    | Models       | 0.2703 | 9  | 0.0300 | 2.6947 | ----- |
| S.E.:- | 0.04    | Measurements | 0.0297 | 3  | 0.0099 | 1.1263 | p>20  |
| VAR:-  | 0.11    | Error        | 0.3009 | 27 | 0.0111 |        |       |

|        | Mx 6-6 | Source       | SS     | df | MS     | F      | P     |
|--------|--------|--------------|--------|----|--------|--------|-------|
| MEAN:- | 56.64  | Total        | 0.7794 | 39 |        |        |       |
| S.D.:- | 0.14   | Models       | 0.5301 | 9  | 0.0589 | 7.1731 | ----- |
| S.E.:- | 0.04   | Measurements | 0.0277 | 3  | 0.0092 | 1.1240 | p>20  |
| VAR:-  | 0.21   | Error        | 0.2217 | 27 | 0.0082 |        |       |

|        | Md 6-6 | Source       | SS     | df | MS     | F      | P     |
|--------|--------|--------------|--------|----|--------|--------|-------|
| MEAN:- | 48.09  | Total        | 1.1210 | 39 |        |        |       |
| S.D.:- | 0.17   | Models       | 0.6285 | 9  | 0.0698 | 4.7977 | ----- |
| S.E.:- | 0.05   | Measurements | 0.0995 | 3  | 0.0332 | 2.2786 | p>20  |
| VAR:-  | 0.25   | Error        | 0.3930 | 27 | 0.0146 |        |       |

# APPENDIX IV

MAXILLARY TEST 2 MODEL  
6 X RAYS OF MODEL 2

| LENGTH | Source       | SS     | df | MS     | F      | P       |
|--------|--------------|--------|----|--------|--------|---------|
| 3-3    |              |        |    |        |        |         |
| MEAN:- | Total        | 0.7319 | 23 |        |        |         |
| S.D.:- | Model x-rays | 0.2740 | 5  | 0.0548 | 2.0475 | 20>p>10 |
| S.E.:- | Measurements | 0.0296 | 3  | 0.0099 | 2.7131 | p>20    |
| VAR:-  | Error        | 0.4283 | 16 | 0.0268 |        |         |
| C:-    |              |        |    |        |        |         |

| LENGTH | Source       | SS     | df | MS     | F       | P     |
|--------|--------------|--------|----|--------|---------|-------|
| R3-6   |              |        |    |        |         |       |
| MEAN:- | Total        | 1.3646 | 23 |        |         |       |
| S.D.:- | Model x-rays | 0.9214 | 5  | 0.1843 | 10.9098 | ----- |
| S.E.:- | Measurements | 0.1630 | 3  | 0.0543 | 3.2161  | ----- |
| VAR:-  | Error        | 0.2703 | 16 | 0.0169 |         |       |
| C:-    |              |        |    |        |         |       |

| LENGTH | Source       | SS     | df | MS     | F      | P       |
|--------|--------------|--------|----|--------|--------|---------|
| 6-6    |              |        |    |        |        |         |
| MEAN:- | Total        | 1.2802 | 23 |        |        |         |
| S.D.:- | Model x-rays | 0.4061 | 5  | 0.0812 | 1.9454 | 20>p>10 |
| S.E.:- | Measurements | 0.2060 | 3  | 0.0687 | 1.6445 | p>20    |
| VAR:-  | Error        | 0.6681 | 16 | 0.0418 |        |         |
| C:-    |              |        |    |        |        |         |

| LENGTH | Source       | SS     | df | MS     | F      | P     |
|--------|--------------|--------|----|--------|--------|-------|
| L3-6   |              |        |    |        |        |       |
| MEAN:- | Total        | 1.4607 | 23 |        |        |       |
| S.D.:- | Model x-rays | 0.7274 | 5  | 0.1445 | 3.6082 | ----- |
| S.E.:- | Measurements | 0.0977 | 3  | 0.0326 | 1.2295 | p>20  |
| VAR:-  | Error        | 0.6407 | 16 | 0.0400 |        |       |
| C:-    |              |        |    |        |        |       |

MAXILLARY TEST 2 MODEL  
6 X RAYS OF MODEL 2

| LENGTH | Source       | SS      | df | MS     | F       | P     |
|--------|--------------|---------|----|--------|---------|-------|
| L6-L6o |              |         |    |        |         |       |
| MEAN:- | Total        | 11.9607 | 23 |        |         |       |
| S.D.:- | Model x-rays | 9.9502  | 5  | 1.9900 | 16.4745 | ----- |
| S.E.:- | Measurements | 0.0778  | 3  | 0.0259 | 4.6586  | 20>p> |
| VAR:-  | Error        | 1.9328  | 16 | 0.1208 |         |       |
| C:-    |              |         |    |        |         |       |

| LENGTH | Source       | SS      | df | MS     | F       | P     |
|--------|--------------|---------|----|--------|---------|-------|
| R3-R3o |              |         |    |        |         |       |
| MEAN:- | Total        | 13.2781 | 23 |        |         |       |
| S.D.:- | Model x-rays | 9.7004  | 5  | 1.9401 | 10.7314 | ----- |
| S.E.:- | Measurements | 0.6825  | 3  | 0.2275 | 1.2573  | p>20  |
| VAR:-  | Error        | 2.8953  | 16 | 0.1810 |         |       |
| C:-    |              |         |    |        |         |       |

| LENGTH | Source       | SS     | df | MS     | F      | P     |
|--------|--------------|--------|----|--------|--------|-------|
| L6o-0o |              |        |    |        |        |       |
| MEAN:- | Total        | 4.0477 | 23 |        |        |       |
| S.D.:- | Model x-rays | 1.6354 | 5  | 0.3271 | 2.3276 | ----- |
| S.E.:- | Measurements | 0.1638 | 3  | 0.0564 | 2.5736 | p>20  |
| VAR:-  | Error        | 2.2484 | 16 | 0.1405 |        |       |
| C:-    |              |        |    |        |        |       |

| LENGTH | Source       | SS     | df | MS     | F      | P     |
|--------|--------------|--------|----|--------|--------|-------|
| R3o-0o |              |        |    |        |        |       |
| MEAN:- | Total        | 2.5033 | 23 |        |        |       |
| S.D.:- | Model x-rays | 0.9877 | 5  | 0.1976 | 2.6599 | ----- |
| S.E.:- | Measurements | 0.2370 | 3  | 0.1080 | 1.4673 | p>20  |
| VAR:-  | Error        | 1.1885 | 16 | 0.0743 |        |       |
| C:-    |              |        |    |        |        |       |

# APPENDIX IV

MAXILLARY TEST 3 MODEL  
6 X RAYS OF MODEL 2

| LENGTH<br>3-3 | Source       | SS     | df | MS     | F      | P    |
|---------------|--------------|--------|----|--------|--------|------|
| MEAN:-        | Total        | 0.6575 | 23 |        |        |      |
| S.D.:-        | Model x-rays | 0.1620 | 5  |        | 1.2450 | p>20 |
| S.E.:-        | Measurements | 0.0792 | 3  | 0.0324 | 1.0141 | p>20 |
| VAR:-         | Error        | 0.4163 | 16 | 0.0260 |        |      |
| C:-           |              |        |    |        |        |      |

| LENGTH<br>R3-6 | Source       | SS     | df | MS     | F      | P       |
|----------------|--------------|--------|----|--------|--------|---------|
| MEAN:-         | Total        | 0.9431 | 23 |        |        |         |
| S.D.:-         | Model x-rays | 0.3799 | 5  |        | 3.0442 | -----   |
| S.E.:-         | Measurements | 0.1638 | 3  | 0.0760 | 2.1875 | 20>p>10 |
| VAR:-          | Error        | 0.3994 | 16 | 0.0546 |        |         |
| C:-            |              |        |    | 0.0250 |        |         |

| LENGTH<br>6-6 | Source       | SS     | df | MS     | F      | P     |
|---------------|--------------|--------|----|--------|--------|-------|
| MEAN:-        | Total        | 1.1995 | 23 |        |        |       |
| S.D.:-        | Model x-rays | 0.6982 | 5  |        | 5.7731 | ----- |
| S.E.:-        | Measurements | 0.1143 | 3  | 0.1396 | 1.5748 | p>20  |
| VAR:-         | Error        | 0.3870 | 16 | 0.0381 |        |       |
| C:-           |              |        |    | 0.0242 |        |       |

| LENGTH<br>L3-6 | Source       | SS     | df | MS     | F      | P       |
|----------------|--------------|--------|----|--------|--------|---------|
| MEAN:-         | Total        | 0.5642 | 23 |        |        |         |
| S.D.:-         | Model x-rays | 0.1522 | 5  |        | 1.2555 | p>20    |
| S.E.:-         | Measurements | 0.0241 | 3  | 0.0304 | 3.0135 | 20>p>10 |
| VAR:-          | Error        | 0.3879 | 16 | 0.0080 |        |         |
| C:-            |              |        |    | 0.0242 |        |         |

MAXILLARY TEST 3 MODEL  
6 X RAYS OF MODEL 2

| LENGTH<br>L6-L6o | Source       | SS     | df | MS     | F      | P     |
|------------------|--------------|--------|----|--------|--------|-------|
| MEAN:-           | Total        | 9.9613 | 23 |        |        |       |
| S.D.:-           | Model x-rays | 9.0121 | 5  |        | 1.8024 | ----- |
| S.E.:-           | Measurements | 0.0853 | 3  | 0.0284 | 1.8985 | p>20  |
| VAR:-            | Error        | 0.8640 | 16 | 0.0540 |        |       |
| C:-              |              |        |    |        |        |       |

| LENGTH<br>R3-R3o | Source       | SS      | df | MS     | F      | P     |
|------------------|--------------|---------|----|--------|--------|-------|
| MEAN:-           | Total        | 10.8455 | 23 |        |        |       |
| S.D.:-           | Model x-rays | 7.6904  | 5  |        | 1.5381 | ----- |
| S.E.:-           | Measurements | 0.2300  | 3  | 0.0767 | 2.2212 | p>20  |
| VAR:-            | Error        | 2.7251  | 16 | 0.1703 |        |       |
| C:-              |              |         |    |        |        |       |

| LENGTH<br>L6o-Oo | Source       | SS     | df | MS     | F       | P     |
|------------------|--------------|--------|----|--------|---------|-------|
| MEAN:-           | Total        | 2.3061 | 23 |        |         |       |
| S.D.:-           | Model x-rays | 0.6342 | 5  |        | 0.1268  | ----- |
| S.E.:-           | Measurements | 0.0186 | 3  | 0.0062 | 1.2274  | p>20  |
| VAR:-            | Error        | 1.6533 | 16 | 0.1033 | 16.6433 | ----- |
| C:-              |              |        |    |        |         |       |

| LENGTH<br>R3o-Oo | Source       | SS     | df | MS     | F      | P     |
|------------------|--------------|--------|----|--------|--------|-------|
| MEAN:-           | Total        | 2.0632 | 23 |        |        |       |
| S.D.:-           | Model x-rays | 1.0129 | 5  |        | 0.2026 | ----- |
| S.E.:-           | Measurements | 0.0823 | 3  | 0.0274 | 3.3485 | p>20  |
| VAR:-            | Error        | 0.9680 | 16 | 0.0605 | 2.2066 | ----- |
| C:-              |              |        |    |        |        |       |

## APPENDIX V

| TST-SQU CENTER |       |              |        |    |        |        |         |  |  |
|----------------|-------|--------------|--------|----|--------|--------|---------|--|--|
| LENGTH A       |       |              |        |    |        |        |         |  |  |
| MEAN:-         | 39.83 | Source       | SS     | df | ms     | F      | P       |  |  |
| S.D.-:         | 0.14  | Total        | 0.5003 | 23 |        |        |         |  |  |
| S.E.-:         | 0.03  | Measurements | 0.1673 | 5  |        | 1.7497 | 20>p>10 |  |  |
| VAR:-          | 0.02  | Measurements | 0.0270 | 3  | 0.0335 | 2.1282 | p>20    |  |  |
| C:-            | 0.35  | Error        | 0.3060 | 16 | 0.0090 |        |         |  |  |
|                |       |              |        |    | 0.0191 |        |         |  |  |
| LENGTH B       |       |              |        |    |        |        |         |  |  |
| MEAN:-         | 39.92 | Source       | SS     | df | ms     | F      | P       |  |  |
| S.D.-:         | 0.17  | Total        | 0.7037 | 23 |        |        |         |  |  |
| S.E.-:         | 0.04  | Measurements | 0.1930 | 5  | 0.0386 | 1.2846 | p>20    |  |  |
| VAR:-          | 0.03  | Measurements | 0.0298 | 3  | 0.0099 | 3.0247 | 20>p>10 |  |  |
| C:-            | 0.43  | Error        | 0.4809 | 16 | 0.0301 |        |         |  |  |
| LENGTH C       |       |              |        |    |        |        |         |  |  |
| MEAN:-         | 40.05 | Source       | SS     | df | ms     | F      | P       |  |  |
| S.D.-:         | 0.21  | Total        | 1.0938 | 23 |        |        |         |  |  |
| S.E.-:         | 0.04  | Measurements | 0.2009 | 5  | 0.0402 | 1.3000 | p>20    |  |  |
| VAR:-          | 0.05  | Measurements | 0.0574 | 3  | 0.0191 | 2.7312 | p>20    |  |  |
| C:-            | 0.52  | Error        | 0.8356 | 16 | 0.0522 |        |         |  |  |
| LENGTH D       |       |              |        |    |        |        |         |  |  |
| MEAN:-         | 39.79 | Source       | SS     | df | ms     | F      | P       |  |  |
| S.D.-:         | 0.16  | Total        | 0.6033 | 23 |        |        |         |  |  |
| S.E.-:         | 0.03  | Measurements | 0.1111 | 5  | 0.0222 | 1.1881 | p>20    |  |  |
| VAR:-          | 0.03  | Measurements | 0.0697 | 3  | 0.0232 | 1.1368 | p>20    |  |  |
| C:-            | 0.40  | Error        | 0.4225 | 16 | 0.0264 |        |         |  |  |

| TST-SQU CENTER |       |              |         |    |        |         |      |  |  |
|----------------|-------|--------------|---------|----|--------|---------|------|--|--|
| LENGTH E       |       |              |         |    |        |         |      |  |  |
| MEAN:-         | 22.8  | Source       | SS      | df | ms     | F       | P    |  |  |
| S.D.-:         | 0.73  | Total        | 12.8585 | 23 |        |         |      |  |  |
| S.E.-:         | 0.15  | Measurements | 5.5693  | 5  | 1.1139 | 2.4832  |      |  |  |
| VAR:-          | 0.54  | Measurements | 0.1102  | 3  | 0.0367 | 12.2070 |      |  |  |
| C:-            | 3.20  | Error        | 7.1769  | 16 | 0.4486 |         |      |  |  |
| LENGTH F       |       |              |         |    |        |         |      |  |  |
| MEAN:-         | 22.62 | Source       | SS      | df | ms     | F       | P    |  |  |
| S.D.-:         | 0.97  | Total        | 22.6691 | 23 |        |         |      |  |  |
| S.E.-:         | 0.2   | Measurements | 9.8138  | 5  | 1.9628 | 2.5255  |      |  |  |
| VAR:-          | 0.94  | Measurements | 0.4204  | 3  | 0.1401 | 1.1549  |      |  |  |
| C:-            | 4.29  | Error        | 12.4349 | 16 | 0.7772 |         |      |  |  |
| LENGTH G       |       |              |         |    |        |         |      |  |  |
| MEAN:-         | 29.9  | Source       | SS      | df | ms     | F       | P    |  |  |
| S.D.-:         | 0.31  | Total        | 2.2677  | 23 |        |         |      |  |  |
| S.E.-:         | 0.06  | Measurements | 0.4813  | 5  | 0.0963 | 1.0488  | p>20 |  |  |
| VAR:-          | 0.09  | Measurements | 0.3180  | 3  | 0.1060 | 1.1550  | p>20 |  |  |
| C:-            | 1.04  | Error        | 1.4684  | 16 | 0.0918 |         |      |  |  |
| LENGTH H       |       |              |         |    |        |         |      |  |  |
| MEAN:-         | 26.56 | Source       | SS      | df | ms     | F       | P    |  |  |
| S.D.-:         | 0.27  | Total        | 1.7968  | 23 |        |         |      |  |  |
| S.E.-:         | 0.06  | Measurements | 0.4541  | 5  | 0.0908 | 1.4014  | p>20 |  |  |
| VAR:-          | 0.07  | Measurements | 0.3056  | 3  | 0.1019 | 1.5717  | p>20 |  |  |
| C:-            | 1.02  | Error        | 1.0370  | 16 | 0.0648 |         |      |  |  |

# APPENDIX VI

TST-SQU  
OVER PAD

| LENGTH |       | TST-SQU<br>OVER PAD |          | LENGTH |         | TST-SQU<br>OVER PAD |       | LENGTH |       |
|--------|-------|---------------------|----------|--------|---------|---------------------|-------|--------|-------|
| E      |       | Source              | SS       | df     | MS      | F                   | P     | A      |       |
| MEAN:- | 23.53 | Total               | 213.4600 | 23     |         |                     |       | MEAN:- | 40.01 |
| S.D.:- | 2.98  | Positions           | 204.9512 | 5      |         |                     |       | S.D.:- | 0.26  |
| S.E.:- | 0.61  | Measurements        | 1.1878   | 3      | 40.9902 | 89.5843             | ----- | S.E.:- | 0.05  |
| VAR:-  | 8.89  | Error               | 7.3210   | 16     | 0.3959  | 1.1557              | p>20  | VAR:-  | 0.07  |
| C:-    | 12.66 |                     |          |        | 0.4576  |                     |       | C:-    | 0.65  |

| LENGTH |       | TST-SQU<br>OVER PAD |          | LENGTH |         | TST-SQU<br>OVER PAD |       | LENGTH |       |
|--------|-------|---------------------|----------|--------|---------|---------------------|-------|--------|-------|
| F      |       | Source              | SS       | df     | MS      | F                   | P     | B      |       |
| MEAN:- | 23.22 | Total               | 206.4151 | 23     |         |                     |       | MEAN:- | 39.78 |
| S.D.:- | 2.93  | Positions           | 187.4825 | 5      |         |                     |       | S.D.:- | 0.18  |
| S.E.:- | 0.50  | Measurements        | 2.8448   | 3      | 37.4965 | 37.2912             | ----- | S.E.:- | 0.04  |
| VAR:-  | 8.60  | Error               | 16.0878  | 16     | 0.9483  | 1.0603              | p>20  | VAR:-  | 0.03  |
| C:-    | 12.62 |                     |          |        | 1.0055  |                     |       | C:-    | 0.45  |

| LENGTH |       | TST-SQU<br>OVER PAD |         | LENGTH |        | TST-SQU<br>OVER PAD |       | LENGTH |       |
|--------|-------|---------------------|---------|--------|--------|---------------------|-------|--------|-------|
| G      |       | Source              | SS      | df     | MS     | F                   | P     | C      |       |
| MEAN:- | 29.88 | Total               | 17.4392 | 23     |        |                     |       | MEAN:- | 40.01 |
| S.D.:- | 0.85  | Positions           | 16.2519 | 5      |        |                     |       | S.D.:- | 0.18  |
| S.E.:- | 0.17  | Measurements        | 0.4471  | 3      | 3.2504 | 70.2380             | ----- | S.E.:- | 0.04  |
| VAR:-  | 0.73  | Error               | 0.7404  | 16     | 0.1490 | 3.2207              | ----- | VAR:-  | 0.03  |
| C:-    | 2.85  |                     |         |        | 0.0463 |                     |       | C:-    | 0.45  |

| LENGTH |       | TST-SQU<br>OVER PAD |         | LENGTH |        | TST-SQU<br>OVER PAD |       | LENGTH |       |
|--------|-------|---------------------|---------|--------|--------|---------------------|-------|--------|-------|
| H      |       | Source              | SS      | df     | MS     | F                   | P     | D      |       |
| MEAN:- | 26.68 | Total               | 19.0621 | 23     |        |                     |       | MEAN:- | 39.87 |
| S.D.:- | 0.89  | Positions           | 17.7083 | 5      |        |                     |       | S.D.:- | 0.22  |
| S.E.:- | 0.18  | Measurements        | 0.1414  | 3      | 3.5417 | 46.7400             | ----- | S.E.:- | 0.05  |
| VAR:-  | 0.79  | Error               | 1.2124  | 16     | 0.0471 | 1.6078              | p>20  | VAR:-  | 0.05  |
| C:-    | 3.34  |                     |         |        | 0.0758 |                     |       | C:-    | 0.55  |

TST-SQU  
OVER PAD

| LENGTH |       | TST-SQU<br>OVER PAD |        | LENGTH |        | TST-SQU<br>OVER PAD |       | LENGTH |       |
|--------|-------|---------------------|--------|--------|--------|---------------------|-------|--------|-------|
| A      |       | Source              | SS     | df     | MS     | F                   | P     |        |       |
| MEAN:- | 40.01 | Total               | 1.5628 | 23     |        |                     |       | MEAN:- | 40.01 |
| S.D.:- | 0.26  | Positions           | 0.6922 | 5      |        |                     |       | S.D.:- | 0.26  |
| S.E.:- | 0.05  | Measurements        | 0.0648 | 3      | 0.1384 | 2.7490              | ----- | S.E.:- | 0.05  |
| VAR:-  | 0.07  | Error               | 0.8058 | 16     | 0.0216 | 2.3304              | p>20  | VAR:-  | 0.07  |
| C:-    | 0.65  |                     |        |        | 0.0504 |                     |       | C:-    | 0.65  |

| LENGTH |       | TST-SQU<br>OVER PAD |        | LENGTH |        | TST-SQU<br>OVER PAD |       | LENGTH |       |
|--------|-------|---------------------|--------|--------|--------|---------------------|-------|--------|-------|
| B      |       | Source              | SS     | df     | MS     | F                   | P     |        |       |
| MEAN:- | 39.78 | Total               | 0.8198 | 23     |        |                     |       | MEAN:- | 39.78 |
| S.D.:- | 0.18  | Positions           | 0.5442 | 5      |        |                     |       | S.D.:- | 0.18  |
| S.E.:- | 0.04  | Measurements        | 0.0558 | 3      | 0.1088 | 7.9214              | ----- | S.E.:- | 0.04  |
| VAR:-  | 0.03  | Error               | 0.2198 | 16     | 0.0186 | 1.3519              | p>20  | VAR:-  | 0.03  |
| C:-    | 0.45  |                     |        |        | 0.0137 |                     |       | C:-    | 0.45  |

| LENGTH |       | TST-SQU<br>OVER PAD |        | LENGTH |        | TST-SQU<br>OVER PAD |       | LENGTH |       |
|--------|-------|---------------------|--------|--------|--------|---------------------|-------|--------|-------|
| C      |       | Source              | SS     | df     | MS     | F                   | P     |        |       |
| MEAN:- | 40.01 | Total               | 0.8029 | 23     |        |                     |       | MEAN:- | 40.01 |
| S.D.:- | 0.18  | Positions           | 0.2988 | 5      |        |                     |       | S.D.:- | 0.18  |
| S.E.:- | 0.04  | Measurements        | 0.1621 | 3      | 0.0598 | 2.7953              | ----- | S.E.:- | 0.04  |
| VAR:-  | 0.03  | Error               | 0.3420 | 16     | 0.0540 | 2.5282              | ----- | VAR:-  | 0.03  |
| C:-    | 0.45  |                     |        |        | 0.0214 |                     |       | C:-    | 0.45  |

| LENGTH |       | TST-SQU<br>OVER PAD |        | LENGTH |        | TST-SQU<br>OVER PAD |       | LENGTH |       |
|--------|-------|---------------------|--------|--------|--------|---------------------|-------|--------|-------|
| D      |       | Source              | SS     | df     | MS     | F                   | P     |        |       |
| MEAN:- | 39.87 | Total               | 1.1707 | 23     |        |                     |       | MEAN:- | 39.87 |
| S.D.:- | 0.22  | Positions           | 0.4436 | 5      |        |                     |       | S.D.:- | 0.22  |
| S.E.:- | 0.05  | Measurements        | 0.1277 | 3      | 0.0887 | 2.3682              | ----- | S.E.:- | 0.05  |
| VAR:-  | 0.05  | Error               | 0.5995 | 16     | 0.0426 | 1.1361              | p>20  | VAR:-  | 0.05  |
| C:-    | 0.55  |                     |        |        | 0.0375 |                     |       | C:-    | 0.55  |

# APPENDIX VII

## Mx-XRAY

| LENGTH<br>3-3 | Source       | SS     | df | MS     | F      | P     |
|---------------|--------------|--------|----|--------|--------|-------|
| MEAN:-        | Total        | 2.0392 | 39 |        |        |       |
| S.D.:-        | Model x-rays | 1.2312 | 9  |        |        |       |
| S.E.:-        | Measurements | 0.0464 | 3  | 0.1368 | 4.8496 | ----- |
| VAR:-         | Error        | 0.7616 | 27 | 0.0155 | 1.8240 | p>20  |
| C:-           |              |        |    | 0.0282 |        |       |

## Mx-XRAY

| LENGTH<br>L6-L6o | Source       | SS     | df | MS     | F      | P     |
|------------------|--------------|--------|----|--------|--------|-------|
| MEAN:-           | Total        | 3.7790 | 39 |        |        |       |
| S.D.:-           | Model x-rays | 2.0218 | 9  |        |        |       |
| S.E.:-           | Measurements | 0.0978 | 3  | 0.2248 | 3.6552 | ----- |
| VAR:-            | Error        | 1.6594 | 27 | 0.0326 | 1.8849 | p>20  |
| C:-              |              |        |    | 0.0615 |        |       |

## LENGTH R3-6

| Source       | SS     | df | MS     | F       | P     |
|--------------|--------|----|--------|---------|-------|
| Total        | 1.9778 | 39 |        |         |       |
| Model x-rays | 1.4976 | 9  |        |         |       |
| Measurements | 0.0506 | 3  | 0.1664 | 10.4570 | ----- |
| Error        | 0.4296 | 27 | 0.0169 | 1.0605  | p>20  |
|              |        |    | 0.0159 |         |       |

## LENGTH R3-R3o

| Source       | SS      | df | MS     | F       | P     |
|--------------|---------|----|--------|---------|-------|
| Total        | 17.3421 | 39 |        |         |       |
| Model x-rays | 13.3009 | 9  |        |         |       |
| Measurements | 0.2317  | 3  | 1.4779 | 10.4747 | ----- |
| Error        | 3.8095  | 27 | 0.0772 | 1.8265  | p>20  |
|              |         |    | 0.1411 |         |       |

## LENGTH 6-6

| Source       | SS     | df | MS     | F      | P     |
|--------------|--------|----|--------|--------|-------|
| Total        | 2.1962 | 39 |        |        |       |
| Model x-rays | 1.2895 | 9  |        |        |       |
| Measurements | 0.2581 | 3  | 0.1433 | 5.9640 | ----- |
| Error        | 0.6486 | 27 | 0.0860 | 3.8512 | ----- |
|              |        |    | 0.0240 |        |       |

## LENGTH L6o-Oo

| Source       | SS      | df | MS     | F      | P     |
|--------------|---------|----|--------|--------|-------|
| Total        | 96.8274 | 39 |        |        |       |
| Model x-rays | 71.5221 | 9  |        |        |       |
| Measurements | 1.0355  | 3  | 7.9469 | 8.8409 | ----- |
| Error        | 24.2697 | 27 | 0.3452 | 1.1129 | p>20  |
|              |         |    | 0.8989 |        |       |

## LENGTH L3-6

| Source       | SS     | df | MS     | F      | P     |
|--------------|--------|----|--------|--------|-------|
| Total        | 2.3629 | 39 |        |        |       |
| Model x-rays | 1.4678 | 9  |        |        |       |
| Measurements | 0.0751 | 3  | 0.1631 | 5.3696 | ----- |
| Error        | 0.8201 | 27 | 0.0250 | 1.2138 | p>20  |
|              |        |    | 0.0304 |        |       |

## LENGTH R3o-Oo

| Source       | SS      | df | MS     | F      | P     |
|--------------|---------|----|--------|--------|-------|
| Total        | 48.0964 | 38 |        |        |       |
| Model x-rays | 35.5605 | 9  |        |        |       |
| Measurements | 1.1379  | 3  | 3.9511 | 9.3598 | ----- |
| Error        | 11.3979 | 27 | 0.3793 | 1.1129 | p>20  |
|              |         |    | 0.4221 |        |       |

APPENDIX VIII

Md-XRAY

| LENGTH<br>3-3 |       | Source       |  | SS     | df | ms     | F      | P     |
|---------------|-------|--------------|--|--------|----|--------|--------|-------|
| MEAN:-        | 28.81 | Total        |  | 1.9929 | 39 |        |        |       |
| S.D.:-        | 0.22  | Model x-rays |  | 1.0845 | 9  | 0.1205 | 1.8999 | ----- |
| S.E.:-        | 0.04  | Measurements |  | 0.0502 | 3  | 0.0187 | 3.5897 | p>20  |
| VAR:-         | 0.05  | Error        |  | 0.8582 | 27 | 3.7914 |        |       |
| C:-           | 0.82  |              |  |        |    |        |        |       |

LENGTH  
R3-6

| Source       |  | SS     | df | ms     | F      | P     |
|--------------|--|--------|----|--------|--------|-------|
| Total        |  | 3.5697 | 39 |        |        |       |
| Model x-rays |  | 2.0492 | 9  | 0.2277 | 4.2423 | ----- |
| Measurements |  | 0.0713 | 3  | 0.0238 | 2.2585 | p>20  |
| Error        |  | 1.4491 | 27 | 0.0537 |        |       |

LENGTH  
8-6

| Source       |  | SS      | df | ms     | F      | P     |
|--------------|--|---------|----|--------|--------|-------|
| Total        |  | 33.0388 | 39 |        |        |       |
| Model x-rays |  | 16.1488 | 9  | 1.7943 | 3.1792 | ----- |
| Measurements |  | 1.5616  | 3  | 0.5505 | 1.0252 | p>20  |
| Error        |  | 15.2384 | 27 | 0.5644 |        |       |

LENGTH  
L3-6

| Source       |  | SS      | df | ms     | F      | P     |
|--------------|--|---------|----|--------|--------|-------|
| Total        |  | 96.4538 | 39 |        |        |       |
| Model x-rays |  | 48.4697 | 9  | 5.3855 | 3.3891 | ----- |
| Measurements |  | 5.0797  | 3  | 1.6923 | 1.0656 | p>20  |
| Error        |  | 42.9043 | 27 | 1.5890 |        |       |

Md-XRAY

| LENGTH<br>L6-L6o |       | Source       |  | SS      | df | ms     | F      | P     |
|------------------|-------|--------------|--|---------|----|--------|--------|-------|
| MEAN:-           | 23.94 | Total        |  | 33.3842 | 39 |        |        |       |
| S.D.:-           | 0.91  | Model x-rays |  | 18.6222 | 9  | 2.0891 | 4.0556 | ----- |
| S.E.:-           | 0.14  | Measurements |  | 0.9867  | 3  | 0.3289 | 1.5512 | p>20  |
| VAR:-            | 0.83  | Error        |  | 13.7753 | 27 | 0.5102 |        |       |
| C:-              | 3.80  |              |  |         |    |        |        |       |

LENGTH  
R3-R3o

| Source       |  | SS      | df | ms     | F       | P     |
|--------------|--|---------|----|--------|---------|-------|
| Total        |  | 13.5385 | 39 |        |         |       |
| Model x-rays |  | 7.9764  | 9  | 0.8863 | 4.6716  | ----- |
| Measurements |  | 0.4398  | 3  | 0.1466 | 1.29415 | p>20  |
| Error        |  | 5.1223  | 27 | 0.1897 |         |       |

LENGTH  
L6o-0o

| Source       |  | SS       | df | ms     | F      | P     |
|--------------|--|----------|----|--------|--------|-------|
| Total        |  | 105.1912 | 39 |        |        |       |
| Model x-rays |  | 63.0771  | 9  | 7.0086 | 4.7046 | ----- |
| Measurements |  | 1.8916   | 3  | 0.6305 | 2.3627 | p>20  |
| Error        |  | 40.2226  | 27 | 1.4897 |        |       |

LENGTH  
R3o-0o

| Source       |  | SS      | df | ms     | F      | P     |
|--------------|--|---------|----|--------|--------|-------|
| Total        |  | 16.2841 | 39 |        |        |       |
| Model x-rays |  | 9.0757  | 9  | 1.0084 | 4.0530 | ----- |
| Measurements |  | 0.4906  | 3  | 0.1635 | 1.5213 | p>20  |
| Error        |  | 6.7177  | 27 | 0.2488 |        |       |

**SINGLE  
TEST**

| Source       | SS     | df | MS     | F      | P       |
|--------------|--------|----|--------|--------|---------|
| Total        | 1.7449 | 23 |        |        |         |
| Model x-ray  | 0.5656 | 5  | 0.0628 | 1.6598 | 20>p>10 |
| Measurements | 0.1570 | 3  | 0.0523 | 1.3818 | p>20    |
| Error        | 1.0223 | 16 | 0.0379 |        |         |

000000

| Source       | SS     | df | ms     | F      | P    |
|--------------|--------|----|--------|--------|------|
| Total        | 2.1715 | 23 |        |        |      |
| Model x-ray  | 0.5142 | 5  |        | 1.0411 | p>20 |
| Measurements | 0.1758 | 3  | 0.0586 | 1.0676 | p>20 |
| Error        | 1.4816 | 16 | 0.0549 |        |      |

## Source \_\_\_\_\_

|         | Source       | SS     | df | MS     | F      | P    |
|---------|--------------|--------|----|--------|--------|------|
| MEAN:-- |              |        |    |        |        |      |
| SD:--   | Total        | 6.8288 | 23 |        |        |      |
| SE:--   | Model x-ray  | 1.0731 | 5  | 0.1192 | 1.5577 | p>20 |
| VAR:--  | Measurements | 0.7410 | 3  | 0.2470 | 1.2398 | p>20 |
| C:--    | Error        | 5.0147 | 16 | 0.1857 |        |      |

## Source \_\_\_\_\_

|        | Source       | SS     | df | ms     | F      | P    |
|--------|--------------|--------|----|--------|--------|------|
| MEAN:- | Total        | 3.7776 | 23 |        |        |      |
| SD:-   | Model x-ray  | 0.9903 | 5  | 0.1100 | 1.1417 | p>20 |
| SE:-   | Measurements | 0.1853 | 3  | 0.0618 | 1.5606 | p>20 |
| VAR:-  | Error        | 2.6021 | 16 | 0.0964 |        |      |
| C:-    |              |        |    |        |        |      |

## APPENDIX X

Student's t-test

Comparison of means of Two Independent Samples:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S_1^2 + S_2^2}{n}}} \quad \text{at } 2n - 2 \text{ degrees of freedom (df)}$$

$\bar{X}$  = MEAN

S = VARIANCE

n = SAMPLE SIZE

Comparison of the maxillary model length measurements with the radiographic maxillary length measurements using the Student's t-test to determine if the mean values of each length are the same

i.e.  $H_0 : \text{MEAN}_{\text{model}} = \text{MEAN}_{\text{xray}}$

n = 40

df = 78

Results :

| LENGTH  | t VALUE | SIGNIF  |
|---------|---------|---------|
| Mx L3-6 | 6.1739  | > 0.005 |
| Mx 3-3  | 11.8491 | > 0.005 |
| Mx R3-6 | 0.3333  | < 0.1   |
| Mx 6-6  | 3.8087  | > 0.005 |