THE SIZE AND FORM OF DENTULOUS AND EDENTULOUS JAWS AS RELATED TO THE DESIGN OF IMPRESSION TRAYS

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PREFACE

Standard or stock impression trays have been used for over a century in the preliminary stages of the construction of full dentures, but no comprehensive study of their design in relation to the size and form of the dentulous and edentulous jaws could be found in the literature, and none of the manufacturers of standard impression trays could supply biometric data on impression tray design.

The present study was undertaken because there appeared to be a need for further data on the subject.

INTRODUCTION

Following the loss of teeth and the consequent resorption of supporting bone the facial contour changes, due to collapse of the lips and cheeks and alteration in the maxillo-mandibular jaw relationship. One of the objectives when making full dentures for edentulous persons is to attempt restoration of this facial contour. For this reason many clinicians have stressed that not only should the artifical teeth be placed in the positions formerly occupied by the natural teeth, but also that an adequate amount of denture base material should be used to replace the lost supporting bone and soft tissue (HOOPER 1934; FISH 1948; LANDA 1954; SWENSON 1959; POUND 1960; LEE 1962; MARTONE 1963; BALLARD 1963).

In the preliminary stages of full denture construction, maxillary and mandibular impressions are taken for the purpose of recording the denture bearing areas of a mouth. They are taken with an impression material in impression trays and casts of the region are produced by pouring plaster of Paris or artificial stone into the impressions.

Many techniques have been described for taking impressions of the denture bearing areas of edentulous patients. These techniques have been reviewed by TUCKFIELD (1950), JAEGGI (1960), WOELFEL (1962) and others. Regardless of the technique employed, impression trays, known as standard or stock trays, are a prerequisite to securing a first or primary impression.

It is a common clinical experience that the size of an impression tray and its shape influences the shape and extent of the resultant impression taken with the tray. Thus an

impression taken in a tray which is too small will not cover the denture bearing area, while an impression tray which is too large may cause an unnatural displacement of the surrounding lips and cheeks and of the vestibular sulcus which is composed of loose areolar tissue.

The designs of the impression trays in this study have been based on the principle that full dentures should replace lost tissue in such a way that the lips and cheeks are restored as far as possible to their pre-extraction contour, and that this restoration should begin at the first or primary impression stage.

AIMS OF THE PRESENT STUDY

i. To devise a method for measuring the size and form of the maxillary and mandibular denture bearing areas of the jaws of a selected sample of dentulous and edentulous human adults.

ii. To apply these measurements to the design of standard impression trays for edentulous human adults.

REVIEW OF THE LITERATURE

A search of the literature revealed only one paper which presented biometric data on impression tray design (NYQUIST 1959).

There were, however, several other papers which yielded data relevant to the present study and these are also reviewed.

1. INVESTIGATIONS OF THE SIZE AND FORM OF EDENTULOUS JAWS

Search of the literature revealed that, apart from general observations, little work has been published on the size and form of edentulous jaws.

NYQUIST (1959), who also noted this absence of biometric data in the literature, measured the maxillary and mandibular casts of 192 edentulous Swedish patients in order to design a range of standard impression trays. Details of the impression technique used to obtain the casts were not given and neither the sex distribution nor the ages of the patients were recorded. A measuring instrument was used similar to that described by LUNDSTROM (1948) and adapted from the calipers originally designed by KORKHAUS (1928). The instrument was a modified compass and was used by hand directly on the cast surfaces without reference to any fixed reference planes. The errors of measurement were not discussed.

On each maxillary cast a "sagittal line" was marked on the palatine raphe. At right angles to the sagittal line, "frontal lines" were marked on the crest of the alveolar ridge and on the palatine raphe. A length measurement was

made along the sagittal line from the crest of the alveolar ridge to the frontal line immediately posterior to the junction between the hard and soft palate. Width measurements were made along each frontal line between the crest of the alveolar ridge on each side. The depth of the palate and buccal sulcus were measured in each frontal line from the crest of the alveolar ridge by means of a vertical pointed rod attached to the instrument.

On each mandibular cast a line was drawn between the most anterior "points" of the retromolar pads and a perpendicular, drawn from this line to a mark on the lingual frenum, was selected as the "sagittal line". "Frontal lines", at right angles to the sagittal line, were marked on the crest of the alveolar ridge on both sides. Length measurements were made from the point where the sagittal line cut the crest of the ridge to the most posterior point of each retromolar pad. These measurements were made directly from one point to the other without regard to "the sagittal curve of the alveolar process" (NYQUIST 1961). Width measurements were made along each frontal line between the crest of the alveolar ridge on each side. The depth of the sulcus was also measured in each frontal line from the crest of the alveolar ridge by means of the vertical pointed rod.

Nyquist discussed the form of the casts and pointed out that the form of the mandibular casts was more complicated than the maxillary casts and, because of this,

much simplification and approximation was necessary in constructing the mandibular impression trays.

From the measurements, (Table I), a range of six maxillary and six mandibular impression trays was recommended, and tolerance measures were listed to accommodate the complex variation in form of the jaws. The trays were found to be clinically acceptable, except in extreme cases, but "they were not obviously better than other standard impression trays".

A number of authors used descriptive terms to describe the size and form of edentulous jaws. BALKWILL (1880) classified edentulous maxillary jaws by the curve of the residual alveolar ridge crest. He enumerated five shapes described as semi-elliptical, semi-circular, Roman arch, Gothic arch and those jaws "which have become quite or almost flat from senile or premature absorption". Coronal and sagittal traces were made of various casts by sawing through the casts and drawing the outlines on paper. YOUNG (1955), CRADDOCK (1956) and others described the shapes of edentulous casts as square, tapering and ovoid and the sizes as small, medium and large. These attempts at classification, however, were merely descriptions based on observation and measurements were not given. The placing of a cast into a particular class depended upon the judgement of the observer.

TABLE I.

Distribution of measurements of casts of 192 * edentulous Swedish persons (NYQUIST 1959).

Casts	Length (mm.)	Number of casts	Greatest width (mm.)	Number of casts
Maxillary	40 to 49	50	35 to 39	16
	50 to 59	140	40 to 44	73
	60 to 69	2	45 to 49	81
			50 to 54	21
			55 to 59	1
Mandibular	30 to 34	2	45 to 49	9
	35 to 39	23	50 to 54	70
	40 to 44	79	55 to 59	94
	45 to 49	70	60 to 64	17
	50 to 54	70	65 to 69	1
	55	3		

* It was noted that the number of casts in the mandibular sample did not total 192.

PENDLETON (1942a) gave a table of composite measurements from "the epithelial crest" of the residual alveolar ridge to the "labiobuccal and lingual muscle attachments" of the edentulous lower jaws of nine cadavers. The method of measurement was not specified and the results had little bearing on the present study.

In addition, a number of reports were found on standard impression tray design but none contained any biometric data of jaw measurement. BANGER (1957) reviewed his clinical experiences with "Jescoform" impression trays. SCHREINEMAKERS (1959 a; 1959 b; 1962) described the use of standard impression trays which he designed. The range included 7 maxillary and 13 mandibular trays but details of measurement were not given. NEVIN (1962) discussed the design of a range of impression trays based on jaw measurements but neither the details of the method nor the results of the measurements were reported.

2. INVESTIGATIONS OF THE SIZE AND FORM OF DENTULOUS JAWS

The dimensions of the dentulous jaws have been studied extensively and, although none of the published work referred to impression tray design, many of the results and methods of measurement had a bearing on the present study.

Numerous biometric studies of arch and palatal dimensions of children and young adults were reported. The bulk of this work was restricted to measurement of the dental arch, defined as "the arch formed by the crowns of the teeth". Measurements of the dental arch were made intra-orally, on casts, on radiographs or, in certain cases, on skull material. It was noted that the maxillary dental arch was studied more frequently than the mandibular dental arch.

Dentition of children

The relevant orthodontic literature on methods of measuring the dentition of children was reviewed by MOORREES (1959) who noted that the choice of measuring points differed among investigators.

The width and length of the dental arch were generally measured by sliding calipers between landmarks selected on teeth. The accuracy of a number of the investigations was doubtful, however, for two reasons :

(i) The position of measuring points on teeth is variable due to variation in the anatomy of the crown, occlusal attrition and caries, and tooth movement.

(ii) The use of sliding calipers, without regard to any fixed planes of reference, is liable to error.

The width of the arch was generally measured between homologous teeth of the right and left sides of the arch in one of three ways : (i) between the cusp tips of the crowns (ii), between the lingual gingival margins (MOORREES 1959) or (iii) between the central fissures (SEIPEL 1946). A more complex method was used by STANTON (1933) who measured from the tooth "centroids" defined by the point of intersection of the mesiodistal and buccolingual diameters. The purpose of using the "centroid" was that this point was located in spite of any tooth mutilation by wear or caries. KEITH (1924) measured arch width between the buccal margins of various teeth but defined no measuring points.

When measuring the length of the arch most workers used as an anterior landmark the mesio-incisal point or a line, defined by MOORREES (1959), as "a line tangent to the labial surfaces of the central incisors". The selection of a posterior landmark varied considerably. The central fossae of the first molars were used by LUNDSTROM (1948), while SEIPEL (1946) measured to the mesial surfaces of the first molars. HOWES (1947) measured to the distal surfaces of the first molars and KEITH (1924) used the distal borders of the third molars. HENRIQUES (1953) measured palate length to the "posterior nasal spine" but he did not specify how this point was located. REES (1953)

defined arch length by the total of the mesiodistal diameters of the teeth from the second premolar on each side of the arch.

Dentition of young adults

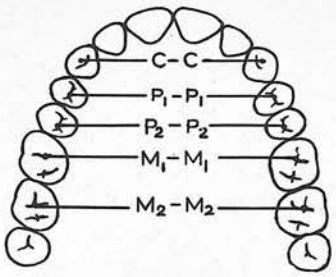
Measurements of the dental arches were made largely on children but a few reports contained results of measurements on young adults over the age of 18 years (Tables 2 & 3). SEIPEL (1946) used calipers to measure the width of the dental arches of 1500 persons, 500 of whom were between 21 and 22 years of age. OLOW (1954) used calipers directly in the mouth to measure the dental arches of 273 persons between 18 and 19 years of age. LYSELL (1958) used calipers, described by LUNDSTROM (1948), to measure the maxillary dental arches of 95 persons whose ages ranged from 21 to 24 years, and GOOSE (1962) used a similar method to investigate the dental arches of 123 modern adult skulls of British origin. GRAHNEN and INGERVALL (1963) studied the casts of 39 males aged between 23 and 24 years.

TABLE 2 .

Measurement of adult dental arches : age and sex distribution of samples used by various authors.

Author	Number of persons in sample			Age (years)	Race
	Total	Male	Female		
Olow	273	143	130	18-19	Swedish
Seipel	500	"almost equal"		21-22	Swedish
Grahnen & Ingervall	39	39	-	23-24	Swedish
Goose	123	78	45	Adult skulls	British
Lysell	95	48	47	21-24	Swedish

MAXILLARY ARCH



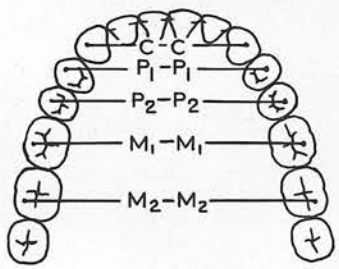
Author	C-C		P_1-P_1		P_2-P_2		M_1-M_1		M_2-M_2	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
GOOSE			36·19	35·26			48·63	46·34		
LYSELL			36·40	34·70			47·70	46·60		
GRAHNÉN & INGERVALL					42·21		48·88		54·66	
SEIPEL			36·10	34·27	41·34	39·29	46·60	44·89	53·04	50·94
OLOW	31·60	30·65			40·83	39·37	46·99	45·06	52·94	50·89

Measurements in millimetres

Table 3

Measurements of the dental arches of young adults over the age of 18 years.

MANDIBULAR ARCH



Author	C-C		P_1-P_1		P_2-P_2		M_1-M_1		M_2-M_2	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
GRAHNÉN & INGERVALL					41·86		49·39		55·60	
SEIPEL			35·17	34·82	41·25	39·98	47·57	46·13	53·30	51·09
OLOW	25·13	24·57			42·15	40·98	47·80	46·25	53·41	51·30

Measurements in millimetres

BARR and GRON (1960) studied the size and form of the palates of 150 dentulous adults. Each maxillary cast was mounted with the occlusal plane horizontal and contour lines, parallel to the occlusal plane, were scribed on the palate surface at 2 mm. vertical intervals. Each cast was then photographed from a constant distance. The midline of the palate and a medial point on the circumference of each tooth were chosen as reference points from which a grid was constructed on each photograph. From this completed grid vertical and horizontal measurements were made and these measurements were used to construct a master cast which represented the mean of the sample. The accuracy of the measurements was assessed as $\pm$ 1.0 mm.

Apical base

A number of authors studied the apical base outline (LUNDSTROM 1925). HOWES (1947) traced casts, oriented to the occlusal plane, by means of the surveying instrument of STANTON (1916), and demonstrated the relationship of the apical base line to the outlines of the teeth. REES (1953) described a simple method of measuring the apical base on a line 8 to 10 mm. from the gingival margins by means of tape and relating this to arch length. Measurement of the apical base outline on a cast is subject to error, however, because of the difficulty in locating the line accurately at the level of the apex of each tooth on a cast surface.

X-ray cephalometry

A number of workers carried out morphological

investigations by means of cephalometric X-rays to determine the variations in the configuration of the head and face in both sagittal and vertical planes (BJORK 1954). Cephalometric X-rays were also used to study and measure arch width but the method had certain limitations (WOODS 1950). Most of these X-ray investigations were conducted primarily for orthodontic purposes and none gave data which could be compared directly with the measurements made in the present study.

Craniometry

The measurements normally made in craniometry were concerned with dentulous skull material and, to a great extent, with the gross bony morphology of the jaws. In addition, the investigations were made largely on non-European material. The measuring methods, landmarks and points of reference used were based largely on those suggested by MARTIN (1928) and the majority of these were concerned with the maxillae. MONTAGU (1960) measured "maxillo-alveolar length" from the most antero-inferior point on the maxillae between the central incisors (prosthion) to the point of bisection of a line tangent to the posterior borders of the alveolar processes. "Maxillo-alveolar width" was measured from the most lateral points on the outer surfaces of the alveolar borders.

A large number of measurements were made on mandibles but these were related mainly to the body and ramus (MORANT 1936).

Few measurements were made in the mouths of living subjects and casts were not used in these craniometric investigations (COMAS 1960). The measuring instruments were sliding calipers of various types, but a number of workers used tracing instruments (SCHWARZ 1925) and craniostatic methods in which measurements were made in relation to known reference planes (BROADBENT 1927; TAYLOR 1962).

YOUNG (1956) devised a shape index method of grouping the curvatures of cranial bones. A grid was superimposed on an X-ray of the bone and perpendiculars from a chord to the outer table of the bone were expressed as percentages of the chord. By this method, which "eliminated the factor of size", cranial bones of similar shape were grouped and morphological comparison was possible between the shape of individual bones and the mean shape of the group. This method was similar to that used by BENINGTON (1911) who devised "type contours", by a process of arithmetic means, to group crania of similar shape into racial types. Although these methods were useful for indicating the mean form, neither made a clear distinction between differences of size of the various bones or crania. A practical application of craniometry was presented by ALEXANDER et al (1961) who used anthropometric data to make a range of three-dimensional faceforms for the purpose of designing face masks for flying personnel. "Key dimensions" of face length and lip length were made to form a "sizing system".

The ranges of the key dimensions were divided into appropriate intervals by adding and subtracting the value of the standard deviation to and from the mean. Other measurements of the face were then incorporated and six different faceforms were sculptured.

Dental arch form

Various classifications and indices have been used to describe the form and size of the dental arches. The literature was reviewed by IZARD (1950a) who described six shapes of the maxillary dental arch : parabolic, hyperbolic, elliptical, circular, ovoid and horseshoe-shaped. This classification was based on observation. COLES (1880) formed a triangle by measuring from the mesio-incisal point to the distal surface of each second maxillary molar. Another measurement was made between the lingual surfaces of the second premolars. From the width and length of the triangle, and the position within it of the interpremolar width, seven maxillary shapes were described. A similar method was described by BRAUN (1938). Arch form was defined by STANTON (1933) as the smooth curve drawn through the tooth centroids. GOLDSTEIN and STANTON (1935) described the form of maxillary arches by means of an index of width related to length. This is the method normally employed in craniometry (SICHER 1960a; MONTAGU 1960). An index, which is the ratio of one measurement to another expressed as a percentage of the larger one, gives no indication, however, of the size of the structure but merely the proportion of

certain dimensions. MOYERS et al (1954) pointed out the importance of arch circumference in arch shape.

MacCONAILL and SCHER (1949) and SCOTT (1957) observed that the shape of maxillary and mandibular dental arches conformed to one or other of the different catenary curves produced by a hanging chain of constant length but variable in distance between its points of suspension. In the early stages of the present study a simple catenometer was made and these general observations of MacConaill & Scher and Scott were partly confirmed. A number of casts were found, however, in which neither the dental arch nor the alveolar process conformed accurately to catenary curves. For this reason, and also because the information was found difficult to relate to the problem of a three-dimensional impression tray design, the investigation was not pursued.

3. DIMENSIONAL CHANGES IN THE JAWS FOLLOWING THE LOSS OF TEETH

One of the earliest workers who investigated the changes in the jaws following the loss of teeth was TOMES (1859) who referred briefly to a small foramen situated in the median line immediately above the upper pair of genial tubercles of the "great majority of mandibles". According to Tomes this foramen "holds its usual position" after the loss of teeth and was used as a point from which measurements were made. He observed that in edentulous mandibles the foramen was within 1/12 to 3/12 of an inch from the alveolar margin, which showed a loss of alveolar height in the oldest jaw of 9/12 of an inch. The number of mandibles examined was not stated.

BLOCH (1922) studied the changes in the shape of the maxilla and mandible after the loss of teeth. The material consisted of skulls, both dentulous and edentulous, whose craniums were approximately the same size "in order to limit the number of errors". The measuring instrument was not mentioned nor was the number of skulls specified, and it is doubtful if the measurements, which were presented as "approximate", were entirely valid as the measuring points were not comparable. Bloch observed that the edentulous maxillary arch was narrower and shorter than the dentulous arch and that this overall reduction altered the original horseshoe form to a pointed arch. He noted that the greatest loss of bone took place in the canine region and averaged about 10 mm. on each side of the arch while the loss in the midline averaged 6 mm. In the mandible there

was an increase in the posterior width of the "arch" after the loss of teeth. This was due to the transverse measurements being made from the tooth sockets in the dentulous series but from the ridge crest in the edentulous series. The horizontal loss of bone in the midline of the mandible averaged about 5 mm.

WRIGHT (1929) discussed the tissue changes under dentures and suggested a method for measuring the amount of alveolar resorption after loss of the teeth and insertion of dentures. A special "slide tube caliper" was used to measure the distance from the infra-orbital margin, which was accepted as a reference base, to the crest of the edentulous maxillary ridge. Further measurements were made at monthly intervals. Neither details of the instrument nor of its method of use were given. The author stated that "a total of 10 mm. of resorption may occur in the average ridge" but no data were given to support this statement.

LONBERG (1951) studied the changes in the size of the mandible on account of age and loss of teeth. The sample consisted of 200 dentulous and 151 edentulous Swedish males. The length of time after extraction of teeth in the edentulous group was not given. The study was conducted partly by direct measurement on the patients, and partly by measurement of radiographs taken by a cephalometric apparatus. The direct measurements were made by sliding calipers. The errors of the latter were not discussed. Measurements of the body and ramus of each

mandible were made and the radiographic errors were calibrated. The results, however, are open to doubt because of the errors inherent in a cross-section radiographic study and the difficulty of finding comparable reference points. Lonberg found that, in males over 65 years of age the height of the mandible was reduced, on average, by 8.32 mm. in the midline and 5.57 mm. in the second molar region after the loss of teeth, while in males around 25 years of age the average reduction was 4.07 mm. in the midline and 5.31 mm. in the second molar region.

ATWOOD (1957) carried out a longitudinal cephalometric X-ray study of the rest position of the mandible in a small adult sample. Results were presented showing the amount of vertical bone resorption which occurred in edentulous ridges after the loss of teeth and subsequent insertion of full dentures. Measurements were made on the radiographs from the nasion to the crest of the maxillary ridge, and from the gnathion to the crest of the mandibular ridge, in the median plane. Both the nasion and gnathion were accepted as fixed points. Atwood concluded that the combined loss of bone in both jaws in the median plane varied from 0.37 to 1.26 mm. per month after the extraction of teeth, and from 0.1 to 0.21 mm. after insertion of full dentures.

SZMYD et al (1958) described a "contourator" for measuring topographic changes of the maxillary residual ridge mucosa. Successive casts of a longitudinal series

were positioned by means of a palate index which fitted the "relatively stable" area of the hard palate. A contour arm was guided over the selected part of the cast, the trace of the cast being recorded on transparent paper. The use of a planimeter enabled topographic changes to be expressed in terms of area. The errors of the method were discussed but no other data were presented.

CAMPBELL (1960) made a comparative study of upper and lower casts of 38 edentulous persons who wore full dentures and 31 edentulous persons who did not. He pointed out the difficulty of establishing fixed landmarks on edentulous casts as a basis for measurement. He used sliding calipers and an instrument called the "occlusal plane projector", which was originally designed by SLOANE and COOK (1953) from mean measurements of a sample of dentulous skulls and casts. Campbell showed that the mean vertical and labiolingual dimensions of the ridges were less in the group who wore dentures than the group who did not, but it is doubtful if his method of measurement was sufficiently accurate to justify this conclusion.

WATT (1960) made a longitudinal study of the morphological changes in the denture bearing area $2\frac{1}{2}$ years after the extraction of maxillary teeth in a sample of male and female adults. Serial pre-extraction and post-extraction casts were oriented by selecting four points on the surface of the cast within a stable area of the palate bounded anteriorly by the third pair of primary rugae, laterally by sagittal planes 10 mm. from the median raphe,

and posteriorly by a coronal plane 5 mm. anterior to the posterior border of the hard palate.

Vertical section tracings, in sagittal and coronal planes, were made by means of an instrument, the stylus of which crossed the stable area of the palate in every cast of a series, so that, by superimposing the stable portions of the resulting traces, changes which occurred in the other parts of the denture bearing area were measured.

Horizontal section tracings were made, by means of another instrument, through the alveolar processes of the pre-extraction and last post-extraction casts of each series. These traces showed the reduction in bucco-lingual width of the residual alveolar ridges, and the widening of the palatal contour, after the loss of teeth.

Results showed that the average buccal change in the incisor and premolar regions after the loss of teeth was 3.5 mm., while in the molar region the change was between 4 and 5 mm. The lingual vertical change was between 3 and 4 mm. except in the median plane, where the change was between 2 and 3 mm.

BASU (1962) presented a technique for contour study of the edentulous maxillary ridge. The technique was used in a longitudinal study of the changes which occurred in the maxillary ridge of one patient after the extraction of five anterior teeth. Impressions and casts were made before the extraction of the teeth and at intervals thereafter up to 26 weeks. In order to orientate all the casts in the series, a cast gold alloy palatal index

was made. This fitted the non-compressible hard palate area which was accepted as the most stable area. Each cast was orientated and mounted by means of the palatal index in an orientation jig which was a modified Ney dental surveyor. The casts were then sectioned in 5 sagittal and 1 frontal plane by means of an electric band saw. Each section, 1 mm. thick, was mounted on a glass slide and projected on to a screen. A tracing was made of the magnified projection. All the sections on the same plane of the series were traced and this showed the progressive ridge resorption. The errors of the technique, however, were not discussed.

ATKINSON & JOHNSON (1962a) used an instrument similar in design to the symmetrograph of KORKHAUS (1930), in longitudinal studies of the changes in the maxillae following the extraction of teeth and the insertion of dentures. The instrument was mounted on three adjustable legs for levelling and a movable circular plate carried an adjustable table to which the cast was luted by sticky wax. All the casts of a series were mounted by means of an artificial stone "frog" which was found to fit a small central area of the posterior portion of the hard palate in each cast. This "frog" was similar to the palatal index of SZMYD et al (1958) and BASU (1962). The errors of the technique were discussed and "it was found that the maximum variation between any two measurements was not more than 0.1 mm.".

ATKINSON and JOHNSON (1962b) also described a profile radiographic technique to show the changes in the upper jaw after the loss of teeth. Serial radiographs were superimposed using sella turcica and nasion as reference points. The authors observed that there was no change in the outline of the posterior part of the hard palate up to three and a half years after the loss of teeth, but there was considerable resorption of the alveolar process in the anterior region.

Neither of these two reports presented any detailed results, but in a subsequent paper, JOHNSON (1963) gave the amount of maxillary alveolar bone loss in 9 patients one year after the loss of teeth. The horizontal bone loss was between 3 mm. and 7 mm.; the vertical bone loss was, in the anterior region, between 2.5 mm. and 5.0 mm. and, in the posterior region, between 3.0 mm. and 7 mm.

HEDEGARD (1962) in a longitudinal study of the changes which took place in the jaws three years after the loss of teeth, used a lateral skull radiographic technique, based on that devised by LONBERG (1951). He pointed out that "the experimental error was rather large". The results indicated that the maxillary changes in 25 patients followed a similar pattern to those described by other workers. The posterior region of the hard palate, in the median plane, remained stable, but the contour of the hard and soft tissues, in the anterior region of the palate and the alveolar ridge, was affected.

The decrease in mandibular height three years after extraction of teeth in seven patients was measured in the incisor, first premolar and second molar regions, and the mean loss of bone was found to be 7.5 mm., 4.2 mm. and 2.2 mm. respectively. In a further communication, HEDEGARD (1963) stated that there appeared to be neither change in position of the genial tubercles, nor a change in position or direction of the lingual alveolar wall in the incisor region, three years after extraction of teeth. He also suggested that there was no significant change in mandibular height in the region of the third molars after the same length of time.

The findings of Hedegard were substantiated by CARLSSON and PERSSON (1963) who also made a longitudinal study of the changes in mandibular height after the extraction of teeth. 36 subjects were studied by a radiographic method similar to that of HEDEGARD (1962). After two years the mean loss of bone was found to be :

Incisor region	:	5.0 mm.
First Premolar	"	:	3.8 mm.
Second molar	"	:	1.5 mm.
Third molar	"	:	1 mm.

and the main loss of bone in the incisor region appeared to take place on the superior and buccal aspects of the ridge, and that the change on the lingual aspect was minimal.

In addition, a number of reports were found in the literature in which opinions were stated with regard to

changes following the extraction of mandibular teeth. Little evidence was presented, however, in support of these opinions which were based on observation. FISH (1947) stated that the position of the superior genial tubercles was unchanged after the loss of teeth. This view was shared by LAMMIE (1956), WOELFEL et al (1962) and OSBORNE (1963). NEUFELD (1958) studied the changes in the trabecular pattern of mandibles following the loss of teeth, and stated that the external oblique ridge and mylohyoid ridge served as more or less constant landmarks and showed the least amount of change. FISH (1947) and OSBORNE (1963) gave similar views. SICHER (1960b) stated that "the atrophy at the distal end of the lower alveolar process .... is halted at the oblique lower end of the temporal crest".

4. TECHNIQUES AND INSTRUMENTS USED FOR STUDYING THE JAWS OR CASTS OF THE JAWS

In addition to the methods already mentioned in this review, many techniques and instruments have been used for studying the dimensions of the jaws or casts of the jaws.

STANTON (1916) described a dental surveying apparatus for tracing the gingival outlines, cusps and incisal edges of a cast which was clamped to the base of the instrument. Above this was a holder for tracing paper. The surveying point and the pencil were moved in the same vertical axis and were controlled by a millimetre wheel, on which was a scale to record the relative height of any particular point on the cast.

SIMON (1924) used "gnathostatic casts". The base of the maxillary cast was made parallel to the Frankfort plane. Lines, representing the orbital and median sagittal planes, were scribed on the maxillary and mandibular casts by means of a symmetrograph. Sagittal and coronal curves of the palate, and occlusal curves of the teeth, were made by an instrument called "the diameter", which consisted of a vertical rod with a movable pointer. The perpendicular distance from any point on the cast to its base could be measured and plotted on graph paper. The projected distance between points on the casts could also be measured by this simple instrument.

SVED (1925) described an "orthographic symmetrograph", by which a trace of the cast was obtained on a plane parallel to the general plane of occlusion.

SCHWARZ (1925) used a "stereograph" by means of which, traces of the gingival outlines and palatal contours of casts were made. The base of the cast was trimmed parallel to the Frankfort plane prior to mounting, and the tracing stylus and pencil were moved vertical to this plane. LYSELL (1955), LINDER-ARONSON (1960), and LUNDSTROM (1961) each used modified versions of the stereograph of SCHWARZ.

The design of the tracing instrument used in the present study was based on the stereograph of SCHWARZ.

According to WEINBERGER (1926), an instrument used by HARWOOD about 1850 consisted of a flat plate with 16 movable steel arms, by means of which the arch shape was recorded on paper. This is similar to the adjustable template used by engineers for taking contours of small curved surfaces. It consists of a number of thin strips of metal held together in a clamp. These can slide over one another when pressed against the curved surface and thus register the contour. KORKHAUS (1930) and Van LOON (1915) also described similar instruments.

CAMPION (1927) measured the depth of the palate by an instrument, two arms of which rested on the palatal cusps of the first molars and a third arm on the incisor teeth. A vertical rod was raised or lowered by a rack and pinion. SEDWICK and BRAWLEY (1938) also described a modified "palatometer", originally devised by TALBOT (1892), by means of which the length, width and depth of the palate was measured. This simple instrument, which was designed

mainly for direct use in the mouth, consisted of a pair of adjustable curved arms and a central horizontal bar, at the end of which was mounted a vertical indicator for reading palate depth.

KORKHAUS (1930) described an "orthodontic symmetrograph" for studying the symmetry of a cast. It consisted of a flat base plate which carried two pillars supporting a bridge. On the latter, a movable slide held a metal pointer. A square plate, which rested in the flat base plate of the instrument, could be moved in one direction. This square plate carried a freely movable circular plate on which the cast was mounted and held by three screws. Graduated scales on the metal pointer, bridge and base plate, allowed readings to be made directly from the cast.

The design of the measuring instrument used in the present study was based on the symmetrograph of KORKHAUS.

STANTON et al (1931) described a dental pantograph which was used to draw enlarged projections of casts on paper. The cast was clamped to a levelling table and a curved stylus was moved around the cast surface. The stylus was connected, by a series of bars, to a plotting point which marked the projection of the cast on paper.

A number of reports were published on the use of photogrammetry. STRENGER (1946) applied stereometric methods to determine the shape of the jaws and position of the teeth on the casts of 15 individuals. In 1951, NYQUIST and THAM produced surface contours of cast surfaces,

and the fitting surfaces of dentures, by photogrammetry. The methods, however, were time consuming and difficult and could not be applied to structures with undercuts.

KROGH-POULSEN et al (1948) described two methods of graphing the surface contour of maxillary casts. Before either method was used, the casts were orientated by means of a modified Hooper duplicator. In the sectioning method, the cast was sectioned through any desired point or plane and a contour made of the cut cast by tracing with a pencil. This method was simple and rapid and undercuts could be traced, but the main disadvantage was that the cast was virtually destroyed.

The other method was based on the plotting of measurements, taken along any desired surface contour of a cast, by means of a modified measuring microscope.

RUPP et al (1957) described a pantographic type of comparator for measuring the surface contours of impressions, casts and dentures. The measurements gave the dimensional difference between two similar surfaces in vertical and horizontal planes. A modification of this instrument was reported by ANTHONY & PEYTON (1959).

RYGE & FAIRHUST (1959) described a "contour meter" for comparison of the surface contour of impressions, casts and dentures, which were positioned by means of three chosen reference points.

WOELFEL et al (1962) used a Leitz toolmaker's microscope to study the contour variations in the maxillary casts and impressions of one edentulous patient, using five different impression materials.

5. ORIENTATION OF CASTS

It was noted that, in many of the investigations already reviewed, measurements of casts were made without regard to any reference planes. It is, of course, essential to valid measurement that casts are similarly oriented prior to measurement. This applies to both longitudinal and cross-section studies.

EXTRA-ORAL PLANES

One method of orienting casts was to relate them to an extra-oral reference plane such as the Frankfort plane. This was done by van LOON (1915), SIMON (1924) and SCHWARZ (1925) but the method is inaccurate because the Frankfort plane, which passes through three points on the skull, cannot be located with certainty by means of surface markings on the face. MODICA (1961) described a complex method of orientating maxillary casts by means of cephalometric X-rays, and thus avoided the use of surface markings on the face. A metal marker was laid in the mouth on the surface of the incisive papilla and another between the fovea palatinae. A profile X-ray was taken and from this, the position of the marks was measured relative to planes of the skull. Using this data, the cast was mounted on the articulator. In cross-section studies, however, individual variations of maxillary development and facial form are inherent sources of inaccuracy in using extra-oral reference planes. This was stressed by KORKHAUS (1957) who suggested intra-oral planes as more suitable when studying the dental arches and alveolar processes.

The difficulties of using extra-oral reference planes are greater for mandibular casts than for maxillary casts. In cross-section studies of mandibles, it is customary to utilise either the inferior border of the horizontal ramus, or points on it, to construct reference planes (MORANT 1936; LONBERG 1951; MURPHY 1957). This is impracticable with casts. If a maxillary dentulous cast is oriented to an extra-oral plane it is, of course, possible to orientate a mandibular dentulous cast to the maxillary cast by means of the occlusion of the teeth, but such a method is obviously not possible with edentulous casts. The latter may be oriented through the medium of "bite blocks" but there is an appreciable error in the clinical judgement of the morphologic face height of edentulous individuals (TALLGREN 1957).

INTRA-ORAL PLANES

A number of workers used intra-oral reference planes, defined by points on the cast surface, in order to orient casts prior to measuring.

Horizontal planes

STANTON (1916) oriented maxillary casts with the "occlusal plane" parallel to the base of the instrument; mandibular casts were then oriented in a similar plane by locating them to the maxillary casts in occlusion. SCHWARZ (1925) used the interdental papilla between the maxillary central incisors and the distal gingival margins of the first maxillary molars as points to define the "alveolar plane". THAM (1946) oriented casts to an

"R plane" which was defined by the "highest points of the lower incisors and the second lower molars". LYSELL (1955) oriented casts with the occlusal plane horizontal. The plane was defined by the incisal edge of the left maxillary central incisor and the mesiolingual cusps of the first maxillary molars. This plane was also used by LUNDSTROM (1961). A similar plane was used by LINDER-ARONSON (1960), but he incorporated both maxillary central incisors as anterior points.

Median Sagittal planes

Regarding the selection of a median sagittal reference plane, it has long been the practice in studies of maxillary casts to construct a plane passing through two points on the palatine raphe. Such a plane was used among others by van LOON (1915), SIMON (1924), SCHWARZ (1925), GRIEVE (1926), KORKHAUS (1934), KROGH-POULSEN et al (1948), IZARD (1950b), LYSELL (1955) and LUNDSTROM (1961).

In studies of mandibular casts, on the other hand, a number of workers have pointed out the difficulties of constructing a median sagittal reference plane. Both KORKHAUS (1934) and IZARD (1950b) suggested using the labial and lingual fraenae as aids to the location of a median plane. STANTON (1922) used a complex method to construct an axis of symmetry through the "centroid" of the dental arch, which was found by measuring, from two bases, the average distance of the "tooth centroids" from each of these bases. SCHWARZ (1925) placed maxillary and mandibular casts in occlusion by means of a wax wafer. The median

raphe line on the maxillary cast was then transferred to the mandibular cast. KORKHAUS (1934) also suggested this method. CAMPBELL (1950) discussed the use of a line connecting the mylohyoid ridges as a means of assessing the symmetry of mandibular casts. Vertical lines were dropped from the occlusal plane opposite the lingual fissures of the first molars to meet the mylohyoid ridges at two points. The base of the cast was then made or trimmed parallel to a line joining these two points, by means of a simple mounting instrument. NYQUIST (1959), who studied edentulous mandibular casts, marked the most anterior points of the retromolar pads and the lingual frenum. The perpendicular from the frenum mark to the line joining the two posterior marks was selected as the median reference line.

Summary of the literature relevant to the present study

1. A search of the literature revealed only one paper which contained biometric data on the design of standard impression trays. This data consisted of measurements of casts of a sample of edentulous persons (NYQUIST 1959). These results are summarised in Table 1 .

2. No publication could be found in the literature on the design of standard impression trays based on measurements of both dentulous and edentulous jaws.

3. The size and form of the dentulous jaws has been extensively studied for orthodontic purposes. This work has been largely confined to the dental arches of children, although a number of studies were made of young adults. The results of the latter are summarised in Tables 2 & 3 . No study could be found, however, which related dentulous jaw measurements to the design of impression trays.

4. The dimensional changes in the jaws following the loss of teeth have been investigated in a number of longitudinal studies. ATWOOD (1957), in a cephalometric X-ray study, indicated the amount of vertical bone resorption of both jaws in the median plane. WATT (1960), in a maxillary cast study, concluded that the average buccal change was between 3.5 and 5 mm. and the average lingual vertical change was between 2 and 4 mm. JOHNSON (1963), in a combined radiographic and maxillary cast study, showed a horizontal bone loss of between 3 and 7 mm. and a vertical bone loss of between 2.5 and 7 mm.

In the few investigations of the changes after the loss of mandibular teeth it was noted that cephalometric X-ray methods were used, and none was found in which pre- and post-extraction mandibular casts were measured. HEDEGARD (1962) and CARLSSON & PERSSON (1963) indicated that the least amount of vertical bone loss occurred in the molar region while, in the incisor region, the least change appeared to occur on the lingual aspect of the alveolar process.

5. Many methods, techniques and instruments for studying the size and form of the jaws have been reported in the literature. Although none of these was entirely applicable, the designs of two instruments used in the present study were partly based on the instruments used by SCHWARZ (1925) and KORKHAUS (1930).

6. Investigation of the literature relating to methods of orienting casts prior to measurement, appeared to indicate that intra-oral reference planes were more applicable to the present study.

MATERIALS and METHODS

1. Introduction.
2. The Sample : i. dentulous sample.
   ii. edentulous sample.
3. Definitions.
4. Reference Points :
   - Maxillary casts : 1. RU point.
     2. Notch Points.
   - Mandibular casts : 1. RL point.
     2. Retromolar Points.
5. Reference Planes :
   - Maxillary casts : 1. Reference Plane.
     2. Median Sagittal Plane.
   - Mandibular casts : 1. Reference Plane.
     2. Median Sagittal Plane.
6. Instruments.
7. Description of Method :
   - Dentulous casts
     i. method of making traces.
     ii. direct measurements.
   - Edentulous casts
     i. direct measurements.
     ii. traces and additional measurements.

MATERIALS and METHODS

INTRODUCTION

The material for this cross-section study comprised the maxillary and mandibular casts of a selected sample of dentulous and edentulous male and female adults.

The sample consisted of 651 persons, 351 of whom were dentulous and 300 were edentulous.

Maxillary and mandibular casts were obtained from impressions of the mouth of each person. Thus 1302 casts comprised the total cast material for this study (Table 4).

TABLE : 4

The cast material of the sample.

	CASTS		
	Maxillary	Mandibular	Totals
Dentulous	351	351	702
Edentulous	300	300	600
Totals	651	651	1302

Measurements and traces of these casts were made in order to determine the size and form of the dentulous and edentulous jaws for the purpose of designing a range of standard impression trays for edentulous patients.

The measurements and traces were made by means of two instruments which were designed and constructed for this study.

The casts were mounted on these instruments in such a way that all measurements and traces were made parallel to one of three reference planes which intersected at a specified reference point on the surface of each cast.

THE SAMPLE

1. The Dentulous Sample

The dentulous sample was selected from a total of 582 persons drawn from university students, hospital patients, army personnel and nurses in Edinburgh, Glasgow and Manchester.

The following criteria were applied to select the maxillary and mandibular casts of 351 persons for this study :

(a) the age and sex of the person was known and the age was 18 or more years.

(b) 24 or more teeth were erupted or partially erupted (unerupted teeth were counted as missing).

(c) not more than two teeth were missing in any one quadrant of the mouth.

(d) no two adjacent teeth were missing in any part of either arch.

(e) the following regions and landmarks were clearly visible on the surface of the casts :

Maxillary casts

i. incisive papilla and palatine raphe.

ii. palate complete to the junction of the hard and soft palates.

iii. soft tissue distal to the tuberosities.

iv. buccal and labial surfaces of alveolar process.

Mandibular casts

i. lingual frenum.

ii. soft tissue distal to the molar teeth.

iii. buccal, labial and lingual surfaces of alveolar process.

Out of the total of 582 dentulous persons, the casts of 231 persons were found deficient in one or more of the above criteria. These casts were rejected. (The casts were selected or rejected in pairs i.e. a fault in a maxillary cast automatically led to the rejection of the mandibular cast and vice versa.)

The maxillary and mandibular casts of the remaining 351 persons comprised the dentulous sample for this study.

The age and sex distribution of the selected sample is shown in Table 5 .

TABLE 5.

Dentulous sample : age and sex distribution.

Age in years	Number of Persons		
	Males	Females	Total
18	7	11	18
19	12	25	37
20	39	40	79
21	32	18	50
22	25	16	41
23	20	16	36
24	18	8	26
25	10	6	16
26	6	7	13
27 to 44	24	11	35
Totals	193	158	351

2. The Edentulous Sample

The edentulous sample was selected from the maxillary and mandibular preliminary casts of 985 edentulous patients who had attended the Prosthetic Department of the Edinburgh Dental Hospital for treatment between the years 1955 and 1962. The complete dental histories of all the patients were not known.

The following criteria were applied to select the maxillary and mandibular casts of 520 persons :

(a) the age and sex of the person was known and the age was 18 or more years.

(b) the following regions and landmarks were clearly visible on the surface of the casts :

Maxillary casts

i. incisive papilla and palatine raphe.

ii. palate complete to the junction of the hard and soft palates.

iii. residual alveolar ridge and soft tissue distal to the tuberosities.

iv. buccal sulcus.

Mandibular casts

i. lingual frenum.

ii. residual alveolar ridge, including the retromolar regions.

iii. buccal and lingual sulcus.

Out of the total of 985 edentulous persons, the casts of 465 were rejected because of deficiency in one or more of the above criteria. The most common reason for rejection of casts was that, owing to obliteration of the name of the patient on the cast, the age and sex were not known.

The casts were selected or rejected in pairs i.e. a fault in a maxillary cast automatically led to the rejection of the mandibular cast and vice versa.

From the casts of the remaining 520 persons random numbers were used to select the casts of 300.

The maxillary and mandibular casts of those 300 persons comprised the edentulous sample for this study. The age and sex distribution of the selected sample is shown in Table 6.

TABLE 6.

Edentulous sample : age and sex distribution.

Age in years	Number of Persons		
	Males	Females	Total
20 to 29	5	6	11
30 " 39	26	23	49
40 " 49	40	26	66
50 " 59	40	41	81
60 " 69	29	36	65
70 " 79	14	10	24
80 " 91	2	2	4
Totals	156	144	300

Impressions and Casts

All the dentulous impressions were taken with alginate impression material in standard impression trays and were poured in either artificial stone (Kaffir D) or equal parts artificial stone and plaster of Paris. The W/P ratio was not standardised.

The edentulous impressions were taken with either impression compound or alginate impression material in standard impression trays and were poured in artificial stone (Kaffir D), equal parts artificial stone and plaster of Paris, or plaster of Paris. The W/P ratio was not standardised.

The dimensional errors from these sources were accepted as they were unlikely to have a significant effect on the results of the study. These matters are discussed further in the chapter on Errors on page 91 .

DEFINITIONS

The following definitions were applied in this study. The method of locating the various points and lines on the surface of casts is described, and the definitions discussed, in appropriate parts of the text.

TERMINOLOGY

The casts were at all times assumed to be in their normal anatomical position when relationships of points were described.

MUCOGINGIVAL LINE

The line of junction between the attached gingiva and the reflected alveolar mucosa marked on the buccal surfaces of maxillary casts and the buccal and lingual surfaces of mandibular casts.

REFERENCE POINT

1. Maxillary casts: the junction of the posterior border of the incisive papilla and the palatine raphe. This point was known as the RU point.
2. Mandibular casts: the point of intersection of the lingual mucogingival line and the median sagittal plane. This point was known as the RL point.

NOTCH POINT

The most superior point of the crescentic ridge of mucosa on the oral surface of each pterygomaxillary notch of a maxillary cast.

TRACE

An ink line marked on tracing paper by the pen of the tracing instrument.

RETROMOLAR REGION

The region on each side of a mandibular cast defined as follows :

1. Dentulous casts : the superior surface of the cast between the crown of the most distal erupted molar and the trimmed distal edge of the cast.
2. Edentulous casts : the superior surface of the residual alveolar ridge in the region of the pear-shaped pad and terminating at the trimmed distal edge of the cast.

RETROMOLAR POINT

The most superior point on the trimmed distal edge of each retromolar region of a mandibular cast.

POSTERIOR MIDPOINT

1. Maxillary casts : a point on the palatine raphe in the region of the posterior border of the hard palate.
2. Mandibular casts : a point on the floor of the cast midway between the Retromolar Points.

FRENUM POINT

A point on the crest of the lingual frenum of a mandibular cast. (When the crest of the frenum was broad or fan-shaped the point was marked midway between the lateral surfaces of the frenum.)

HORIZONTAL PLANES

Planes of orientation parallel to the base of the tracing or measuring instrument as determined by spirit levels.

REFERENCE PLANE

1. Maxillary casts : the plane through the RU point and the Notch Points.
2. Mandibular casts : the plane through the RL point and the Retromolar Points.

MEDIAN SAGITTAL PLANE

1. Maxillary casts : the plane through the RU point and the Posterior Midpoint perpendicular to the horizontal plane.
2. Mandibular casts : the plane through the Frenum Point and the Posterior Midpoint perpendicular to the horizontal plane.

   Planes parallel to this plane were called Sagittal Planes.

CORONAL PLANES

Planes perpendicular to both the horizontal plane and the median sagittal plane.

MEASUREMENTS

(a) Vertical measurements : measurements made perpendicular to the horizontal plane.

(b) Horizontal measurements : measurements made parallel to the horizontal plane.

(c) Length denoted a measurement along the line of intersection of a sagittal plane with the horizontal plane.

(d) Width denoted a measurement made along the line of intersection of a coronal plane with the horizontal plane.

REFERENCE POINTS IN THE PRESENT STUDY

It was important in this study that the dentulous and edentulous casts were oriented to similar horizontal and median sagittal intra-oral reference planes in order to make possible the comparison of the measurements and traces of the casts.

For the purpose of defining these reference planes comparable points were sought which were common to dentulous and edentulous mouths.

After much investigation no easily identifiable anatomical points could be found where change was absent following the loss of teeth but certain maxillary and mandibular points were found where change was minimal. The errors produced by the change at these points were studied and were not of sufficient magnitude to invalidate this study. Thus these points, though not ideal, were selected as no better points could be found.

MAXILLARY POINTS

It has been demonstrated by WATT (1960), HEDEGARD (1962), ATKINSON & JOHNSON (1962 a & b) and JOHNSON (1963) that the part of the maxillary denture bearing area that undergoes least change after the loss of teeth is a small central area of the palate. In a longitudinal study, therefore, comparative measurements may be made from points within this area. In a cross-section study, however, comparable anatomical points within this area cannot be identified and points were sought in other regions of the casts.

1. Reference point (RU point) :

The junction of the posterior border of the incisive papilla and the palatine raphe.

Evidence provided by the work of ATWOOD (1957), WATT (1960), HEDEGARD (1962), ATKINSON & JOHNSON (1962 a & b) and JOHNSON (1963) showed that resorptive changes occur in the anterior part of the palate after the loss of teeth and produce a change in position of the incisive papilla. LYSELL (1955) in a cross-section study of the incisive papilla in six separate age groups stated that "the difference in the size and shape of the incisive papilla observed in the age groups and sexes may be due to loss of teeth". WATT (1960) observed a change in position of the incisive papilla following the extraction of maxillary incisors. The mean horizontal forward movement of the posterior border of the incisive papilla after $2\frac{1}{2}$ years was 1.6 mm. (range 0.6 to 2.7 mm.). The mean vertical movement of the posterior border of the incisive papilla was 1.55 mm. (range 0.1 to 3.3 mm.). He also suggested that "changes in the shape of the incisive papilla commonly accompany the extraction of maxillary incisors".

It was accepted, therefore, that the loss of teeth and denture wearing produced changes in the form and position of the incisive papilla, so that a point in the midline at the posterior border of the papilla was not exactly comparable between dentulous and edentulous mouths. Nevertheless, the junction of the incisive papilla and the palatine raphe was an anatomical point which could be located with certainty on

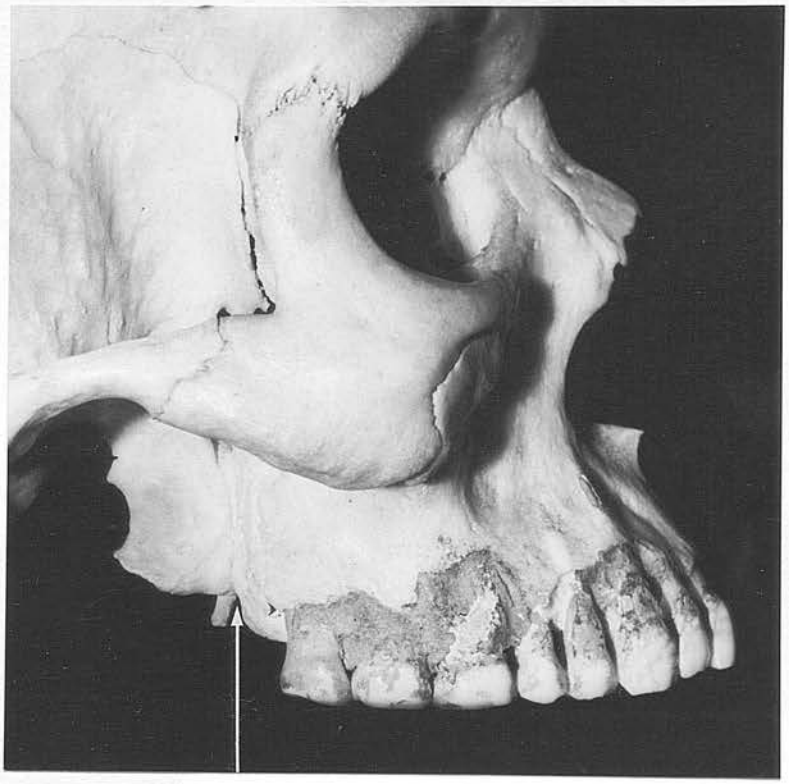
the anterior part of dentulous and edentulous casts and the changes in this area appeared to be small compared to the changes in other areas. For these reasons this point was selected for the purpose of the present study.

2. Notch Points :

The most superior point of the crescentic ridge of mucosa on the oral surface of each pterygomaxillary notch.

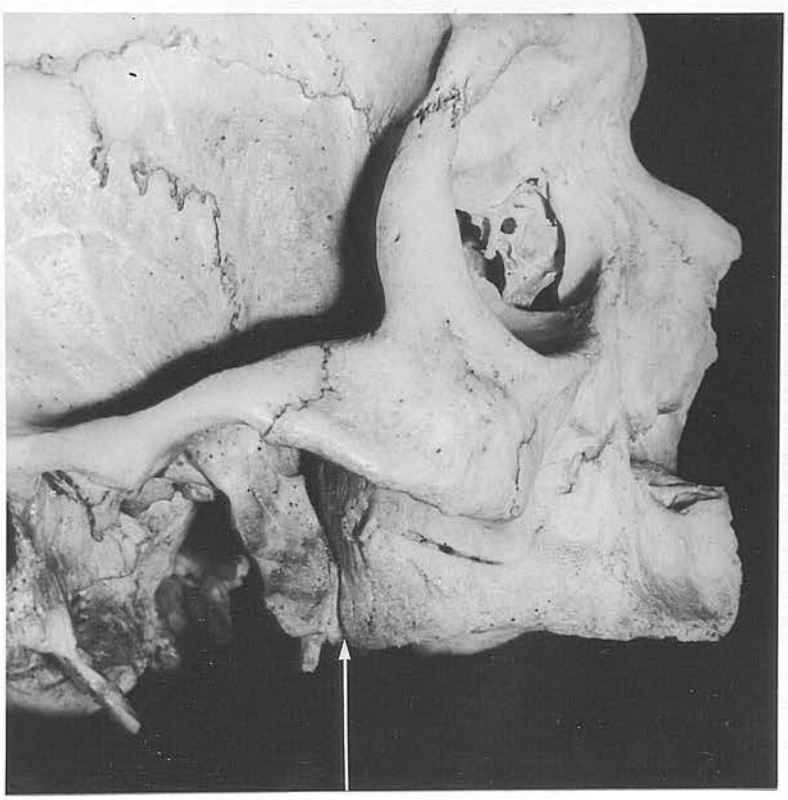
The pterygomaxillary notch is the bony fissure formed by the junction of the maxilla and the pterygoid process of the sphenoid bone (Fig. 1). The oral mucosa in the notch forms a crescentic ridge which passes postero-medially from the maxillary tuberosity to merge with the mucosa of the soft palate in the area of the hamular process. The crescentic ridge is concave in the sagittal plane and convex in the coronal plane, the degree of concavity and convexity varying from one dentulous cast to another (Figs. 2). After the loss of teeth the sagittal concavity of the crescentic ridge appeared to flatten due to resorption of the alveolar bone anterior to it (Fig. 3).

This change in form of the crescentic ridge after the loss of teeth was investigated in a collection of casts which became available during the present study. The collection consisted of maxillary casts of 41 patients. The casts were made before and after the extraction of teeth. The purpose of this investigation was to study the change in form, if any, of the crescentic ridges after the loss of teeth.

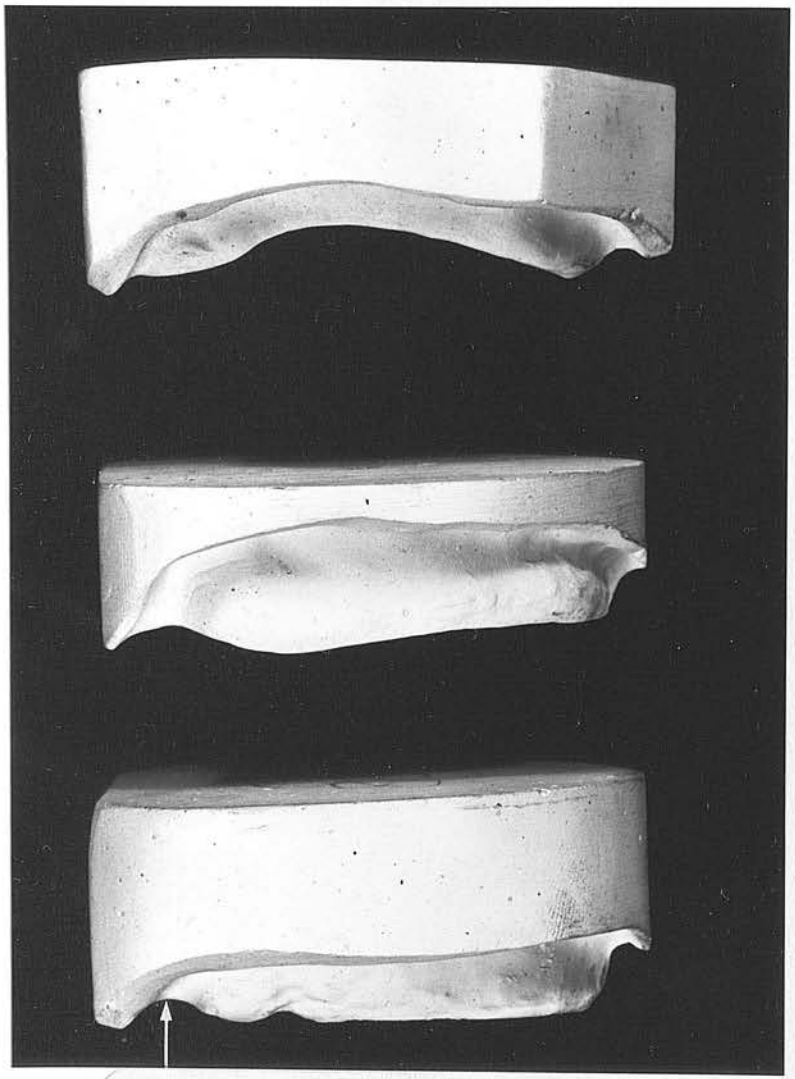


Pterygomaxillary notch in dentulous skull.

Fig. 1

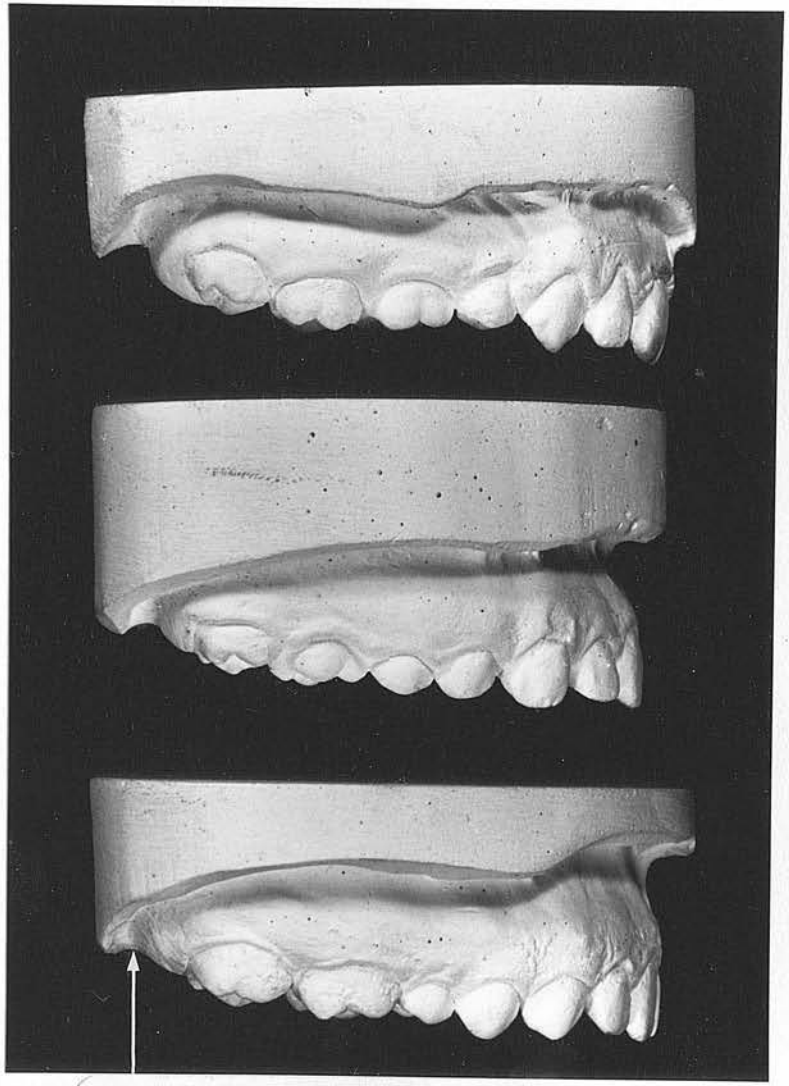


Pterygomaxillary notch in edentulous skull.



The variation in the sagittal concavity of the crescentic ridge of edentulous casts.

Fig. 3



The variation in the sagittal concavity of the crescentic ridge of dentulous casts.

Fig. 2

The following criteria were applied in the selection of casts from the collection for this investigation :

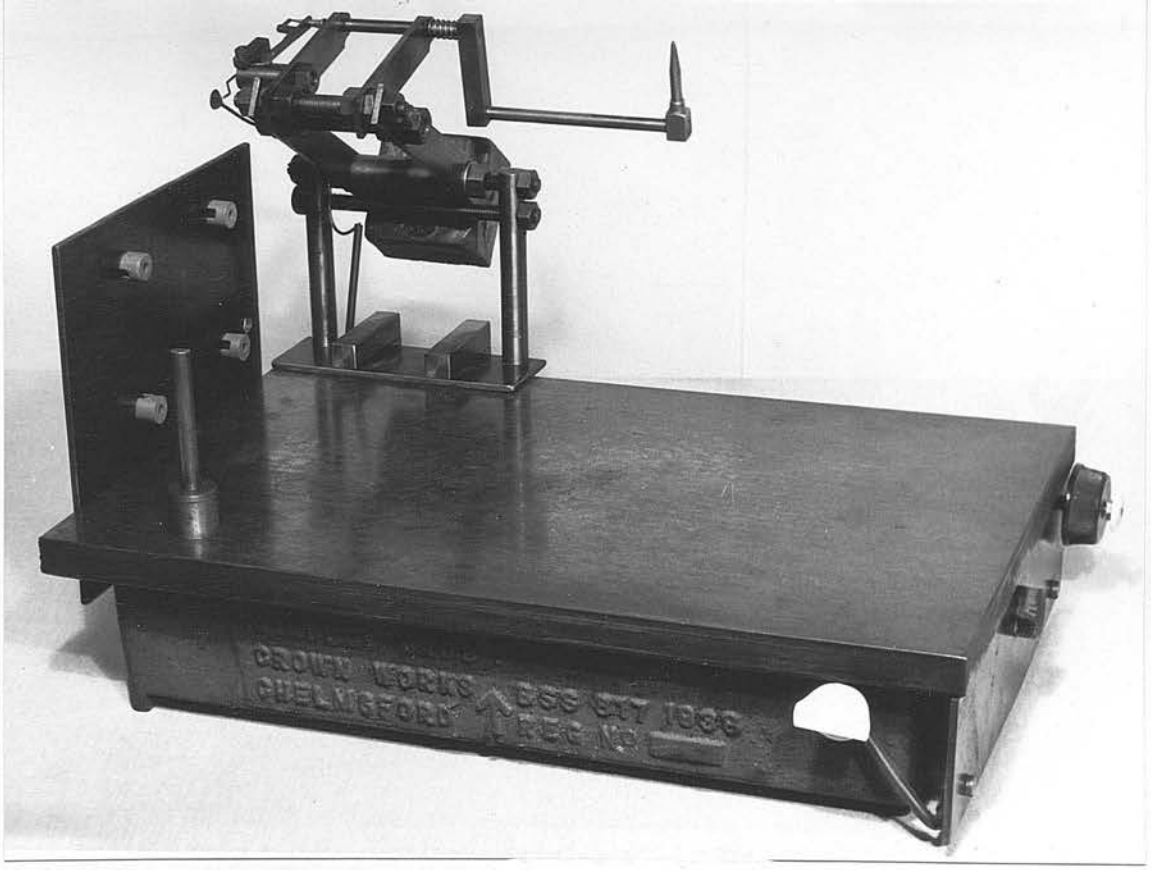
(a) the second and/or the third molars were erupted in the pre-extraction cast and

(b) the crescentic ridges were clearly defined on both the pre-extraction and post-extraction casts.

From the total collection, the casts of only 9 patients were found to be suitable. From each patient two casts were used, a pre-extraction and a post-extraction cast. The interval of time between the two casts varied from 3 to 32 months, with a mean interval of 19 months.

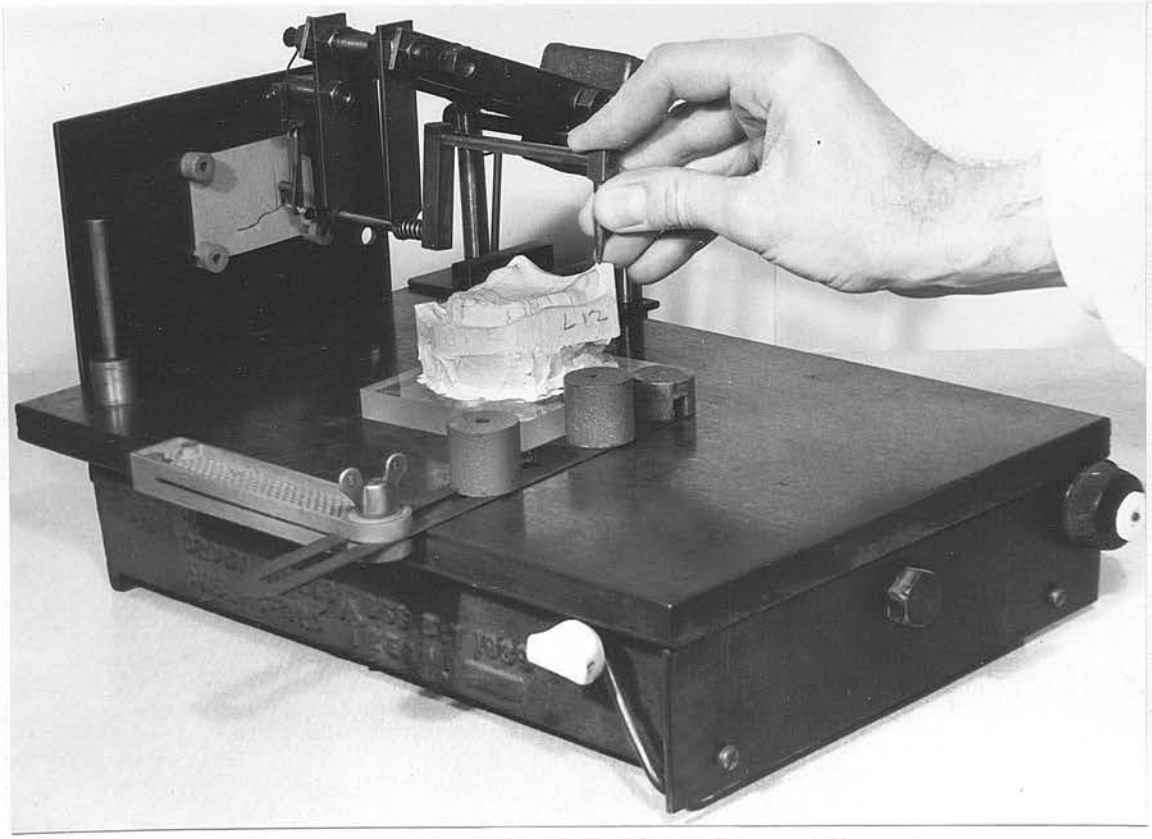
The following method was used to investigate each pair of casts :

The casts were oriented and mounted on identical Perspex bases by means of an instrument described by WATT (1960). This ensured that the pre-extraction and post-extraction casts were oriented in identical positions. The post-extraction cast was transferred to an instrument for making vertical traces (WATT 1960) (Fig. 4). The Perspex base was adjusted in a set square and the point of the tracing stylus was moved antero-posteriorly along the crescentic ridge and the residual alveolar ridge on one side of the cast. A trace was made on tracing paper clamped to the back of the instrument. The point of the stylus was then laid on the most superior point of the concavity of the crescentic ridge and a vertical line was drawn on the tracing paper by the pen which was guided by a vertical bar held by a pot magnet to the instrument base. This vertical line served as a reference line (Fig. 5).



Instrument for making vertical traces.

Fig. 4



Tracing of post-extraction maxillary cast.

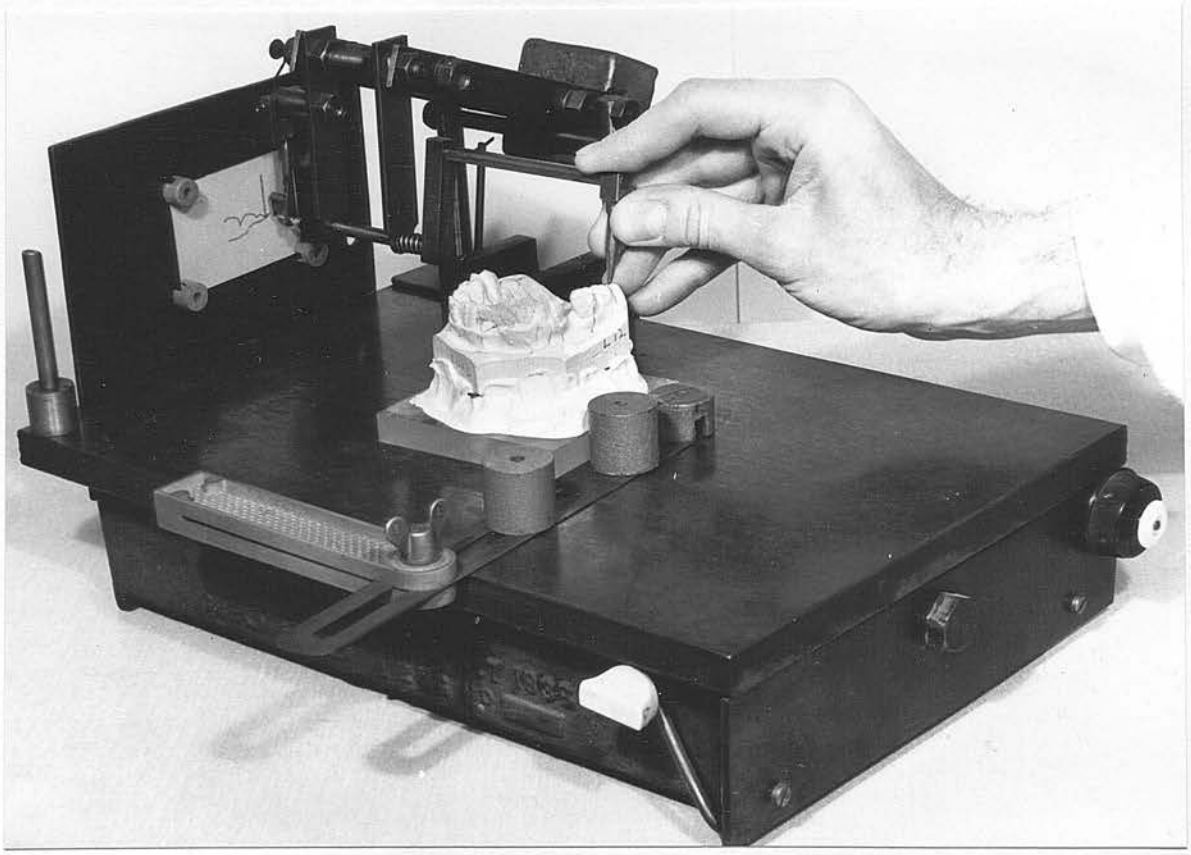
Fig. 5

Without removing the tracing paper, the pre-extraction cast was then located in exactly the same position in the set square and the stylus was moved antero-posteriorly along the crescentic ridge and the molar teeth. This trace was superimposed on the trace of the post-extraction cast (Fig. 6). The point of the stylus was then laid on the most superior point of the concavity of the crescentic ridge of the pre-extraction cast and another vertical line was drawn.

The combined trace showed the change in form of the crescentic ridge and the vertical lines showed the shift in position of the most superior point of the concavity of the crescentic ridge after the loss of teeth.

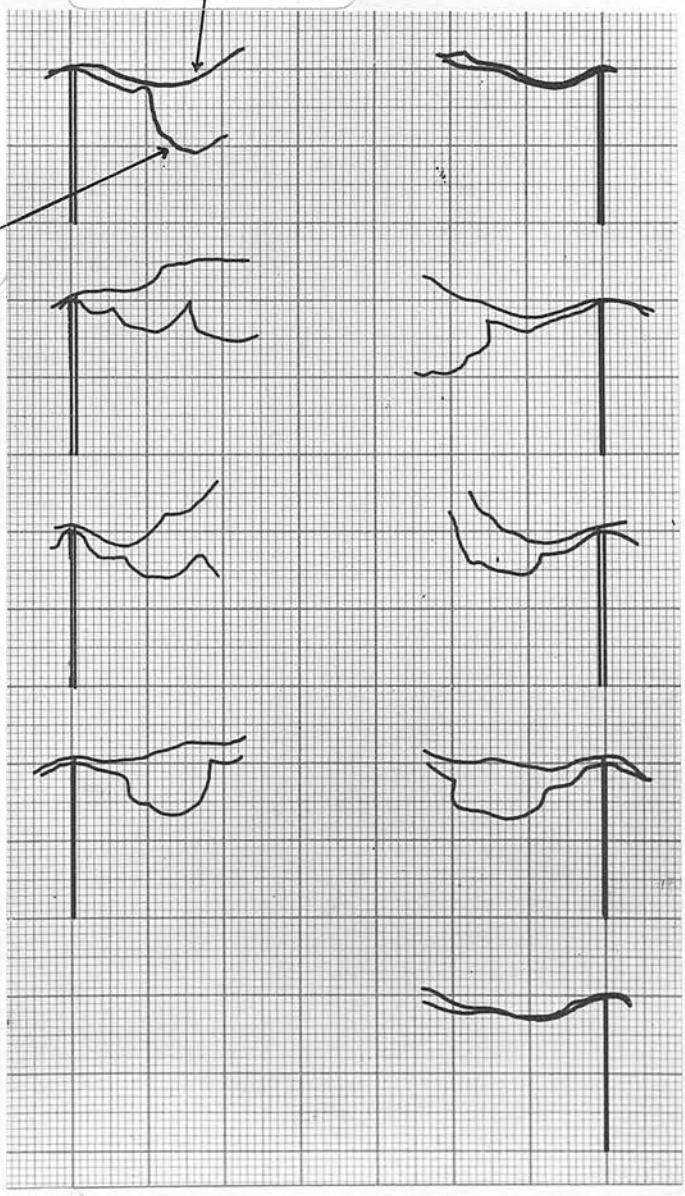
Study of the 9 combined traces (Fig. 7) showed a flattening of the sagittal concavity of the crescentic ridge after the loss of teeth. This flattening occurred, to a greater or lesser extent, in all cases. While it was realised that this longitudinal sample of casts was small, and that the length of time after the loss of teeth was short, it was concluded from this investigation that the most superior point of the crescentic ridge appeared to move about 1 mm. upwards and forwards after the loss of teeth.

It was accepted, therefore, that the loss of teeth produced changes in the form of the crescentic ridge so that a point selected on it was not exactly comparable between dentulous and edentulous mouths. Nevertheless, it appeared that changes in the crescentic ridge were small compared with changes in other parts and, since the crescentic ridge provided an anatomical feature which could be located with certainty in the posterior part of dentulous and edentulous



Tracing of pre-extraction maxillary cast, showing the superimposition of the traces.

Fig. 6



Vertical lines show the shift of the most superior point of the crescentic ridge.

Combined traces of 9 different patients showing the change in form of the crescentic ridges after the loss of teeth.

Fig. 7

casts, the Notch Point was selected for the purpose of this study.

The method of locating the Notch Points on casts is described on page 72.

MANDIBULAR POINTS

A search of the literature revealed that little work has been published regarding the changes in the mandibular denture bearing area after the loss of teeth. This was probably due to the difficulties in orienting pre-extraction and post-extraction mandibular casts in comparable positions.

Evidence provided by the work of HEDEGARD (1962; 1963) and CARLSSON & PERSSON (1963), however, suggested that resorptive changes in the anterior lingual and retromolar regions after the loss of teeth were small compared with changes in other parts of the mandibular denture bearing area.

Changes in these areas were investigated in a collection of mandibular casts which became available during the present study. The collection consisted of mandibular casts of 41 patients. The casts were made before and after the extraction of teeth.

The purpose of this investigation was to study the change in form, if any, of the mucosal surface in the retromolar and anterior lingual regions after the loss of teeth.

Casts were selected from those cases where a number of teeth were still present on the post-extraction cast, these teeth being used to orient the pre-extraction and post-extraction casts of each patient in identical positions. From the total collection, the casts of only 8 patients were

found to be suitable in this respect. From each patient two casts were used, a pre-extraction and a post-extraction cast. The interval of time between the two casts varied from 4 to 51 months, with a mean interval of 20 months.

In 6 of the 8 cases the retromolar regions before and after the extraction of teeth were investigated in the following way :

A self-polymerising acrylic veneer was made to fit the crowns of a number of teeth of both the pre-extraction and post-extraction casts. One cast was then oriented by means of a mounting instrument described by WATT (1960). The acrylic veneer was attached to the vertical arm of the instrument and the cast located into it. Beneath the cast was placed a Perspex base which lay in a set square clamped to the surface table. The set square ensured that each base was held in the same position. Plaster of Paris mixed with anti-expansion solution was placed on the Perspex base and the cast lowered into it to a pre-arranged height. The other cast was oriented in another base, of the same dimensions, in exactly the same way. Thus both casts were oriented in identical positions. It was realised that tooth movement during the interval of time between the pre-extraction and post-extraction casts may have influenced the exact location of the acrylic veneer. However, in the 6 selected cases, tooth movement appeared to be slight and this error was accepted in this investigation. (Acrylic veneers were made for a number of other casts in the total collection but it was found that tooth movement made it impossible to locate the veneers on both pre- and post-extraction casts. These casts were rejected.)

The pre-extraction cast was now transferred to an instrument for making vertical traces of casts (WATT 1960) (Fig. 4). The Perspex base was adjusted in a set square so that the point of the tracing stylus could be moved along the cusps of certain teeth on one side of the cast to terminate posteriorly at the most superior point of the retromolar region of that side. A trace was made on tracing paper clamped to the back of the instrument.

Without removing the tracing paper the post-extraction cast was then located in the same position in the set square and the stylus was moved along the cusps of the standing teeth and along the crest of the residual alveolar ridge to the most superior point of the retromolar region on that side of the cast. This trace was superimposed on the trace of the pre-extraction cast. The outlines of the teeth coincided.

Study of the 6 combined traces (Fig. 8) showed that the change in the retromolar region after the loss of teeth was small.

In 2 of the 8 cases the anterior lingual regions were investigated. In both these cases only the incisors and canines were extracted. The acrylic veneer fitted the premolar and molar occlusal surfaces. The method of orienting and mounting the casts was as already described.

The tracing stylus was moved in contact with the pre-extraction cast surface in a sagittal plane through the midline and a trace was made on tracing paper. The point of the stylus was positioned on the mucogingival line and a

vertical line was drawn on the tracing paper by the pen which was guided by a vertical bar held by a pot magnet to the instrument base. This vertical line served as a reference line. Without removing the tracing paper the post-extraction cast was then located in the set square and the same procedure was used. The trace of this cast was superimposed on the trace of the pre-extraction cast.

In these two cases the time interval between pre-extraction and post-extraction casts was 26 and 31 months.

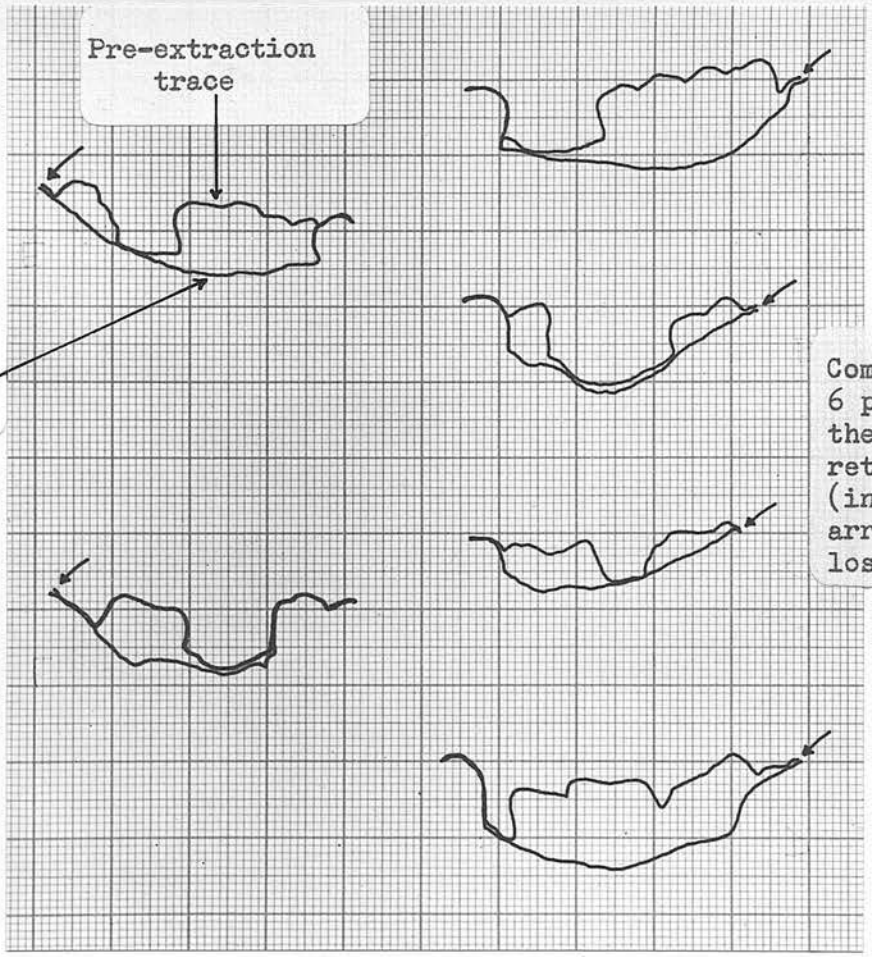
Study of the 2 combined traces (Fig. 9) showed that a point on the mucogingival line in the lingual incisor region appeared to move forward about 1 mm. after the loss of teeth.

It was not possible to draw definite conclusions from this longitudinal sample in which the number of casts was small and the length of time after the loss of teeth was short. The findings, nevertheless, agreed with those of Hedegard and Carlsson & Persson in that changes in the anterior lingual and retromolar regions appeared to be small. Points were, therefore, sought in these regions of the dentulous and edentulous mandibular casts.

1. Reference point (RL point) :

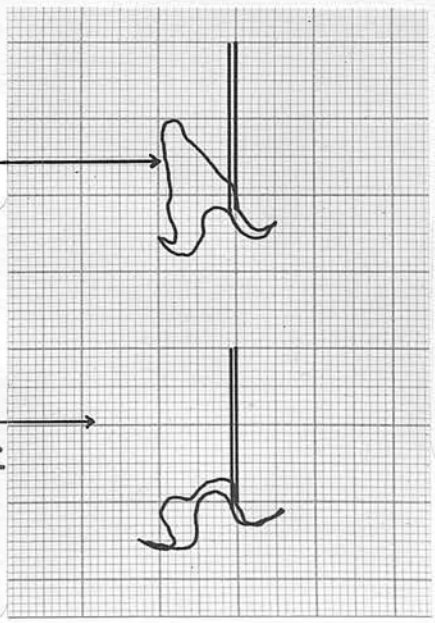
The point of intersection of the lingual mucogingival line and the median sagittal plane.

A point was marked on the crest of the lingual frenum of all dentulous and edentulous casts. This point was known as the Frenum Point and served as one of the points through which the Median Sagittal Plane was constructed. This point, however, was not suitable as a means of



Combined traces of 6 patients showing the change in the retromolar regions (indicated by the arrows) after the loss of teeth.

Fig. 8



Combined traces of 2 patients showing the forward movement of a point on the mucogingival line after the loss of teeth.

Fig. 9

constructing a horizontal reference plane because of the variability in form of the lingual frenum and, therefore, a Reference point was sought elsewhere in the anterior lingual region.

The attachment of the lingual frenum to the lingual alveolar mucosa was investigated as a point common to dentulous and edentulous casts. It was found, however, that such a point could not be used because in the majority of casts the lingual frenum did not reach the lingual alveolar mucosa. This finding was in agreement with that of SICHER (1960c).

Another point considered was on the curved junction of the lingual alveolar mucosa with the mucosa of the floor of the mouth. On casts, however, this curved junction was extremely variable in form and it was found impossible to locate a point there with reasonable certainty.

The RL point was finally selected at the intersection of the lingual mucogingival line and the median sagittal plane for the following reasons :

(a) changes in this area appeared to be small after the loss of teeth.

(b) the mucogingival line was a definite anatomical landmark.

(c) the position of the mucogingival line in the anterior lingual region was located on both dentulous and edentulous casts. (The ability of an observer to locate and mark the position of the mucogingival line on casts was carefully investigated. This investigation is fully reported in the Appendix on page 201.)

The method of locating the RL point on casts is described on page 80 .

2. Retromolar Points :

The most superior point on the trimmed distal edge of each retromolar region of a mandibular cast.

It was not possible to define the retromolar regions of mandibular casts in precise anatomical terms. This was due to the absence of anatomical landmarks at the distal ends of dentulous and edentulous casts. The extent of the retromolar region of a cast was influenced by the following factors :

i. the extent of the impression from which the cast was made.

ii. the trimming of the cast in the laboratory.

iii. on dentulous casts, the number and position of the teeth present.

In addition to these factors, there are anatomical differences between dentulous and edentulous mouths which make it difficult to define comparable points on the retromolar regions. In a dentulous mouth, with all mandibular teeth erupted, the retromolar papilla of the third molar lies directly over the base of the bony retromolar triangle. Lying immediately behind the papilla is the soft retromolar pad. After the loss of teeth, the retromolar pad persists. Mesial to it, approximately in the area of the third molar socket, there forms the pear-shaped pad (CRADDOCK 1953) which may be seen frequently as a definite prominence at the distal end of the residual alveolar ridge (Fig. 10). In many edentulous mouths, however, the pear-shaped pad is not prominent but is seen

only as a broadening of the ridge while, in other cases, the residual alveolar ridge may reach the retromolar pad without any marked change in form (Fig. 11).

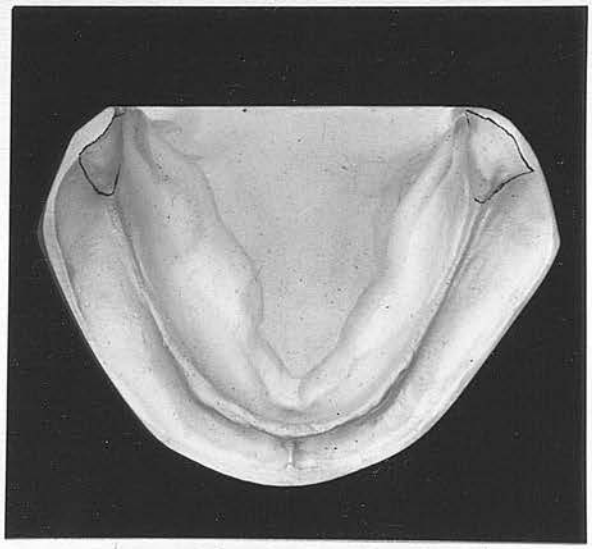
Because of the variations in the casts, and the absence of definite anatomical landmarks, the following definitions were applied to describe the retromolar regions in the present study :

Dentulous casts : the superior surface of the cast between the crown of the most distal erupted molar and the trimmed distal edge of the cast.

Edentulous casts : the superior surface of the residual alveolar ridge in the region of the pear-shaped pad and terminating at the trimmed distal edge of the cast.

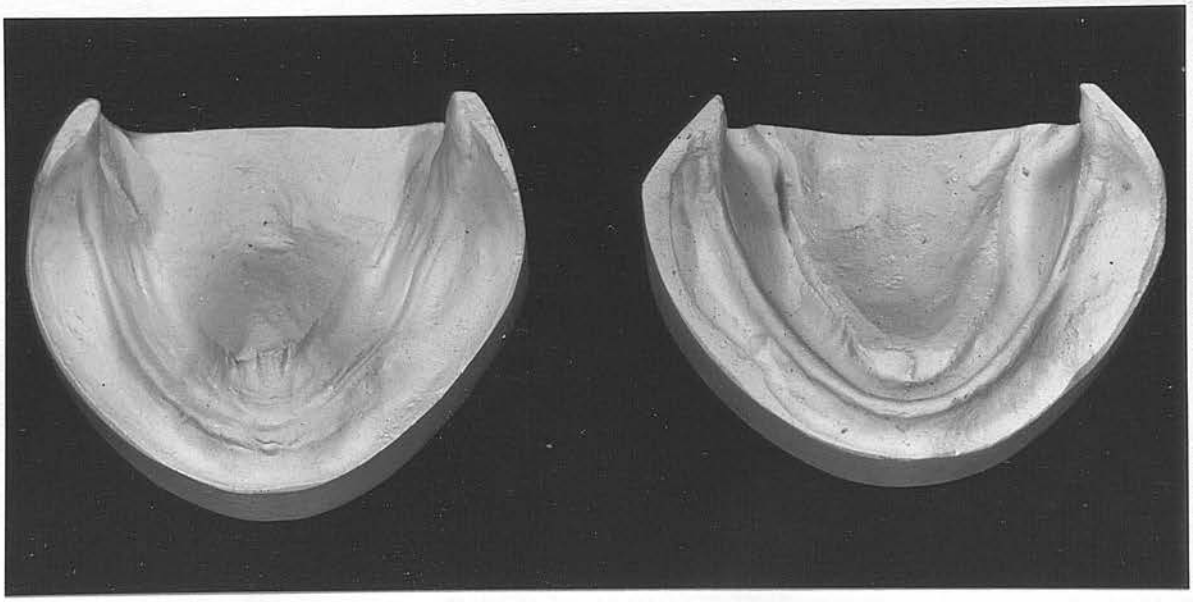
It was realised that points selected on the retromolar regions of dentulous and edentulous casts were not exactly comparable. Nevertheless, since the distal edge of the retromolar region represented the posterior limit of the impressions from which the casts were obtained, it was appropriate that a point on this edge should be selected as it was used later to define the posterior limit of the impression trays designed in this study.

The method of locating the Retromolar Points on casts is described on page 79 .



Mandibular edentulous cast with prominent pear-shaped pads.

Fig. 10



Mandibular edentulous casts in which the pear-shaped pads are absent.

Fig. 11

REFERENCE PLANES IN THE PRESENT STUDY

MAXILLARY CASTS

1. Reference Plane : the plane through the RU point and the Notch Points.

The dentulous and edentulous maxillary casts were mounted on the tracing and measuring instruments and oriented in such a way that a plane passing through the RU point and the left and right Notch Points was horizontal. This plane was the horizontal reference plane of each cast.

This plane was considered to be satisfactory as it was common to dentulous and edentulous casts and all the casts oriented to this plane lay reasonably close to an acceptable anatomical position i.e. the occlusal surfaces of the teeth of the dentulous casts and the crests of the residual alveolar ridges of the edentulous casts were approximately horizontal.

The errors in orientation of the casts, due to changes in position of the horizontal reference plane after the loss of teeth, are discussed further on page 103.

2. Median Sagittal Plane : the vertical plane through the RU point and the Posterior Midpoint.

These two points on the palatine raphe provided a means of constructing a median sagittal plane on dentulous and edentulous casts. Deviations and S-shaped curvatures of the raphe were found on some casts but these aberrations were not sufficiently large to invalidate the choice of the raphe for this study.

MANDIBULAR CASTS

1. Reference Plane : the plane through the RL point and the Retromolar Points.

If a mandibular cast was oriented with the Reference Plane horizontal the cast was abnormally tilted in the sagittal plane. This tilt caused a foreshortening of the measurements and traces.

The anatomical position most suited to this study was one in which the occlusal plane was horizontal. This is a generally accepted position of orienting casts prior to measurements. However, because the occlusal plane did not exist on edentulous casts, a search was made for a method of orienting edentulous casts in a position comparable to dentulous casts. After much investigation a method was adopted which relied on the mean angle between the Reference Plane and the Occlusal Plane of a random sample of 100 dentulous casts. This mean angle was found in the following way :

100 mandibular casts were selected by random numbers from the dentulous sample.

The horizontal level of the tracing instrument (Fig. 15) was checked by spirit levels and each cast was secured to the adjustable platform. The edge of the plate of a spirit level (Fig. 12) was laid in contact with the Retromolar Points; the point of the leg was laid on the RL point. The platform to which the cast was secured was adjusted until the spirit levels read zero. This ensured that the Reference Plane was horizontal.

The Occlusal Plane of the cast was defined by a flat metal plate laid over the incisal edges and occlusal surfaces of all the teeth except the third molars (Fig. 13). In the majority of casts the plate touched only the incisors and second molars but this varied from cast to cast depending on the number and position of the teeth present.

A protractor, mounted on a vertical stylus by means of a mild steel tube, was then brought into contact with the edge of the flat metal plate on the cast (Fig. 14). The angle formed between the flat metal plate and the horizontal was then read to the nearest whole degree (0.5° read as 1°). This was the angle between the Reference Plane and the Occlusal Plane of the cast.

The mean angle of the sample of 100 dentulous casts was 19.6° (Table 7).

This angle of 19.6° was used in the method of orienting dentulous and edentulous casts. An offset spirit level carrier was constructed in such a way that , when the carrier was in contact with the RL point and both Retromolar Points of a cast and the spirit levels read zero, then the occlusal plane of each dentulous cast, and the "imaginary" occlusal plane of each edentulous cast, were oriented to an approximate horizontal plane.

The errors of this method, which was based on the use of a mean angle, are discussed on page 105 .

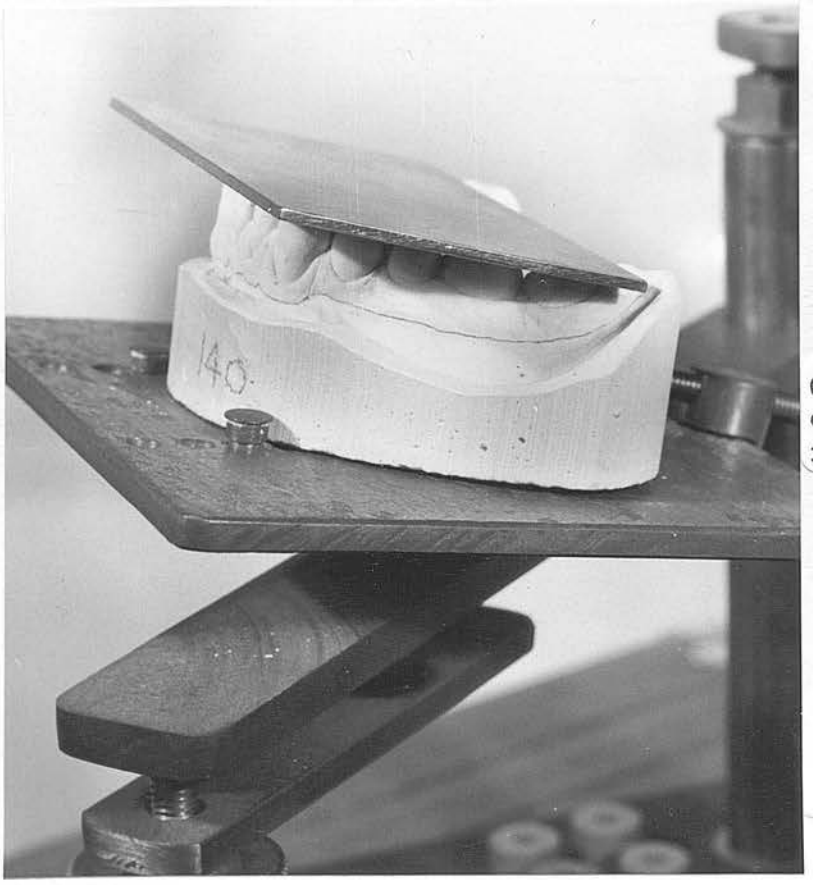
2. Median Sagittal Plane : the vertical plane through the Frenum Point and the Posterior Midpoint.

The Frenum Point was selected on the crest of the lingual frenum or, when the latter was broad or fan-shaped, midway between the lateral surfaces of the frenum. Such a point was accepted as being comparable on dentulous and edentulous casts.

The Posterior Midpoint was found by means of an attachment to the measuring instrument (see page 80). The point was marked on the floor of the cast midway between the Retromolar Points.

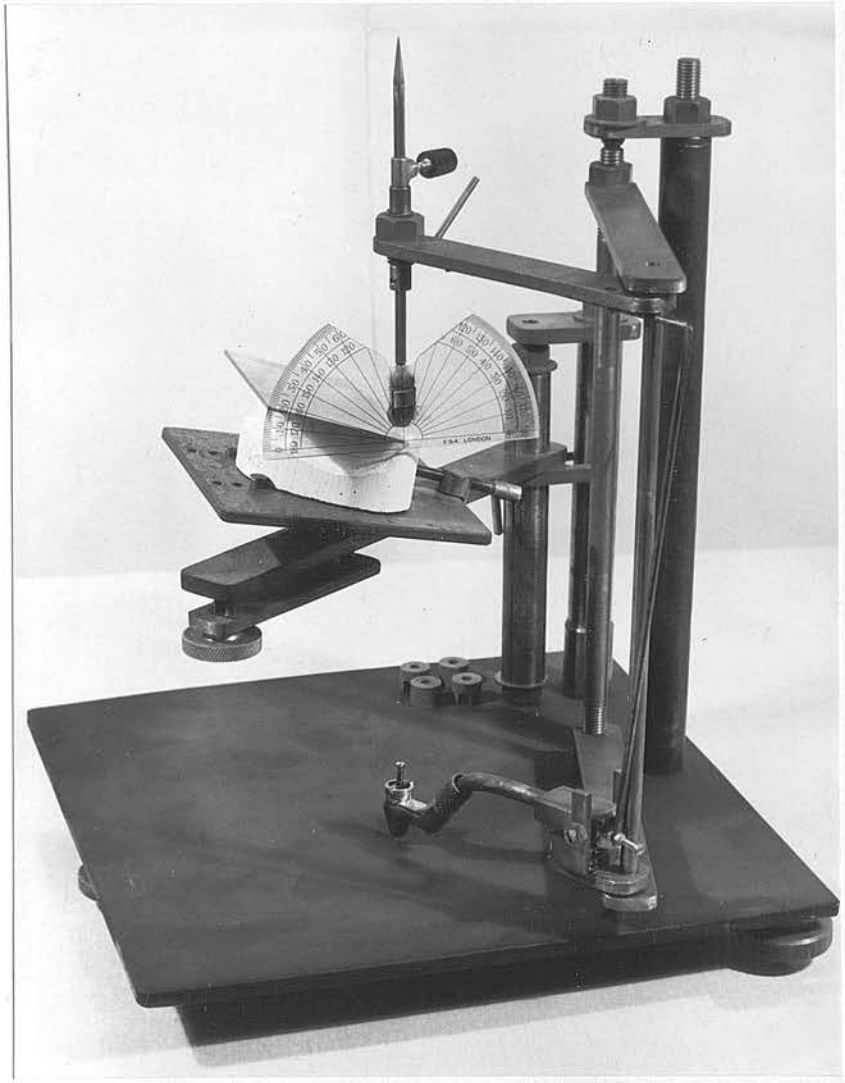
Orienting the Reference Plane parallel to the horizontal plane.

Fig. 12



Occlusal Plane defined by a flat metal plate.

Fig. 13



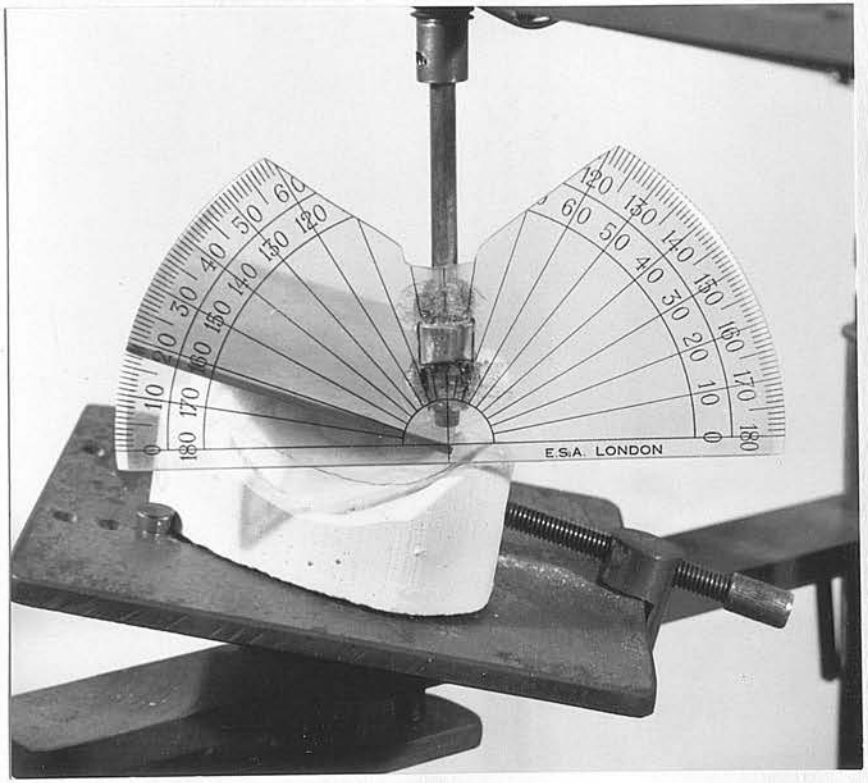
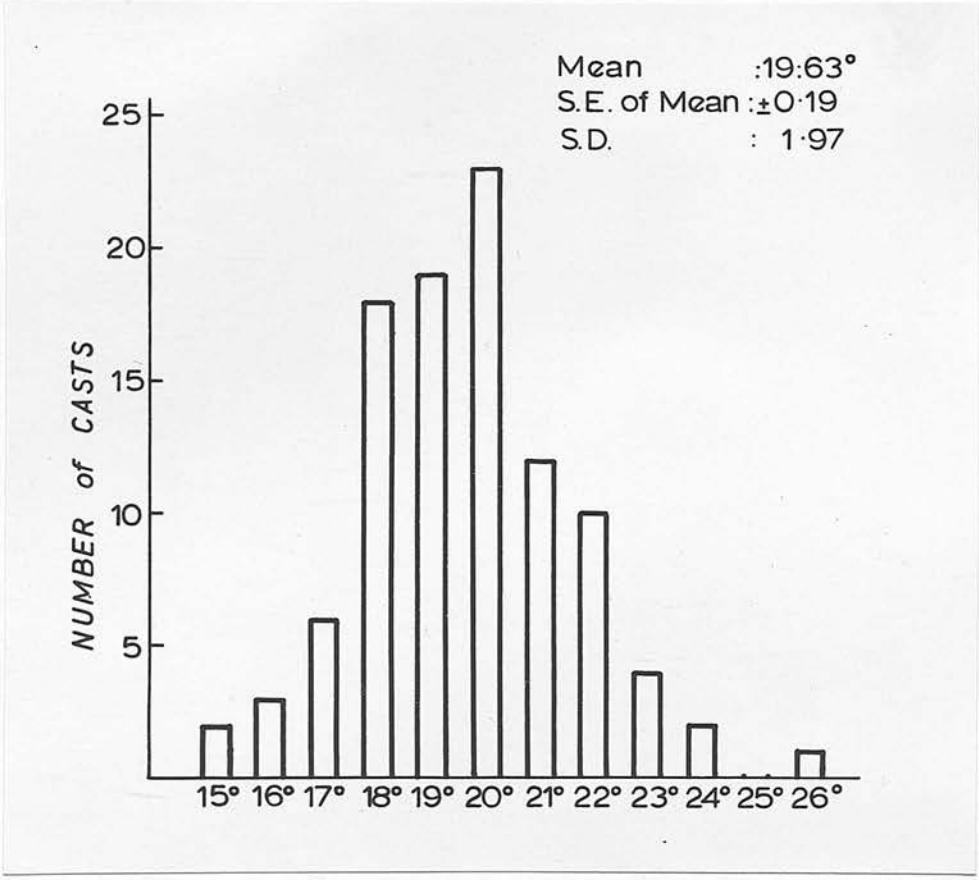


Fig. 14

Protractor mounted on a vertical stylus in contact with the flat metal plate.



Frequency distribution of the angle between the Reference Plane and Occlusal Plane of 100 dentulous mandibular casts.

Table 7

INSTRUMENTS

Tracing Instrument (Fig. 15).

The base of the instrument was made of $\frac{1}{4}$" mild steel plate supported on three adjustable legs for levelling to the horizontal plane. Two vertical rods were bolted to the back of the base. An adjustable platform, on which the casts were mounted, was attached to one of the rods. A movable frame, which carried a stylus and pen, was attached to the other rod.

The adjustable platform, which lay at a height of 13 centimetres above the surface of the base, was carried on a horizontal bar. The bar and platform assembly could be swung outwards in the horizontal plane in order to give a clear view of the instrument base. In the tracing position the bar and platform assembly was clamped rigidly by a locking fork. The adjustable platform, which pivoted on a ball and socket, could be moved through 20° from the horizontal plane in all directions and could be locked in any position by a thumb screw. The casts were firmly secured to the platform by means of two adjustable metal pegs in front and a thumb screw behind.

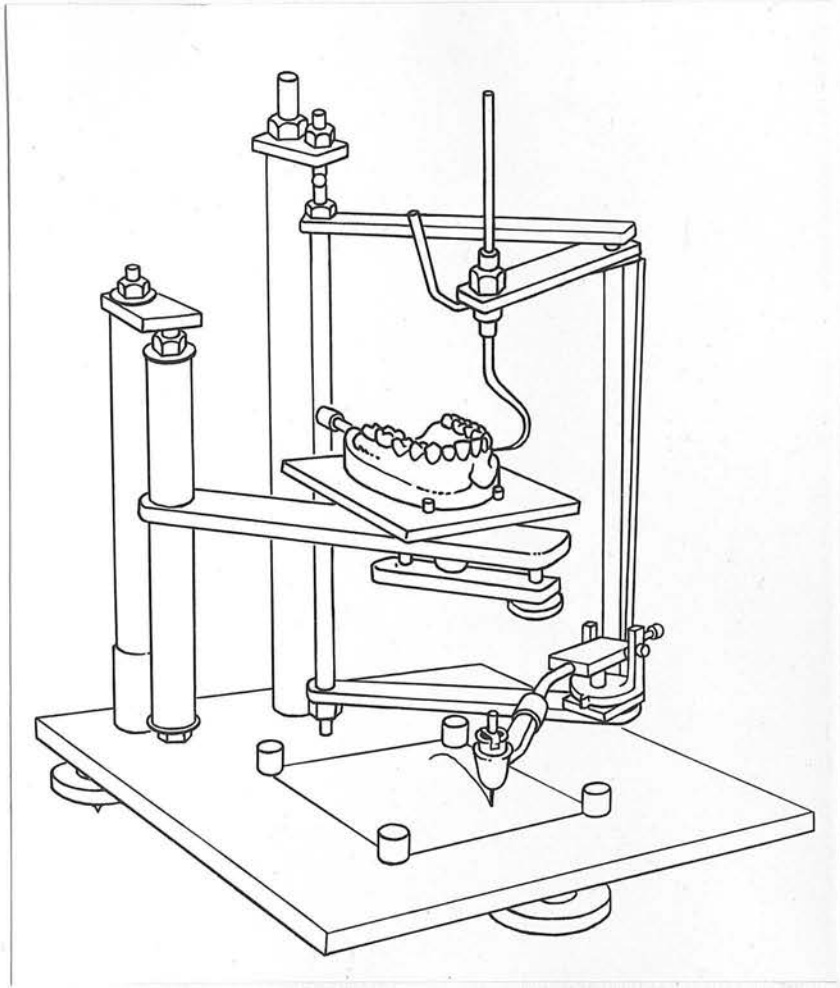
The movable double jointed frame was attached, through ball bearings, to the other vertical rod bolted to the base of the instrument. The frame could be swung freely in the horizontal plane. A cast brass pen holder, designed to cradle a "Uno Standard Pen" (size 0), was soldered to the lower free end of the frame. The pen holder could be raised

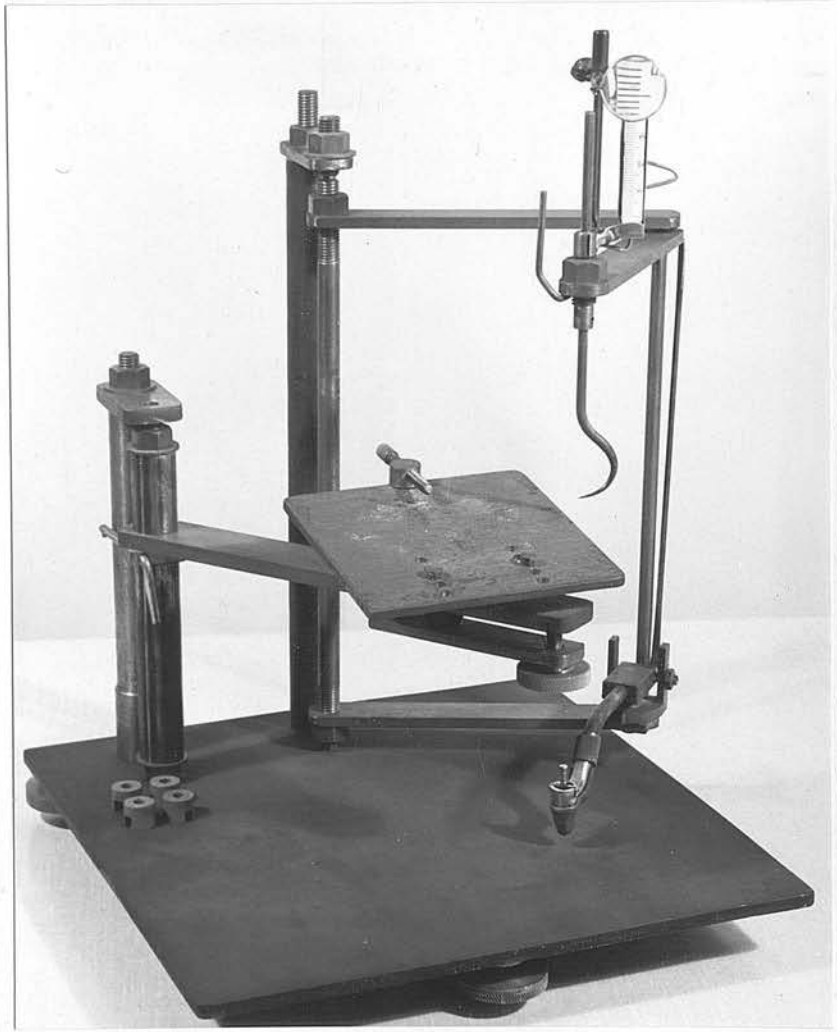
and lowered by a small control handle which was connected to an eccentric pivot linked by a ratio adjustment through to the holder. Traces were made by the pen on tracing paper held by button magnets to the base of the instrument.

When the pen was in contact with the paper the pen tip was in the same vertical axis as the point of the tracing stylus which was attached to the upper free end of the frame.

The stylus, made of $\frac{1}{8}$" tempered silver steel rod, was inserted through a mild steel tube bushed with phosphor bronze and reamed to $\frac{1}{8}$". Two types of stylus were used, a straight and a sickle-shaped, the latter being designed to enter undercuts in the casts. Each stylus could be rotated about a vertical axis which passed through its point.

A vertical millimetre scale was attached above the stylus. A sliding pointer in close contact with the scale registered vertical movements of the stylus. A magnifying glass was added to facilitate reading of the scale and a mark on the glass eliminated parallax errors. The pointer could be locked at the top of its runner when not required.





The Tracing Instrument

Fig. 15

Measuring Instrument (Fig. 16).

The base of the instrument was made of $\frac{1}{4}$" mild steel plate supported on three adjustable legs for levelling to the horizontal plane. Two machined steel runners were bolted to the base. A sliding plate was set between the runners and could be moved from front to back of the instrument. The sliding plate could be locked in any position by a wing nut.

An adjustable platform, on which the casts were mounted, was carried by the sliding plate. The platform, which pivoted on a ball and socket, could be moved through 20^{o} from the horizontal plane in all directions but could also be locked in any position by a screw and tommy-bar. The casts were firmly secured to the platform by means of two adjustable metal pegs in front and a thumb screw behind.

A horizontal steel gantry straddled the platform at a height of 12 centimetres and was bolted to the base at each side of the instrument. The gantry carried a slide on which a vertical stylus was mounted in such a way that it could be raised, lowered or rotated about a vertical axis. The stylus mount was a mild steel tube bushed with phosphor bronze. Two types of stylus were used, a straight and a sickle-shaped, the latter being designed to enter undercuts in the casts. Each stylus could be rotated about a vertical axis which passed through its point.

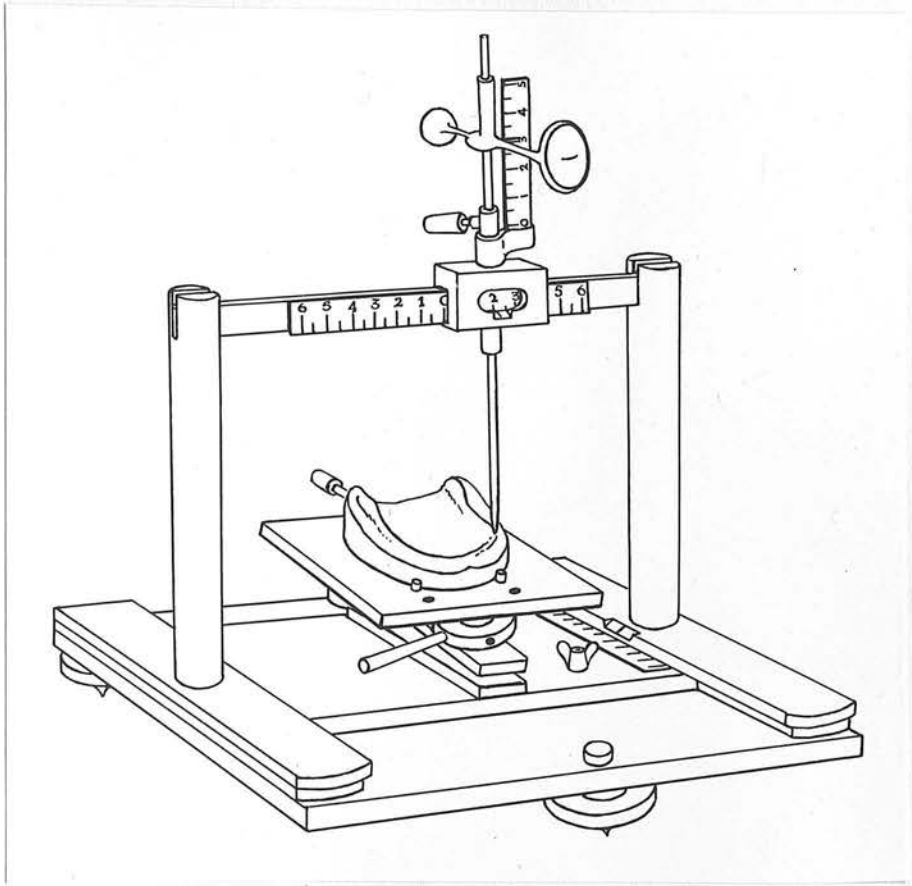
Three millimetre scales were attached to the instrument :

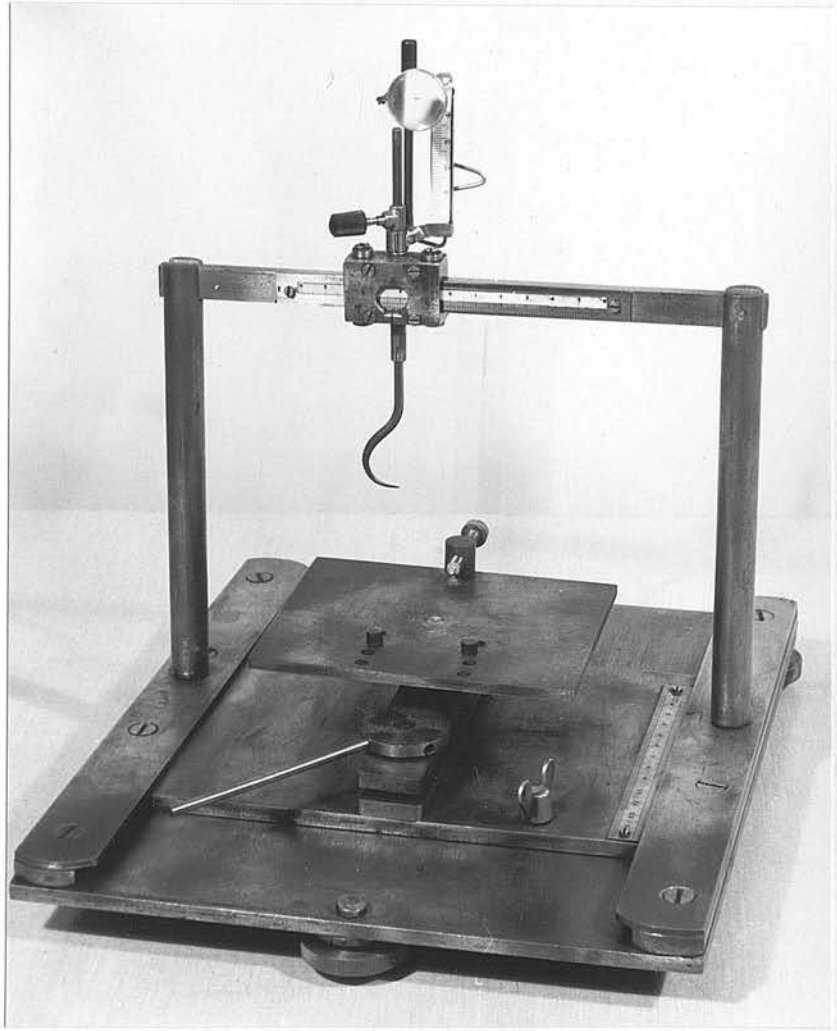
i. a vertical scale, mounted above the stylus, measured the vertical movement of the stylus.

ii. a horizontal scale on the gantry measured movements of the stylus across the instrument in the coronal plane of the mounted cast.

iii. a horizontal scale at the base of the instrument measured front to back movements of the sliding plate and hence the relative movement of the stylus in the sagittal plane of the mounted cast.

By means of the three millimetre scales the co-ordinates of any point on the mounted cast could be measured.





The Measuring Instrument

Fig. 16

DESCRIPTION of METHOD

MEASUREMENTS OF DENTULOUS CASTS

1. A trace of the projection of the mucogingival line on the horizontal plane was made by means of the tracing instrument of each of the 702 dentulous casts in the sample.
2. Direct measurements were made by means of the measuring instrument of each of the 702 dentulous casts in the sample. The total number of measurements made on these casts was in the region of 9000.

MEASUREMENTS OF EDENTULOUS CASTS

1. Direct measurements were made by means of the measuring instrument of each of the 600 casts in the edentulous sample. The total number of measurements made on these casts was in the region of 12000.
2. The position of the buccal mucogingival line was marked on 198 casts from the edentulous sample. A trace of the projection of this line on the horizontal plane was made of each cast by means of the tracing instrument. Additional direct measurements were made of the maxillary casts by means of the measuring instrument.
3. A trace of the projection of the crest line on the sagittal plane was made of each of the 300 edentulous mandibular casts in the sample.

DENTULOUS MAXILLARY CASTS

1. The method of making traces of the Dentulous Maxillary casts

The following procedure was used with each of the 351 dentulous maxillary casts in order to produce a trace of the projection of the mucogingival line on the horizontal plane :

Each cast was examined under a good light and a hand magnifying glass and the following points and lines were marked on the cast surface with a sharp 3H pencil (Fig. 17).

The Reference Point (known as the RU point) was marked at the junction of the posterior border of the incisive papilla and the palatine raphe. The Posterior Midpoint was marked on the palatine raphe in the region of the posterior border of the hard palate. This point was ringed for future identification. The position of the Mucogingival Line at the junction between the attached gingiva and the reflected alveolar mucosa was marked on the buccal surface of the cast. The ability of an observer to locate and mark the position of the mucogingival line on the surface of maxillary and mandibular casts was investigated. This investigation is reported fully in the Appendix on page 201 .

The horizontal level of the tracing instrument base was checked by spirit levels and the cast was then secured to the adjustable platform (Fig. 18).

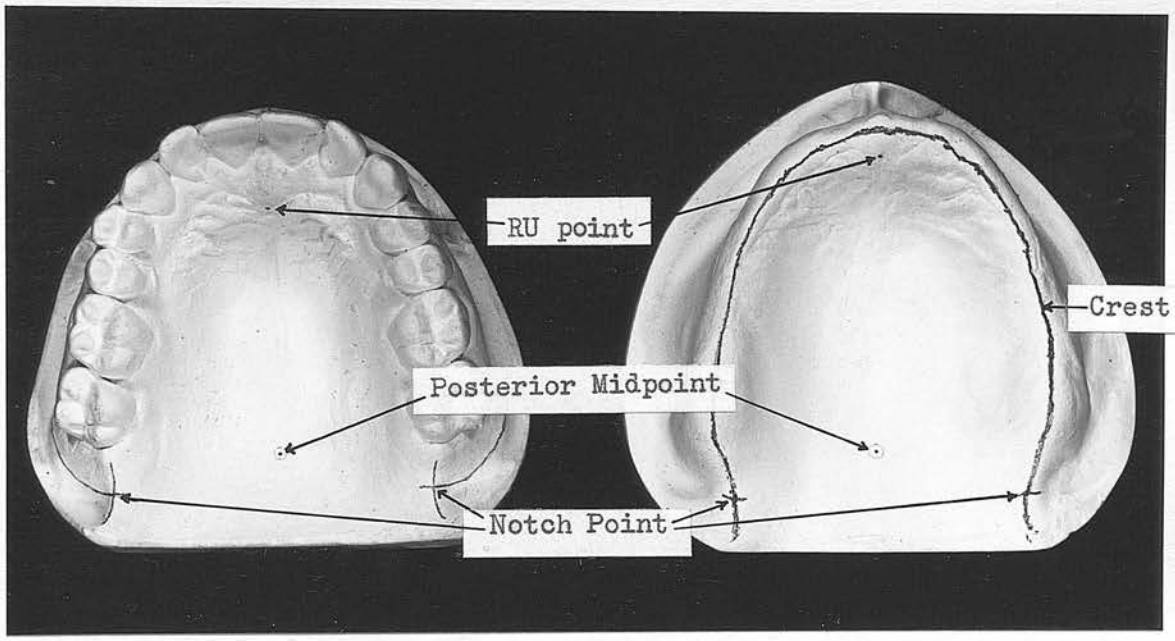
A preliminary horizontal orientation of the cast was made by means of a spirit level (Fig. 19). The edge of the plate of the spirit level was laid in contact with the crescentic ridge on the oral side of the pterygomaxillary

notch on each side of the cast. The point of the leg was laid on the RU point (Fig. 20). In order that the spirit level could be used for any cast, this leg was adjustable in any direction in a horizontal plane. The platform to which the cast was secured was adjusted until the spirit levels read zero. A horizontal graphite rod was moved along each crescentic ridge from the tuberosity to the posterior limit of the cast (Fig. 21). The most superior * point on each graphite line was found by means of a straight stylus and vertical millimetre scale and a pencil mark was made at this point (Fig. 22). This pencil mark was the Notch Point of each crescentic ridge. The spirit level was then re-positioned with the vertical plate on the Notch Points and the anterior leg on the RU point. A final horizontal orientation of the cast was then made by means of the adjustable platform.

The sickle stylus was tracked along the mucogingival line in contact with the cast surface (Fig. 23) and the pen scribed an ink line on the tracing paper held to the base by button magnets. The sickle stylus was replaced by a straight stylus which was then laid in turn on the RU point, the Posterior Midpoint and the Notch Points. These points were marked on the tracing paper. The number of the cast was also recorded on the tracing paper and a note made of the right and left sides.

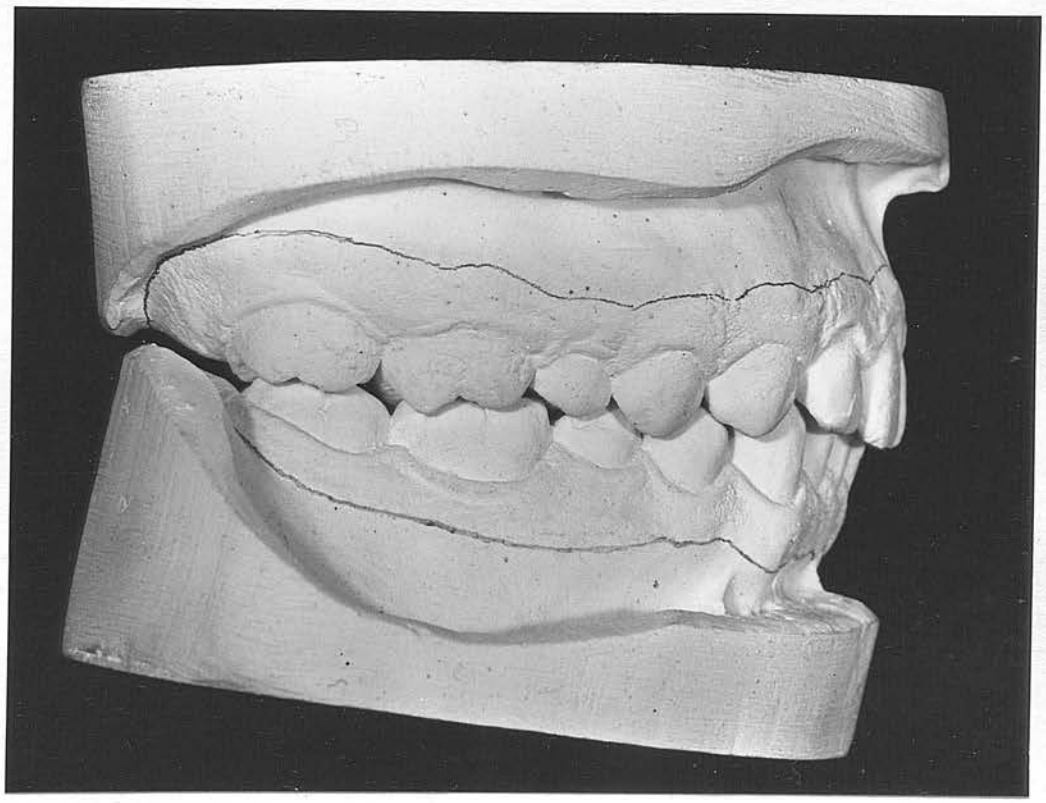
This trace (Fig. 24) was a projection of the mucogingival line of the cast on the horizontal plane.

* "superior" is used in its anatomical sense.

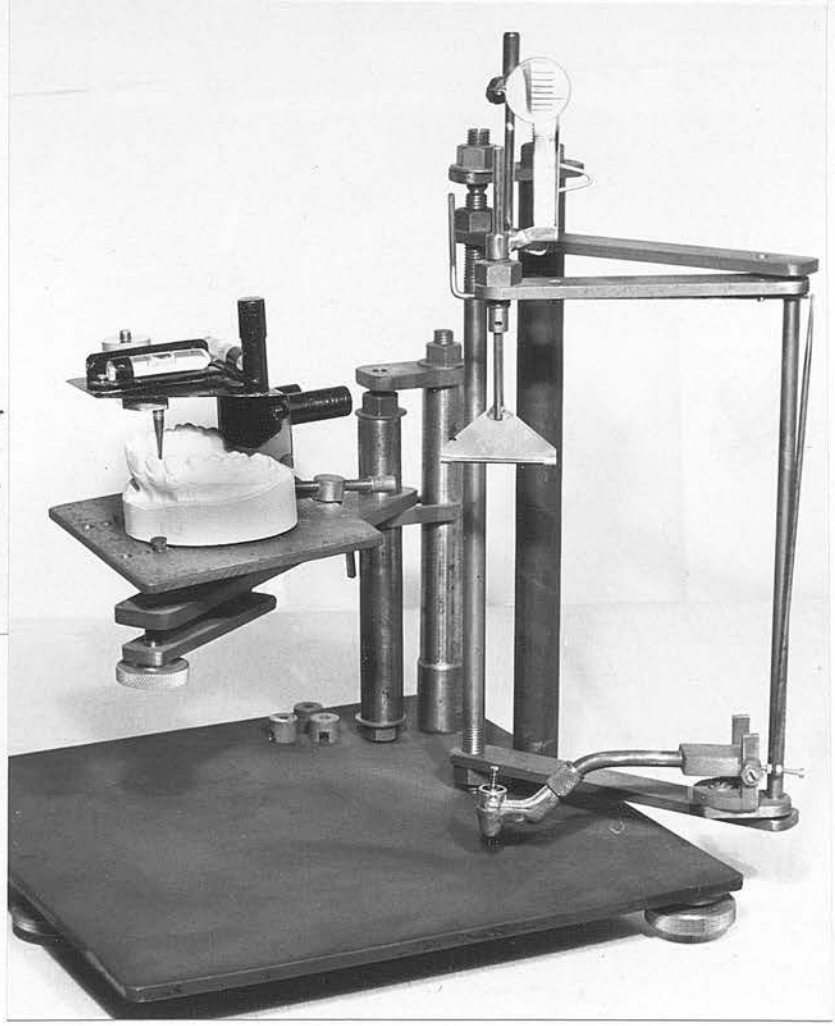


Points and lines marked on casts.

Fig. 17

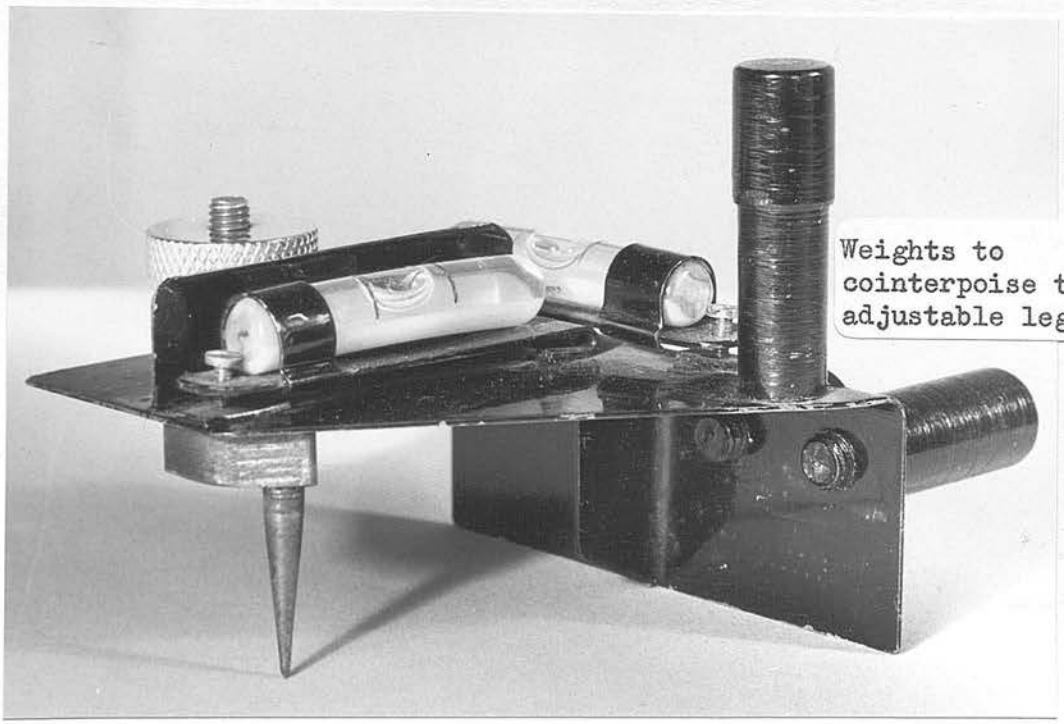


Mucogingival lines marked on dentulous casts.



Dentulous maxillary cast secured to tracing instrument.

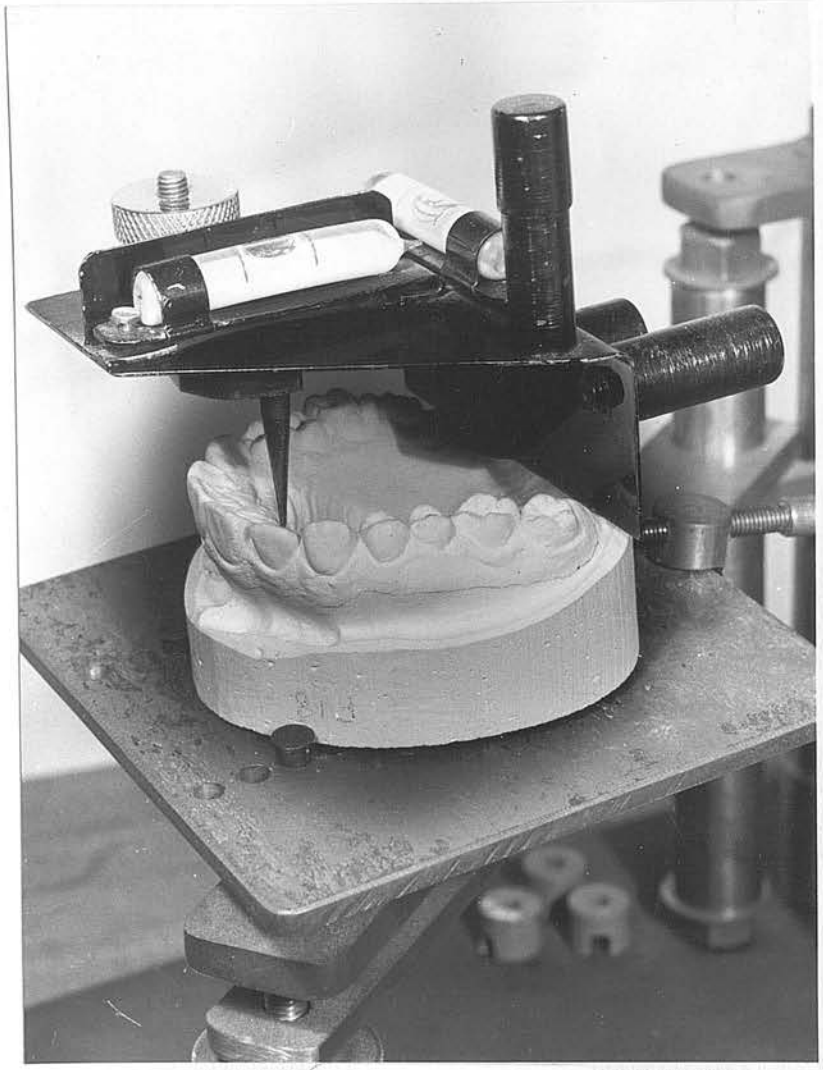
Fig. 18



Weights to cointerpoise the adjustable leg.

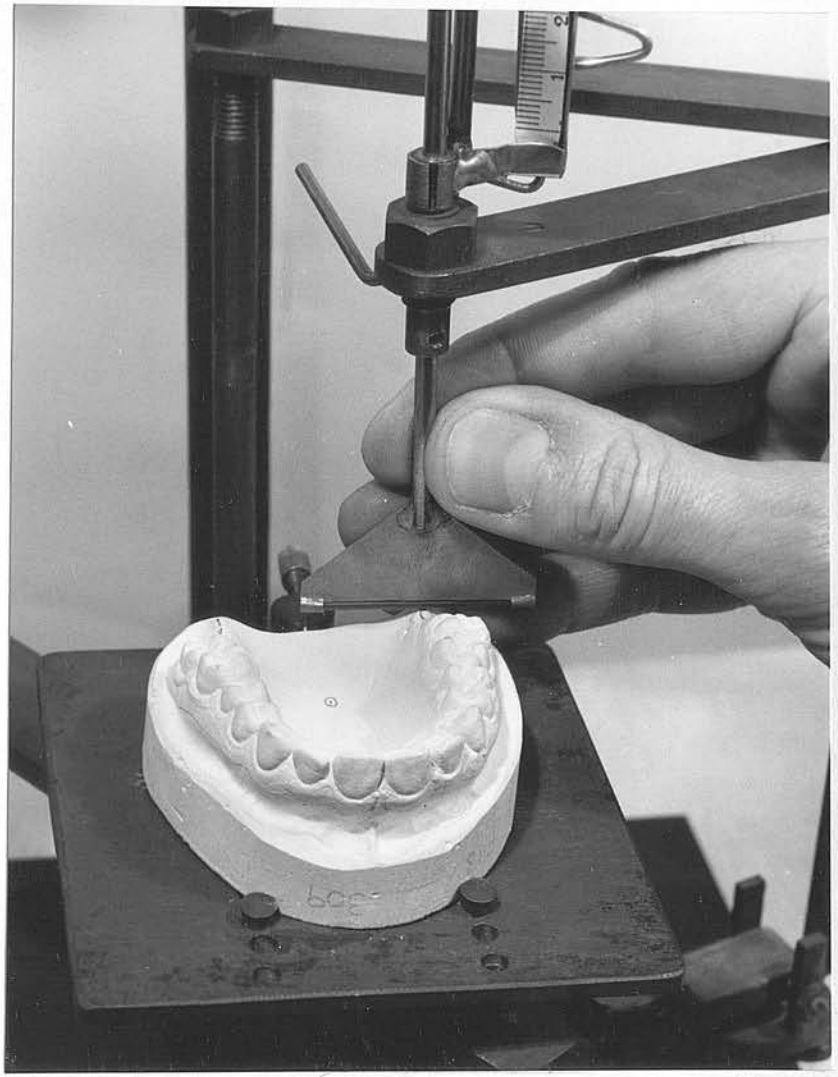
Spirit level

Fig. 19



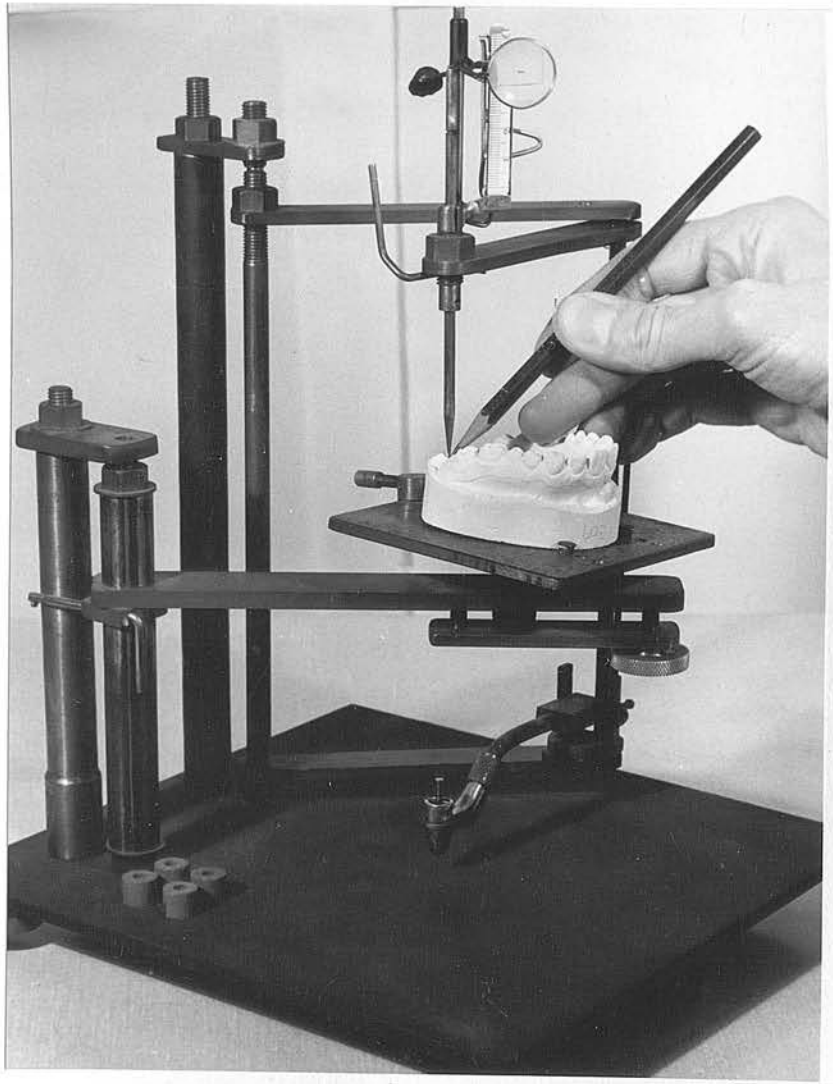
Spirit level on RU point and crescentic ridges.

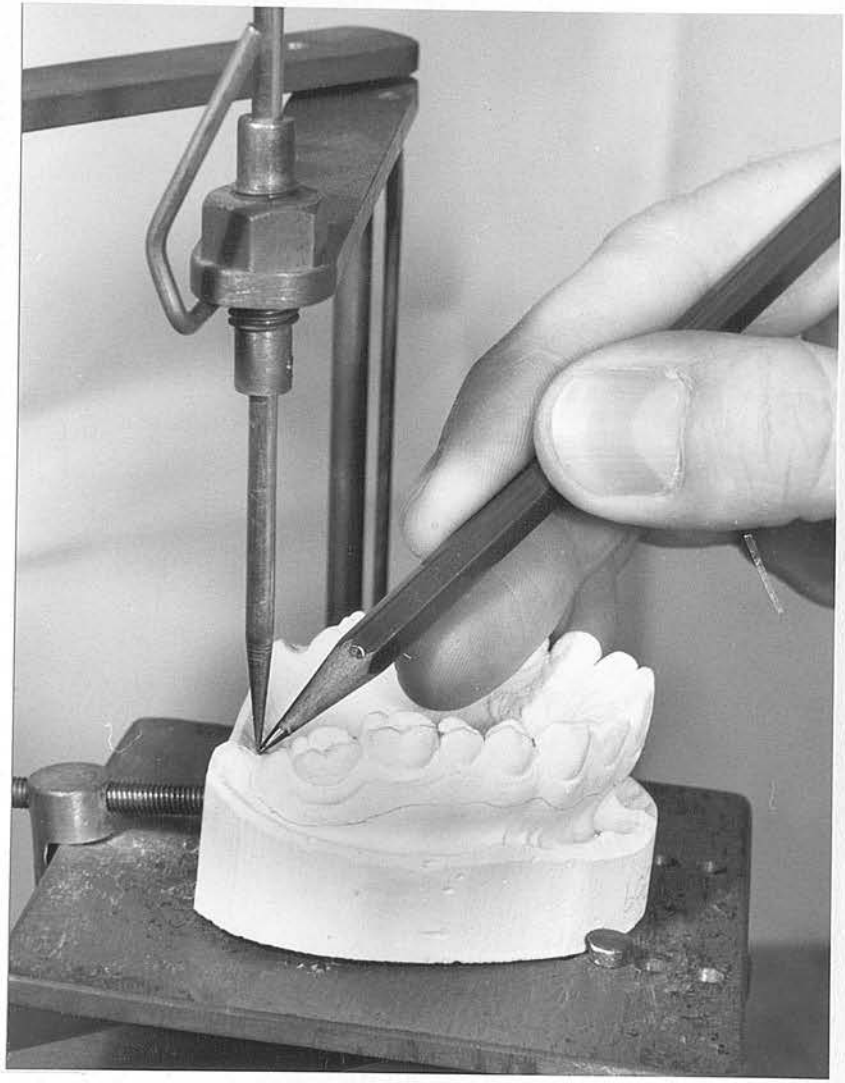
Fig. 20



Marking the crescentic ridges.

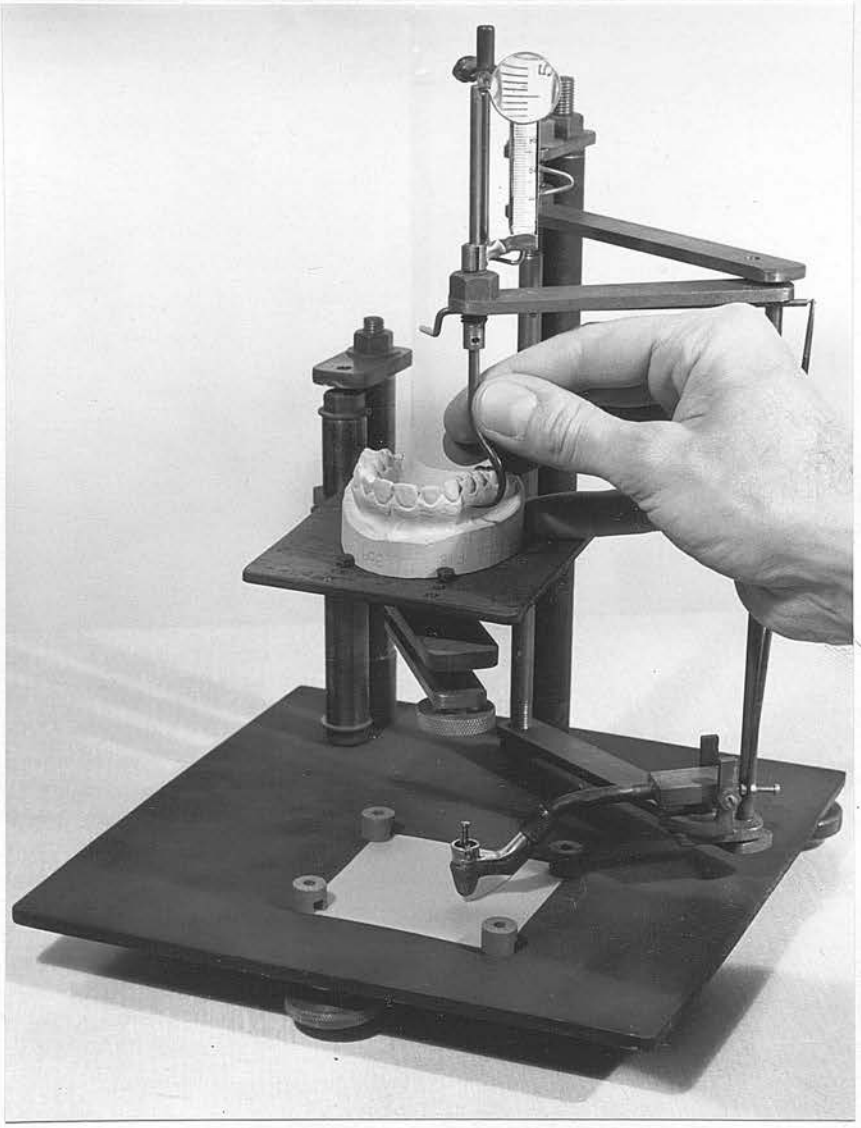
Fig. 21





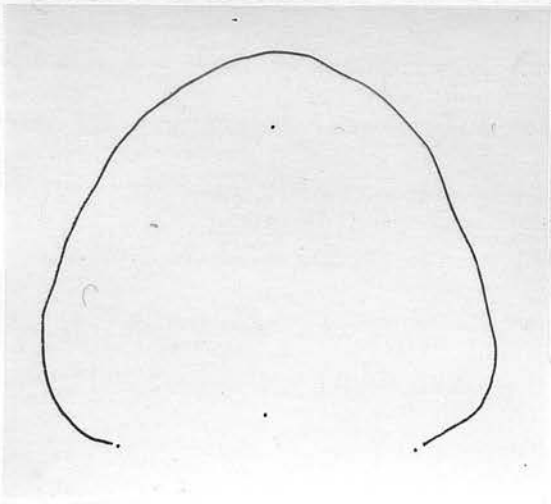
Locating and
marking the
Notch Points.

Fig. 22



Tracing along the mucogingival line.

Fig. 23



Trace of the projection of the mucogingival line of a dentulous maxillary cast on the horizontal plane.

Fig. 24

2. Direct measurement of the Dentulous Maxillary casts

Vertical measurements of the 351 dentulous maxillary casts were made to the nearest 0.5 mm. by means of the measuring instrument. The following procedure was used with each cast :

The horizontal level of the measuring instrument base was checked by spirit levels and the cast was secured to the adjustable platform. The reference plane of the cast was oriented to the horizontal by a spirit level positioned on the RU point and the Notch Points (Fig. 25). The sliding plate was moved to check that the point of a stylus lay on the RU point and the Posterior Midpoint. This ensured that the median sagittal plane of the cast coincided with the sagittal plane of the instrument. The point of the stylus was then laid in turn on the RU point and the Notch Points and readings were made from the vertical scale (Fig. 26) as a further check to ensure that the reference plane of the cast was correctly oriented.

The point of the stylus was returned to the RU point and readings from the three millimetre scales on the instrument were made and recorded on a specially prepared printed sheet. Thus the horizontal, sagittal and coronal co-ordinates of the RU point were recorded and all subsequent readings were made relative to this point.

The stylus was moved along the gantry and a reading on the vertical millimetre scale was made and recorded with the point of the stylus in contact with the mucogingival line on one side of the cast (Fig. 27). A reading was made in a similar manner on the other side of the cast.

In this way vertical measurements from the mucogingival line to the horizontal reference plane of the cast were made in a coronal plane passing through the RU point.

The sliding plate was then moved at intervals of 10 mm. as measured on the millimetre scale on the base of the instrument. At each 10 mm. interval the point of the stylus was laid on the mucogingival line on each side of the cast and also on the surface of the palate in the median sagittal plane (Fig. 28). Readings of the vertical millimetre scale were made and recorded at each stylus position. Each 10 mm. shift of the sliding plate, therefore, enabled three measurements to be made in coronal planes at intervals of 10 mm. from the RU point. The various coronal planes in which measurements were made were termed respectively the 10 mm., 20 mm., 30 mm., 40 mm. and 50 mm. coronal planes, the figure signifying the horizontal distance of each plane from the coronal plane through the RU point. The number of coronal planes in which it was possible to make vertical measurements on any one cast was obviously limited by the length of the cast. In each cast the posterior limit of measurement was the more posterior of the two Notch Points and no measurement was made posterior to this point.

Finally, the sliding plate was moved until the stylus point lay on the labial mucogingival line in the median sagittal plane. A reading of the vertical millimetre scale was made.

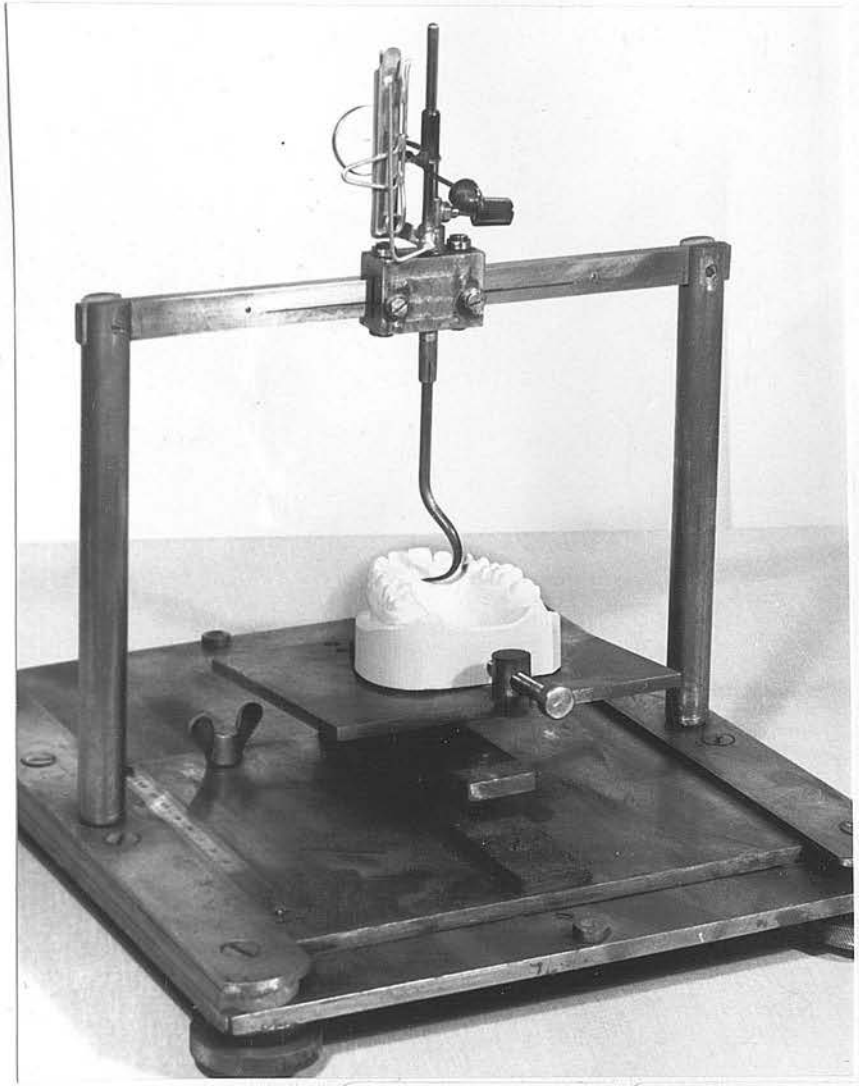
Thus on each dentulous maxillary cast vertical measurements were made from the horizontal reference plane to :

i. the point of intersection of the mucogingival line with the median sagittal plane.

ii. the points of intersection of the mucogingival line on the right and left sides of the cast with the coronal plane through the RU point and coronal planes at 10 mm. horizontal intervals from the RU point.

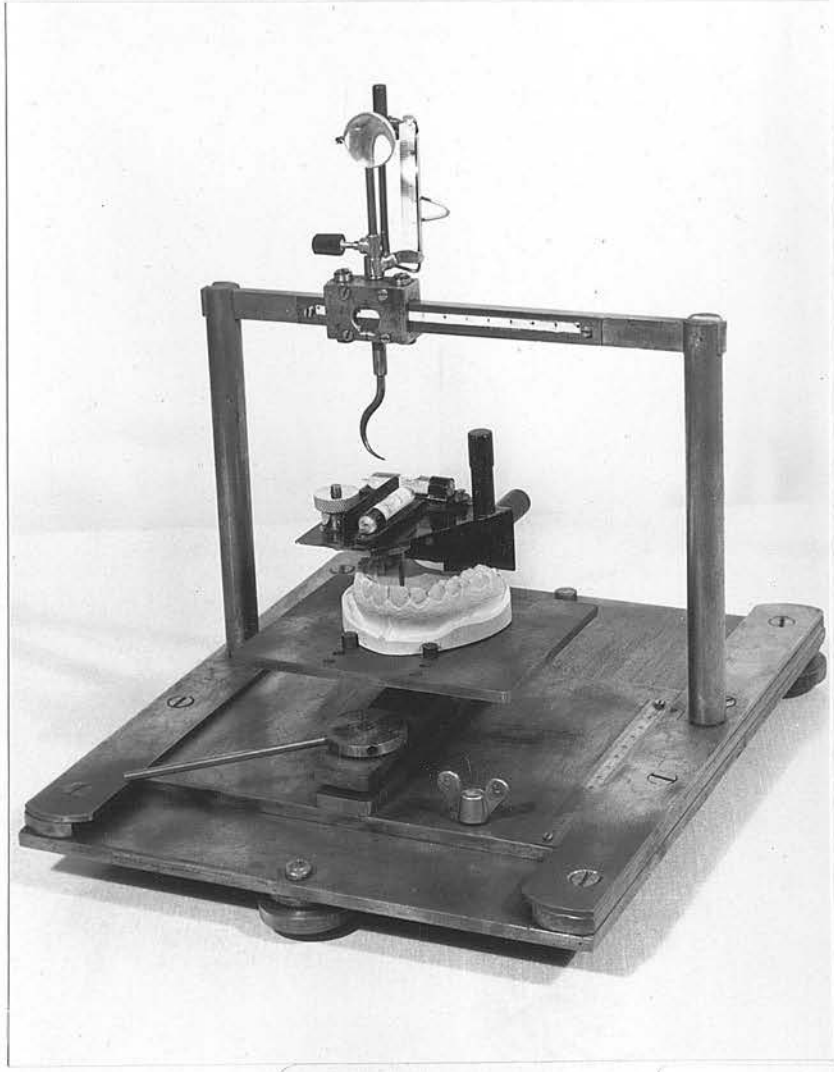
iii. the surface of the palate at the points of intersection of the median sagittal plane with coronal planes at 10 mm. horizontal intervals from the RU point.

The sagittal and coronal planes in which the above measurements were made are shown diagrammatically in Fig. 29 .



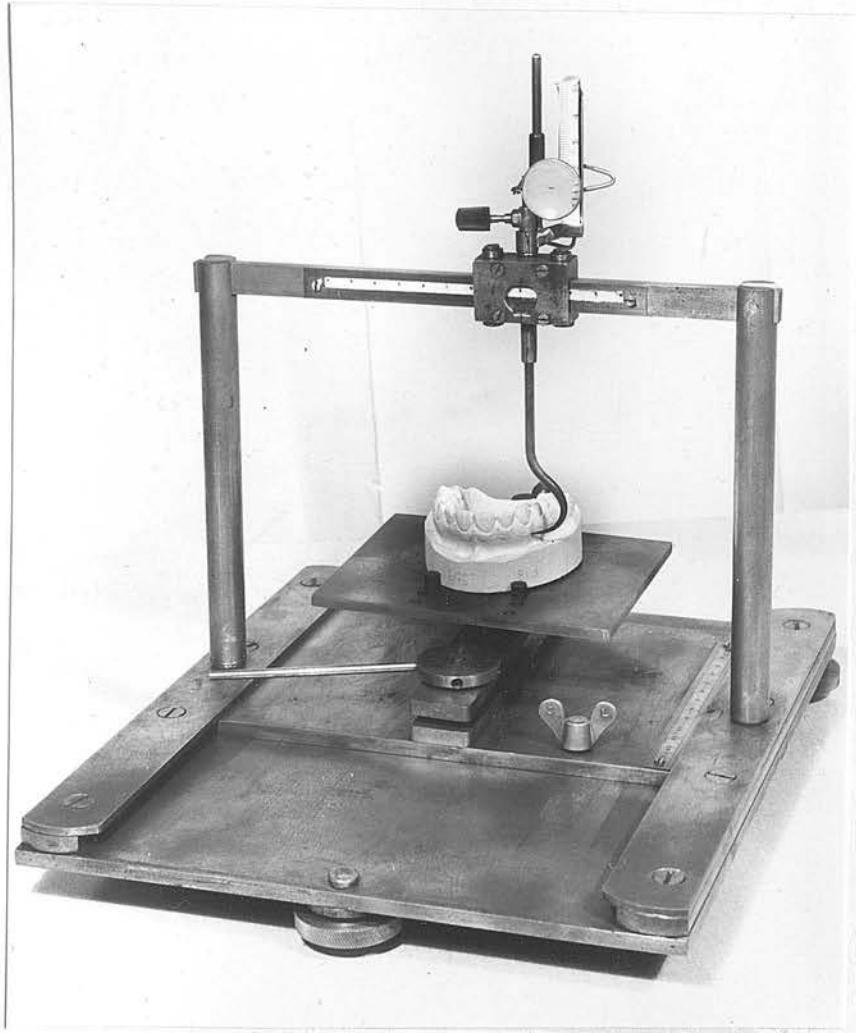
Point of stylus on the RU point.

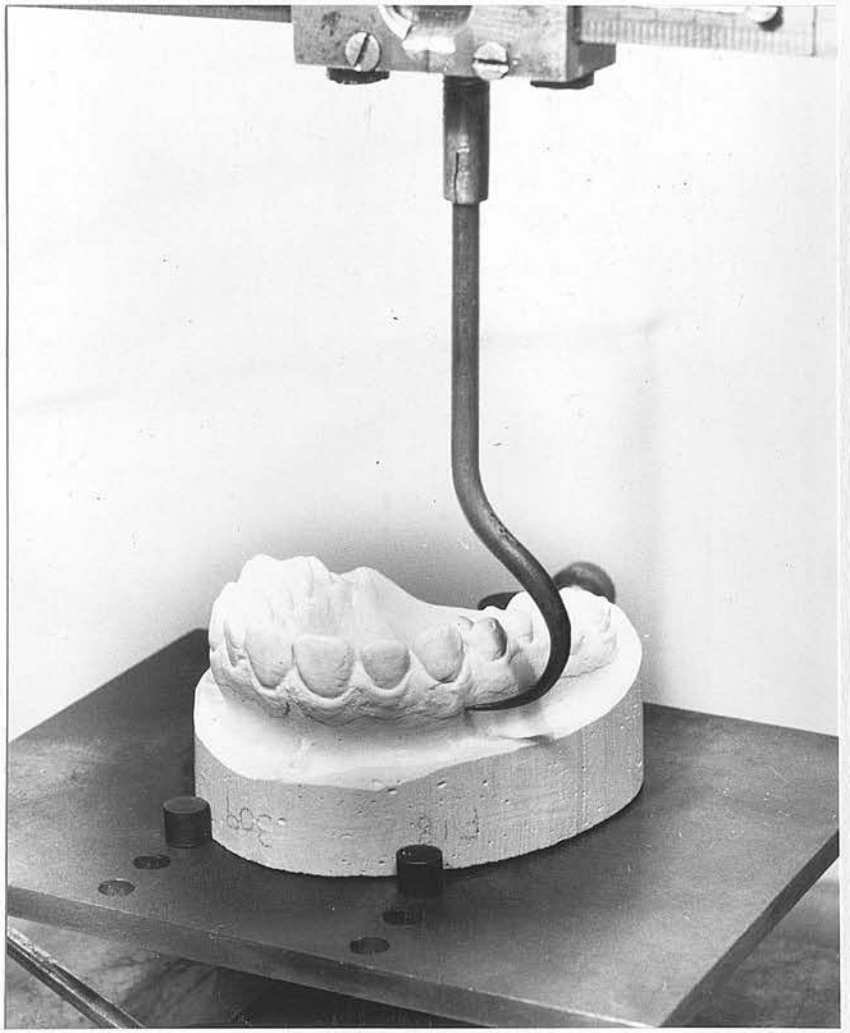
Fig. 26



Dentulous maxillary cast secured to measuring instrument.

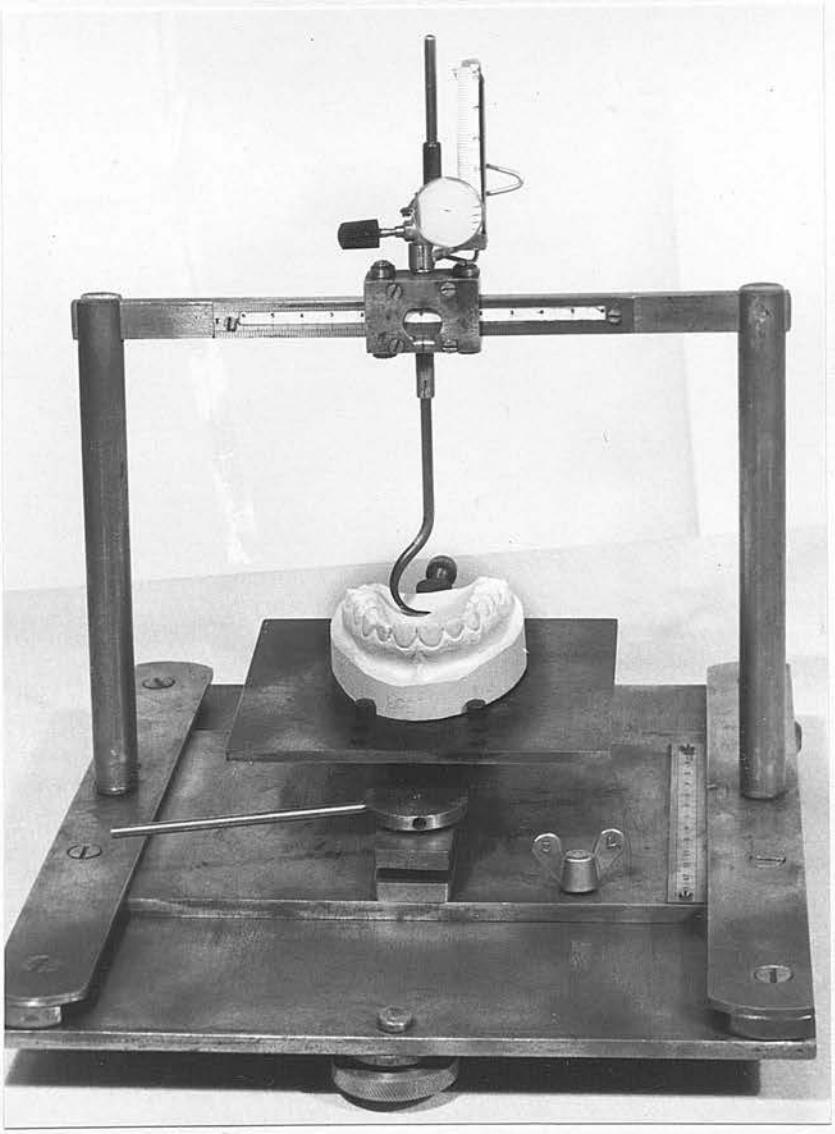
Fig. 25





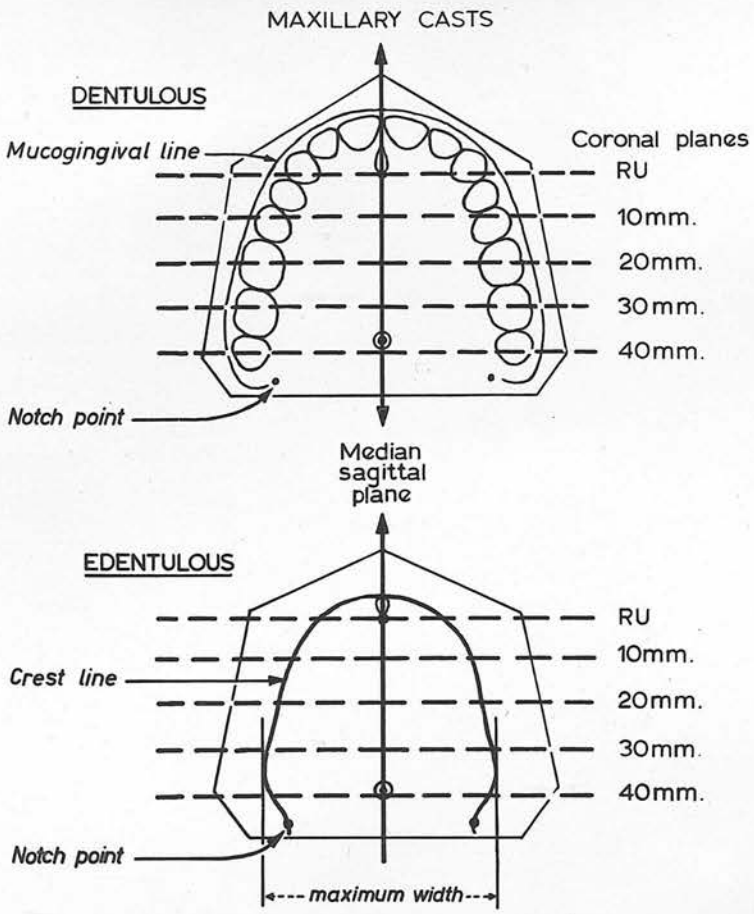
Point of stylus on the muco-gingival line.

Fig. 27



Point of stylus on the palate in the median sagittal plane.

Fig. 28



DIAGRAMS SHOWING SAGITTAL & CORONAL PLANES IN WHICH DIRECT MEASUREMENTS WERE MADE

Fig. 29

EDENTULOUS MAXILLARY CASTS

Direct measurement of the casts

Direct measurements were made of each of the 300 edentulous maxillary casts. The following procedure was used :

The RU point was marked at the junction of the posterior border of the incisive papilla and the palatine raphe. The Posterior Midpoint was marked on the palatine raphe in the region of the posterior border of the hard palate and ringed for future identification.

The cast was then mounted on the tracing instrument in order to locate the Notch Points and the Crest Line. The horizontal base of the tracing instrument was checked by spirit levels and the cast was secured to the adjustable platform (Fig. 30). The Notch Points were located and marked in the same way as on dentulous maxillary casts (Figs. 31 32). The spirit level was then positioned with the vertical plate on the Notch Points and the anterior leg on the RU point. A final horizontal orientation of the cast was then made by means of the adjustable platform. The crest of the residual alveolar ridge was then marked on the cast by moving the horizontal graphite rod along the residual alveolar ridge from one Notch Point to the other (Fig. 33). The line made by the graphite rod was the Crest Line. On casts in which the Crest Line was interrupted by an uneven residual alveolar ridge (Fig. 34) the Crest Line was marked midway between the broken lines.

This completed the marking of points and the cast was transferred to the measuring instrument. The horizontal level of the instrument base was checked by spirit levels and the cast was secured to the adjustable platform. The reference plane of the cast was oriented to the horizontal by the spirit level positioned on the RU point and Notch Points (Fig. 35). The sliding plate was moved to check that the point of a stylus lay on the RU point and the Posterior Midpoint (Fig. 36). This ensured that the median sagittal plane of the cast coincided with the sagittal plane of the instrument. The point of the stylus was then laid in turn on the RU point and the Notch Points and readings were made from the vertical millimetre scale as a further check to ensure that the reference plane of the cast was oriented to the horizontal plane.

The point of the stylus was returned to the RU point and readings from the three millimetre scales on the instrument were made and recorded on a specially prepared printed sheet. Thus the horizontal, sagittal and coronal co-ordinates of the RU point were recorded and all subsequent readings were made relative to this point.

The following measurements of each cast were then made :

1. Vertical measurements from the horizontal reference plane to :
   - i. the point of intersection of the Crest Line with the median sagittal plane.
   - ii. the points of intersection of the Crest Line on the right and left sides of the cast with the coronal plane through the RU point and coronal planes at

10 mm. horizontal intervals from the RU point (Fig. 37).

iii. the surface of the palate at the points of intersection of the median sagittal plane with coronal planes at 10 mm. horizontal intervals from the RU point (Fig. 38).

2. Width measurements

i. between the points of intersection of the Crest Line with the coronal plane through the RU point and with coronal planes at 10 mm. horizontal intervals from the RU point.

ii. maximum width, defined as the maximum measurement between sagittal planes which cut the Crest Line on the right and left sides of the cast. The measurement was made in the coronal plane.

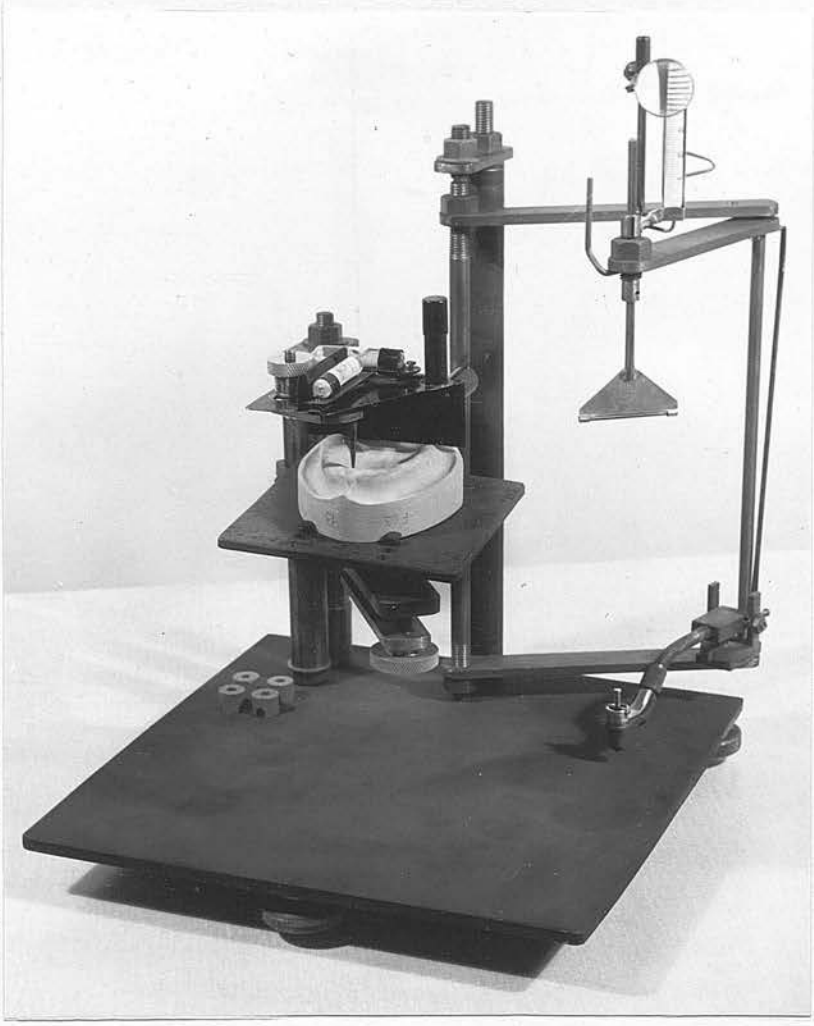
3. Length measurements in the median sagittal plane from the point of intersection of the Crest Line with the median sagittal plane to :

i. the coronal plane through the RU point.

ii. the coronal plane through the more posterior of the two Notch Points. This measurement was called the maximum length of the cast.

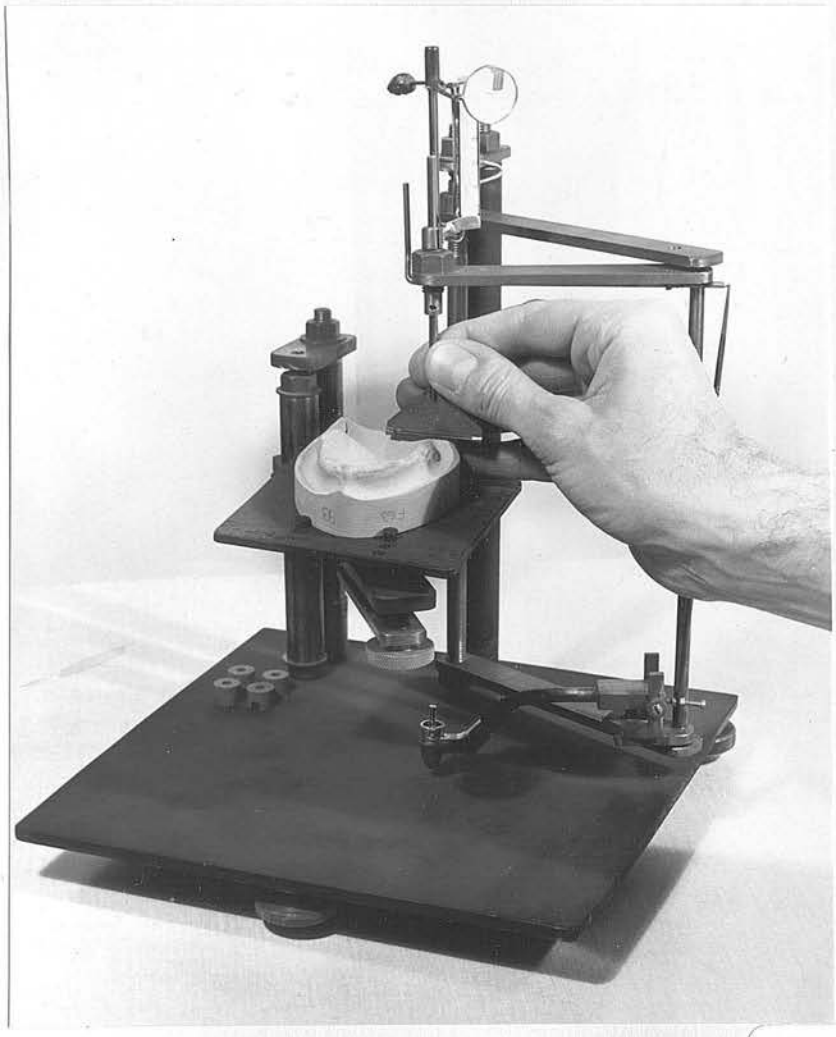
Vertical measurements were made to the nearest 0.5 mm.; width and length measurements were made to the nearest whole millimetre (.5 mm. read as 1 mm.).

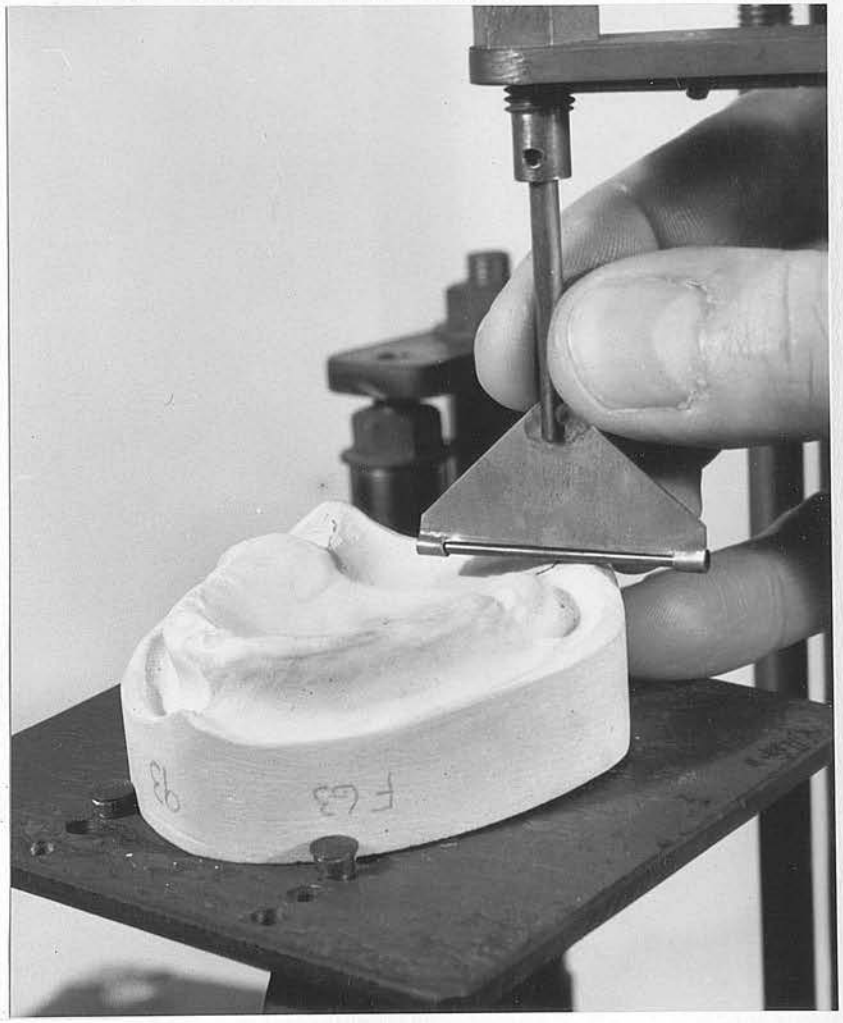
The sagittal and coronal planes in which the above measurements were made are shown diagrammatically in Fig. 29 .



Edentulous maxillary cast secured to tracing instrument.

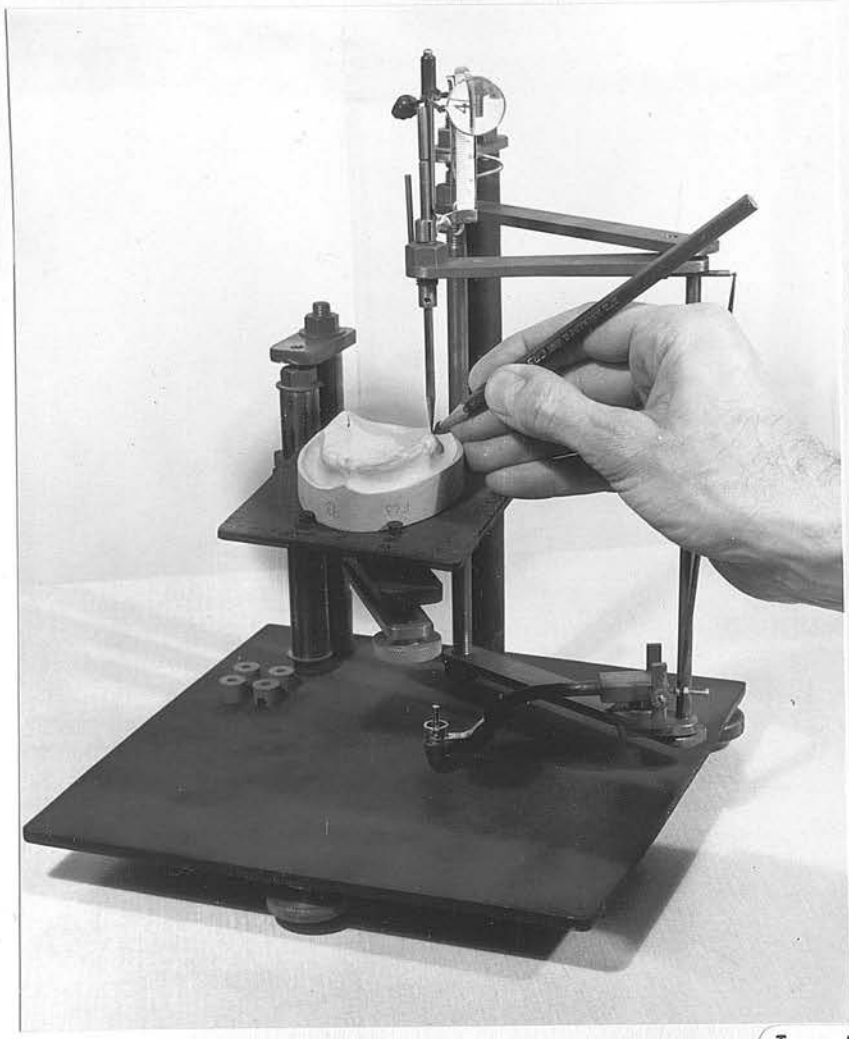
Fig. 30

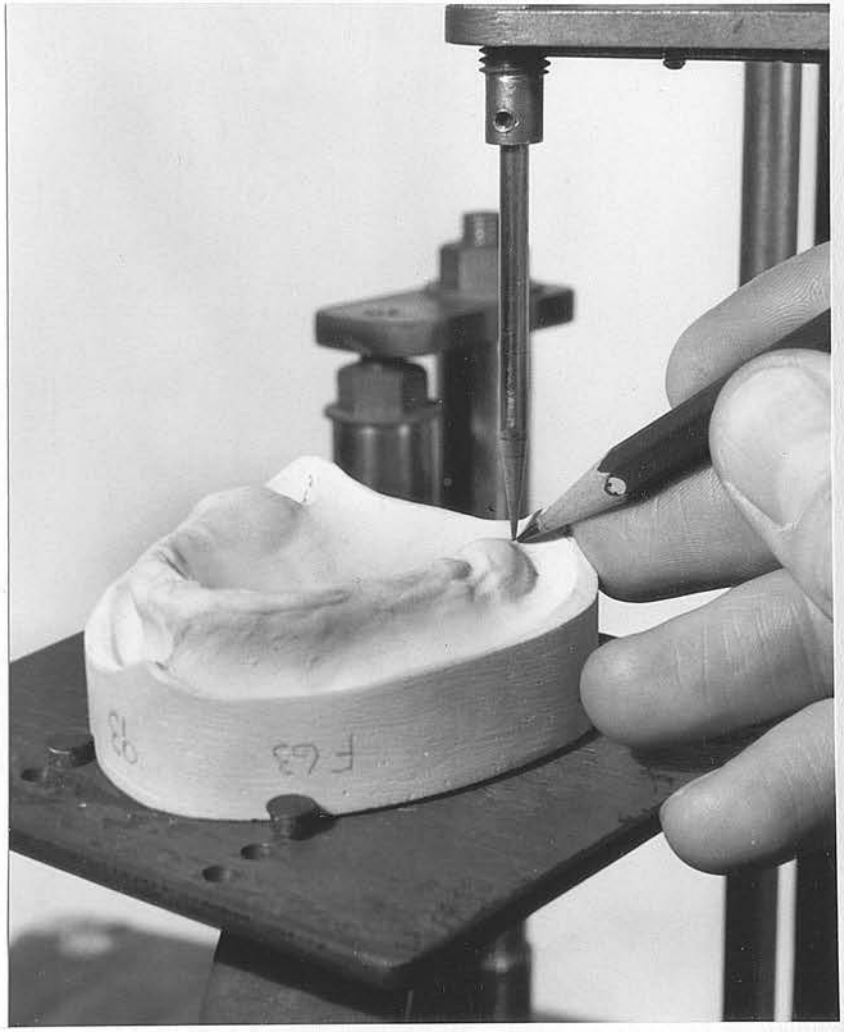




Marking the crescentic ridges.

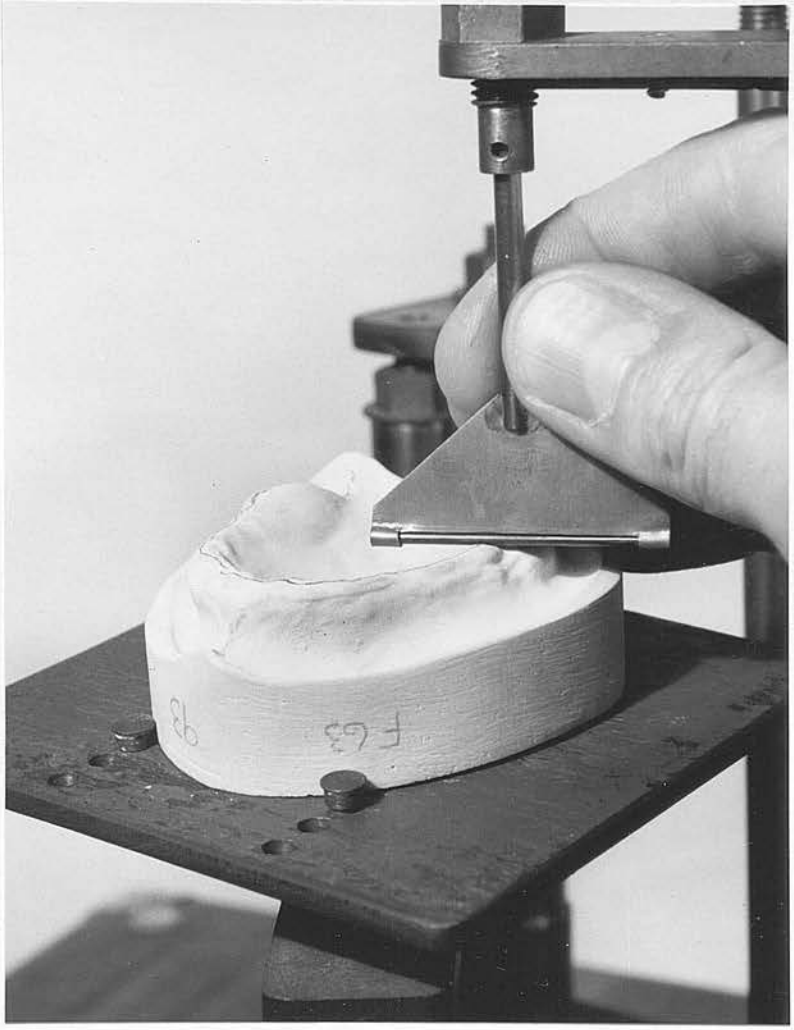
Fig. 31





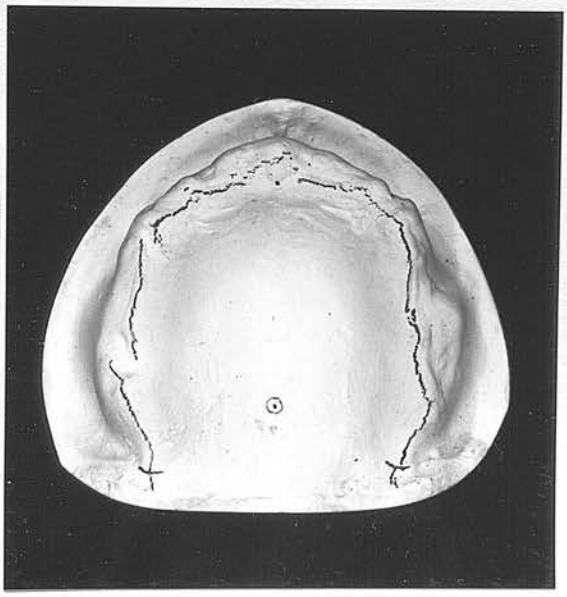
Locating and marking the Notch Points.

Fig. 32



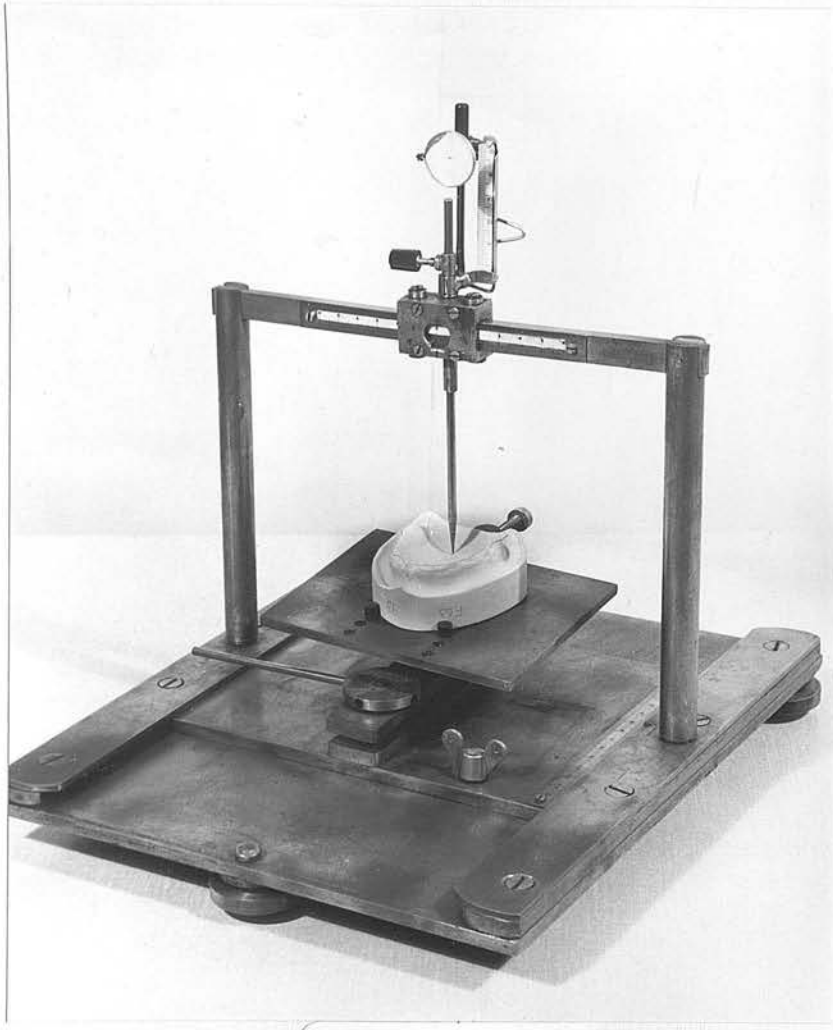
Marking the Crest Line.

Fig. 33



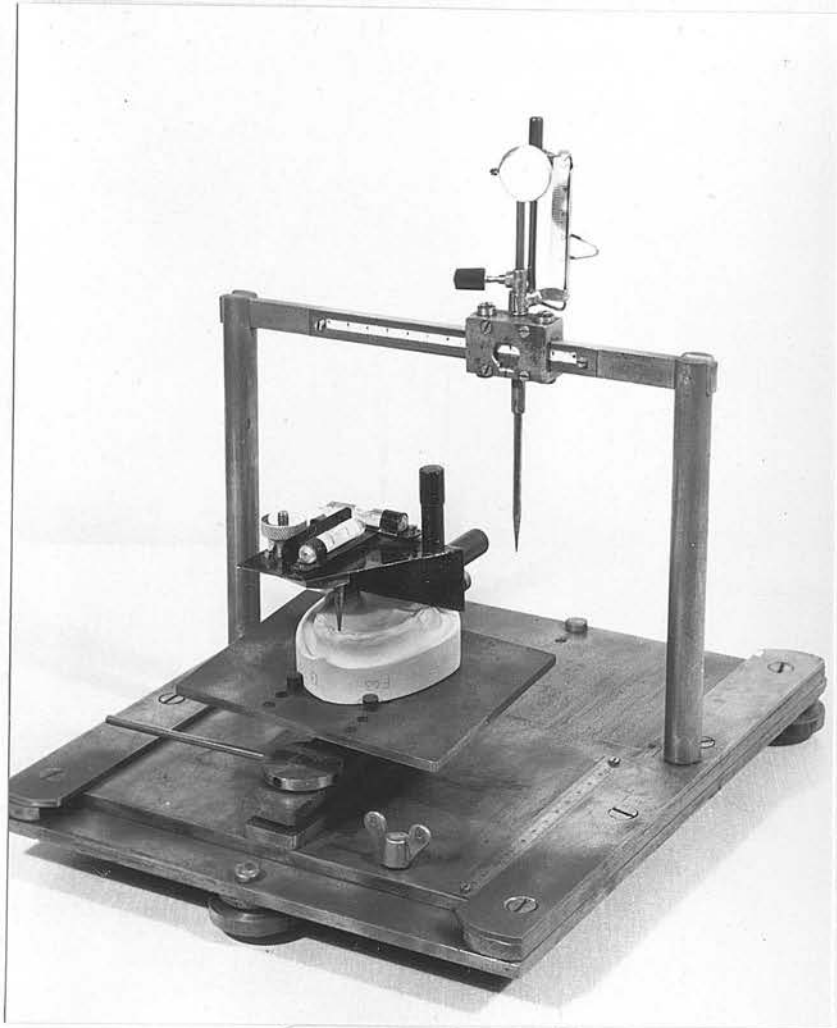
Edentulous maxillary cast on which the Crest Line is interrupted.

Fig. 34



Point of stylus on Posterior Midpoint.

Fig. 36



Edentulous maxillary cast secured to measuring instrument.

Fig. 35

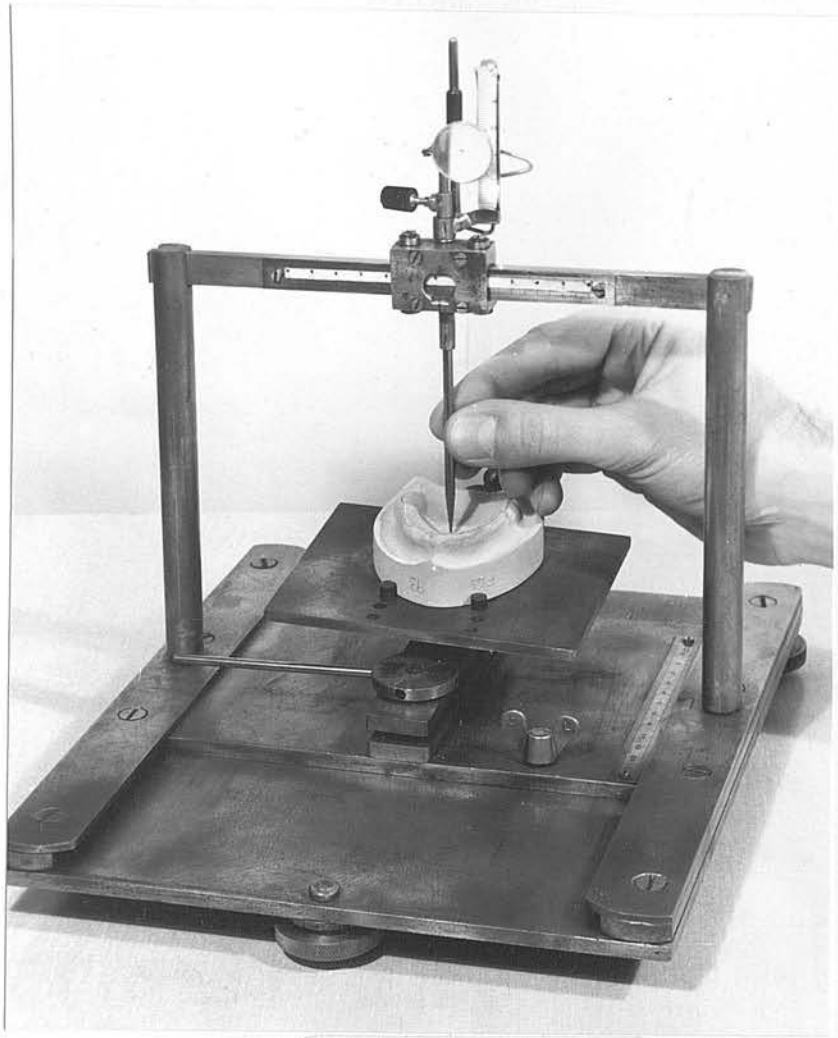
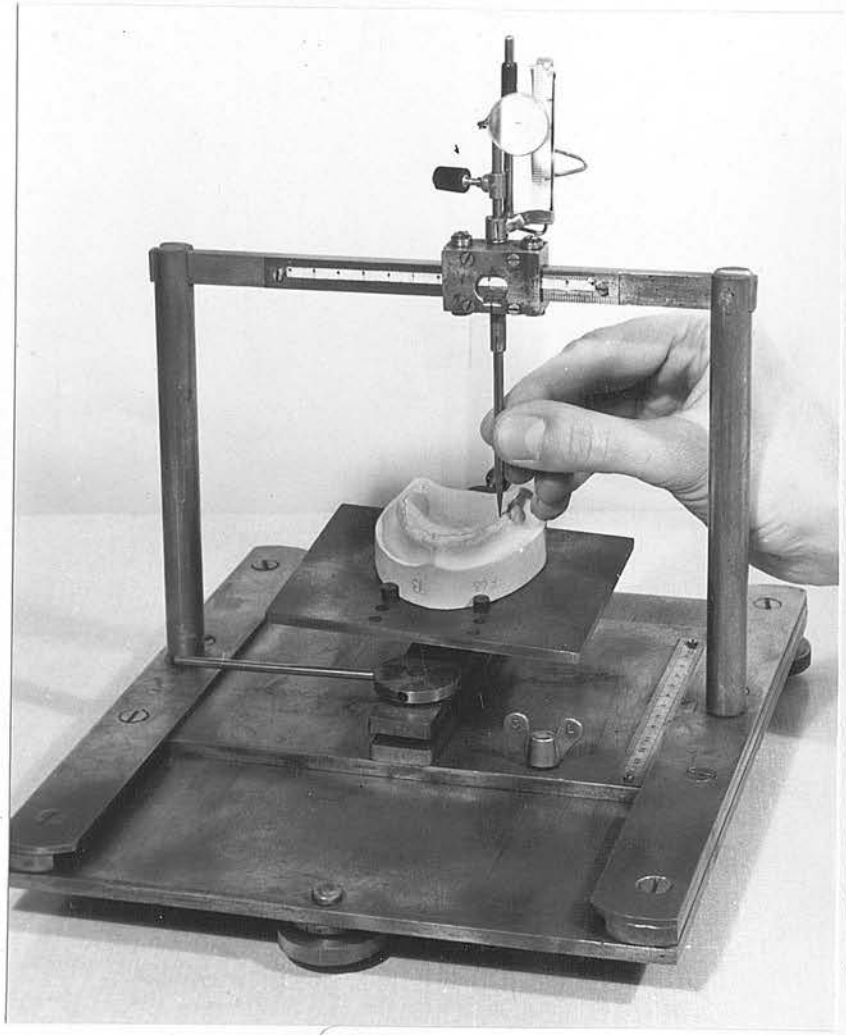


Fig. 38

Point of stylus on the palate in the median sagittal plane.



Point of stylus on the Crest Line.

Fig. 37

DENTULOUS MANDIBULAR CASTS

1. Direct measurement of the Dentulous Mandibular casts

Vertical measurements of the 351 dentulous mandibular casts were made by means of the measuring instrument. The following procedure was used with each cast :

The position of the Mucogingival Lines was marked on the buccal and lingual surfaces.

A pencil mark was made on the crest of the lingual frenum. This mark was the Frenum Point. In most casts the frenum presented as a definite ridge but in those casts where it was broad or fan-shaped, the pencil mark was made midway between the lateral surfaces of the frenum.

The horizontal level of the measuring instrument base was checked by spirit levels and the cast was secured to the adjustable platform. A transverse spirit level, mounted on the cross-piece of a T-shaped brass carrier, was then used to correct the lateral tilt of the cast (Fig. 39). The cross-piece, which was triangular in section, was laid in contact with the trimmed distal edge of each retromolar region; the limb of the carrier contacted the incisal edges of the incisor teeth. The platform was adjusted until the spirit level read zero. A horizontal graphite rod was then moved along the trimmed distal edge of each retromolar region (Fig. 40). The most superior points on the graphite lines were found by means of a straight stylus and vertical millimetre scale and pencil marks were made at these points. These marks were known as the Retromolar Points (Fig. 41).

The Posterior Midpoint was then marked on the cast. A pointed stylus carried a horizontal millimetre scale on which were mounted two vertical sliding needles. The points of the needles were placed on the Retromolar Points equidistant from the middle of the scale. The central stylus was then positioned on the floor of the cast (Fig. 42). A pencil mark was made at this point and ringed for future identification.

The platform, to which the cast was secured, was now adjusted until the median sagittal plane of the cast coincided with the sagittal plane of the instrument. This was checked by moving the sliding plate so that the point of the stylus lay first on the Posterior Midpoint (Fig. 43) and then on the Frenum Point. The transverse spirit level was again used to check the lateral tilt of the cast. The sliding plate was then moved until the point of the stylus contacted the pencilled lingual mucogingival line. At the point of contact, a pencil mark was made (Fig. 44). This mark was the Reference Point (the RL point).

The cast was finally oriented by means of an offset spirit level carrier, the design of which was based on the mean angle of 19.6° between the occlusal plane and the plane through the RL point and Retromolar Points of a random sample of 100 dentulous mandibular casts (this investigation was reported on page 62). Two spirit levels were mounted on a T-shaped brass carrier (Fig. 45). A vertical L-shaped brass rod was soldered to the cross-piece of the carrier. A sliding leg, which ended in a pointed shoe, was attached

to the rod. The cross-piece of the carrier, which was triangular in section, was laid in contact with the Retromolar Points. The point of the shoe was laid on the RL point. The platform to which the cast was secured was now adjusted until the spirit levels read zero (Fig. 46). This ensured that, because of the design of the spirit level carrier, the reference plane through the RL point and the Retromolar Points of each cast was oriented at an angle of 19.6° to the horizontal plane.

The sliding plate was again moved backwards and forwards to check that the point of the stylus lay on both the RL point and the Posterior Midpoint thus ensuring that the median sagittal plane of the cast still coincided with the sagittal plane of the measuring instrument.

This completed the marking of points (Fig. 47) and the orientation of the cast and direct vertical measurements were then made, to the nearest 0.5 mm., on each cast. The point of the stylus was placed on the RL point (Fig. 48) and readings from the three millimetre scales on the instrument were made and recorded on a specially prepared printed sheet. Thus the horizontal, sagittal and coronal co-ordinates of the RL point were recorded and all subsequent readings were made relative to this point.

The stylus was moved along the gantry and a reading on the vertical millimetre scale was made and recorded with the point of the stylus in contact with the buccal mucogingival line on one side of the cast (Fig. 49). A reading was made in a similar manner on the other side of the cast.

Thus vertical measurements from the buccal mucogingival line to a horizontal plane through the RL point of the cast were made in a coronal plane passing through the RL point.

The sliding plate was then moved in intervals of 10 mm., at each interval the point of the stylus being laid on the buccal and lingual mucogingival line on each side of the cast (Fig. 50). Readings of the vertical millimetre scale were made and recorded at each stylus position. The number of coronal planes in which it was possible to make vertical measurements was limited by the length of the cast. In each cast the posterior limit of measurement was the more posterior of the two Retromolar Points and no measurement was made posterior to this point.

Finally the sliding plate was moved until the stylus point lay on the buccal mucogingival line in the median sagittal plane. A reading of the vertical millimetre scale was made.

Thus on each dentulous mandibular cast vertical measurements were made from the horizontal plane through the RL point to :

i. the point of intersection of the buccal mucogingival line with the median sagittal plane.

ii. the points of intersection of the buccal mucogingival line on the right and left sides of the cast with the coronal plane through the RL point and coronal planes at 10 mm. horizontal intervals from the RL point.

iii. the points of intersection of the lingual mucogingival line on the right and left sides of the cast with coronal planes at 10 mm. horizontal intervals from the RL point.

The sagittal and coronal planes in which the above measurements were made are shown diagrammatically in Fig. 51 .

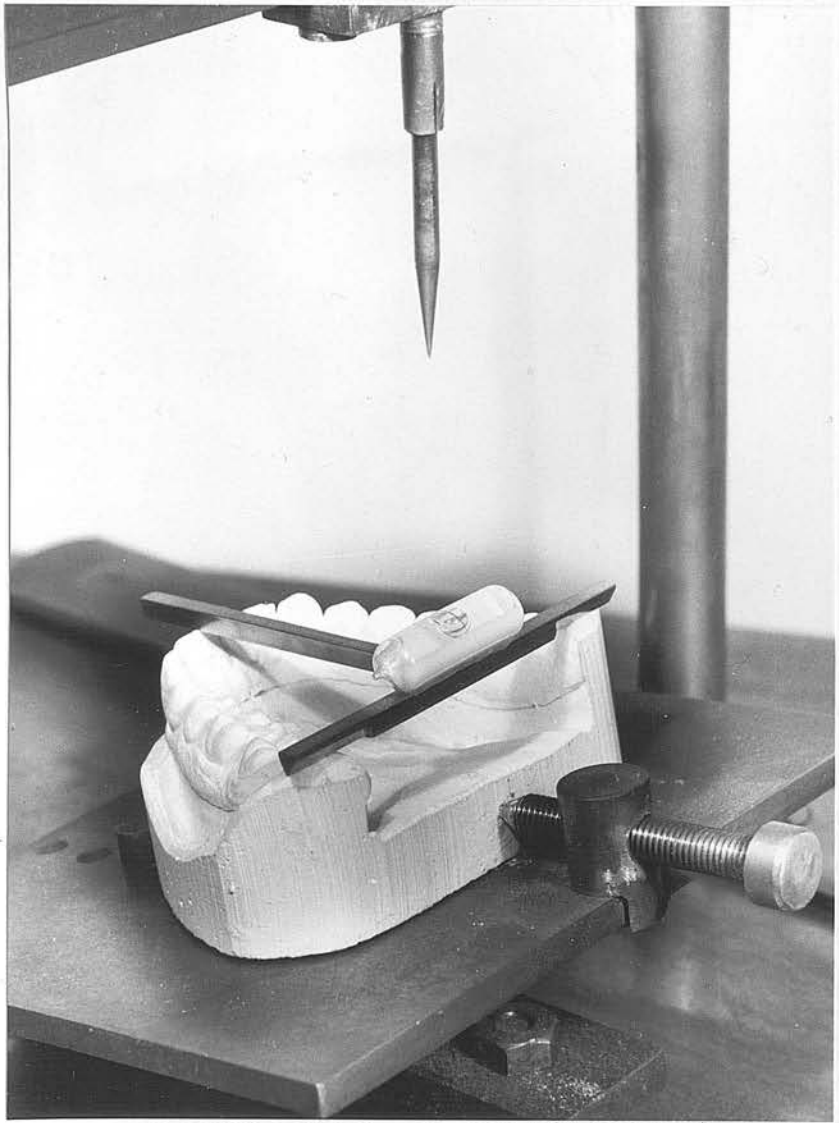
2. <u>The method of making traces of the Dentulous Mandibular casts</u>

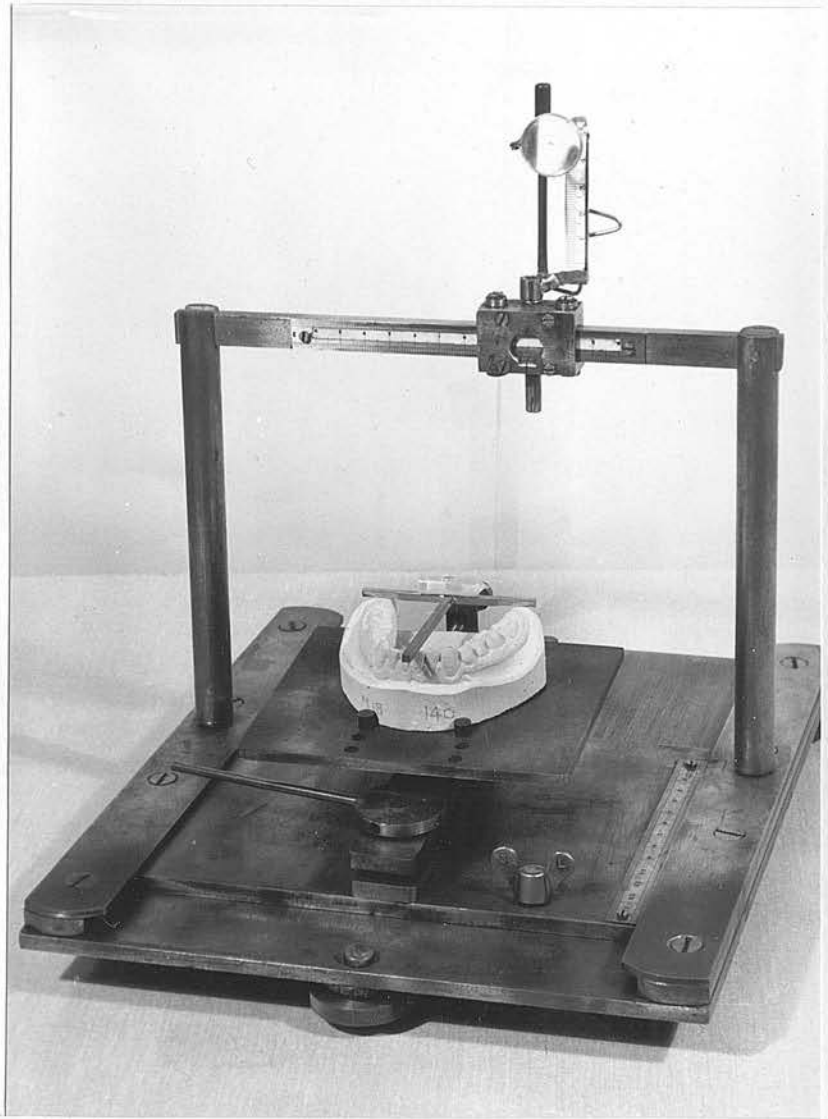
The following procedure was used with each of the 351 dentulous mandibular casts in order to produce a trace of the projection of the buccal and lingual mucogingival lines on the horizontal plane :

The horizontal level of the tracing instrument base was checked by spirit levels and the cast was secured to the adjustable platform. The cast was oriented by means of the offset spirit level carrier which ensured that the reference plane through the RL point and the Retromolar Points of the cast lay at an angle of 19.6° to the horizontal plane (Fig. 52).

The sickle stylus was tracked along the mucogingival line in contact with the buccal and lingual surfaces of the cast (Fig. 53). The pen scribed a line on the tracing paper (Fig. 54). The sickle stylus was then replaced by a straight stylus which was laid in turn on the RL point, the Posterior Midpoint and the Retromolar Points. These points were marked on the tracing paper. The number of the cast was recorded on the tracing paper and a note made of the right and left sides.

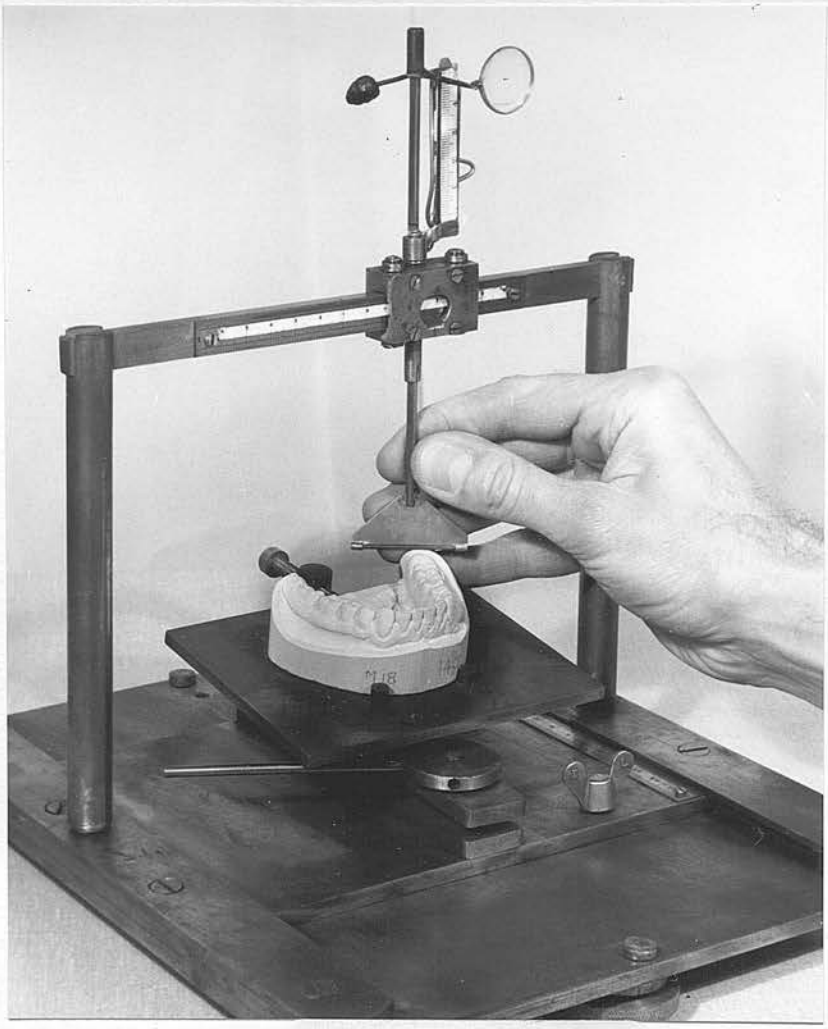
This trace (Fig. 55) was a projection of the buccal and lingual mucogingival lines of the cast on the horizontal plane.





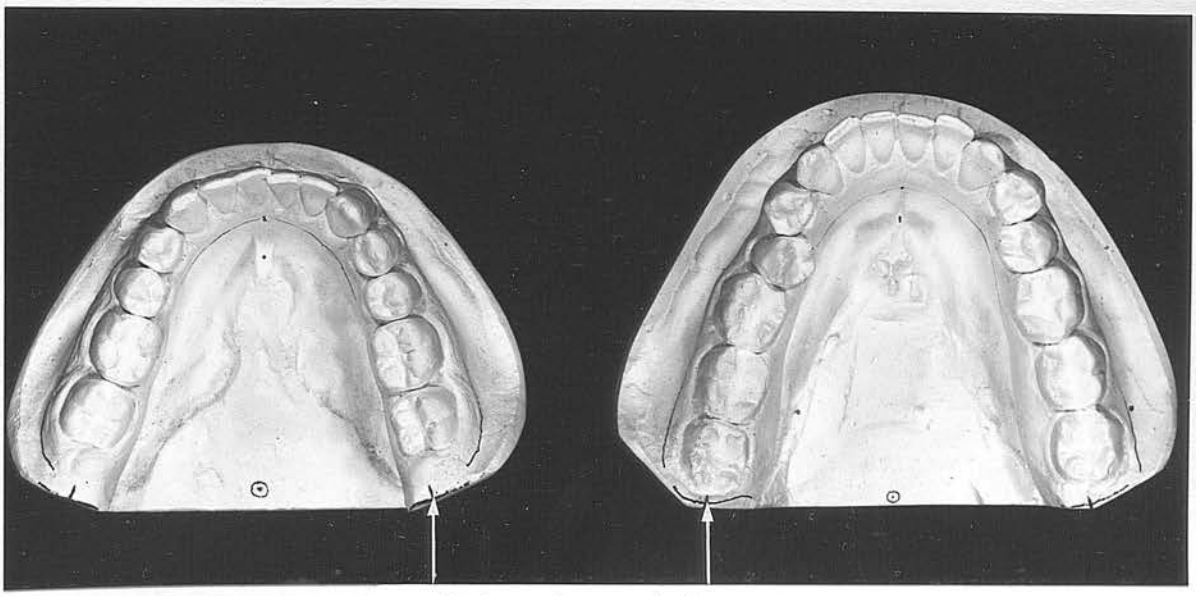
The transverse spirit level used to correct the lateral tilt of a mandibular cast.

Fig. 39



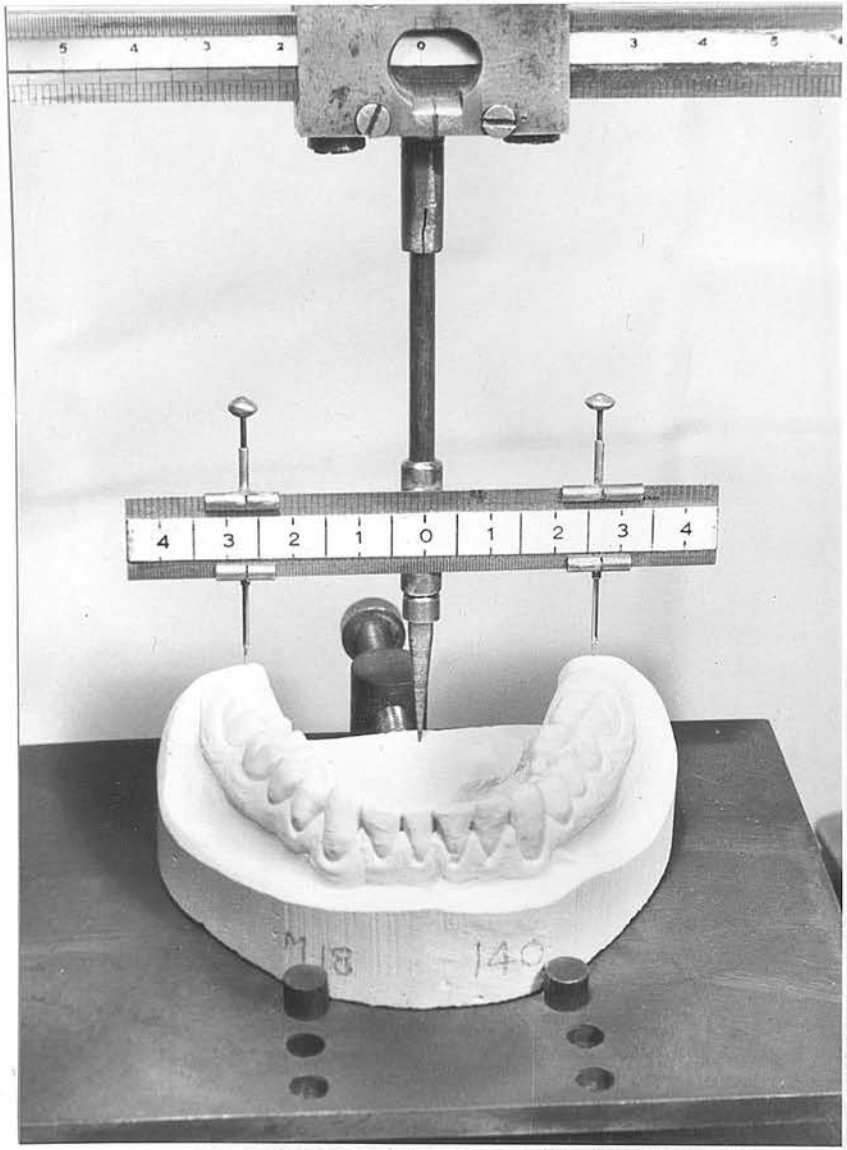
Marking the distal edge of the retromolar region prior to locating the Retromolar Point.

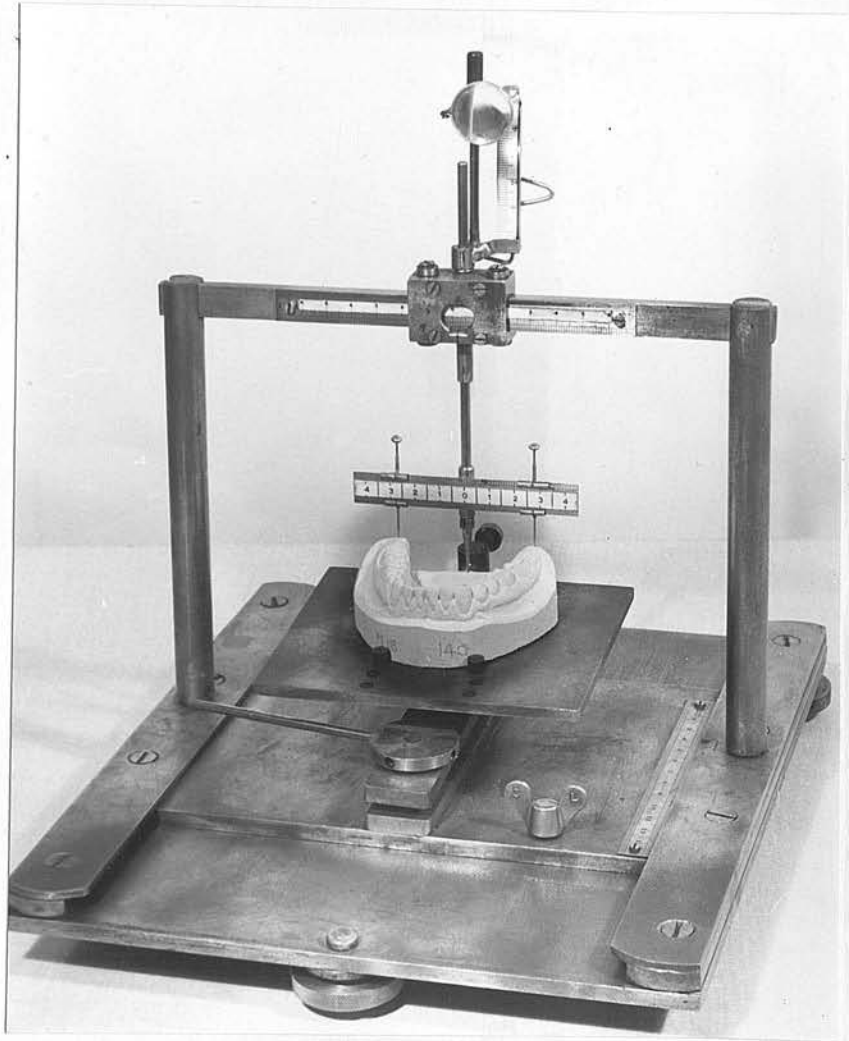
Fig. 40



Retromolar points

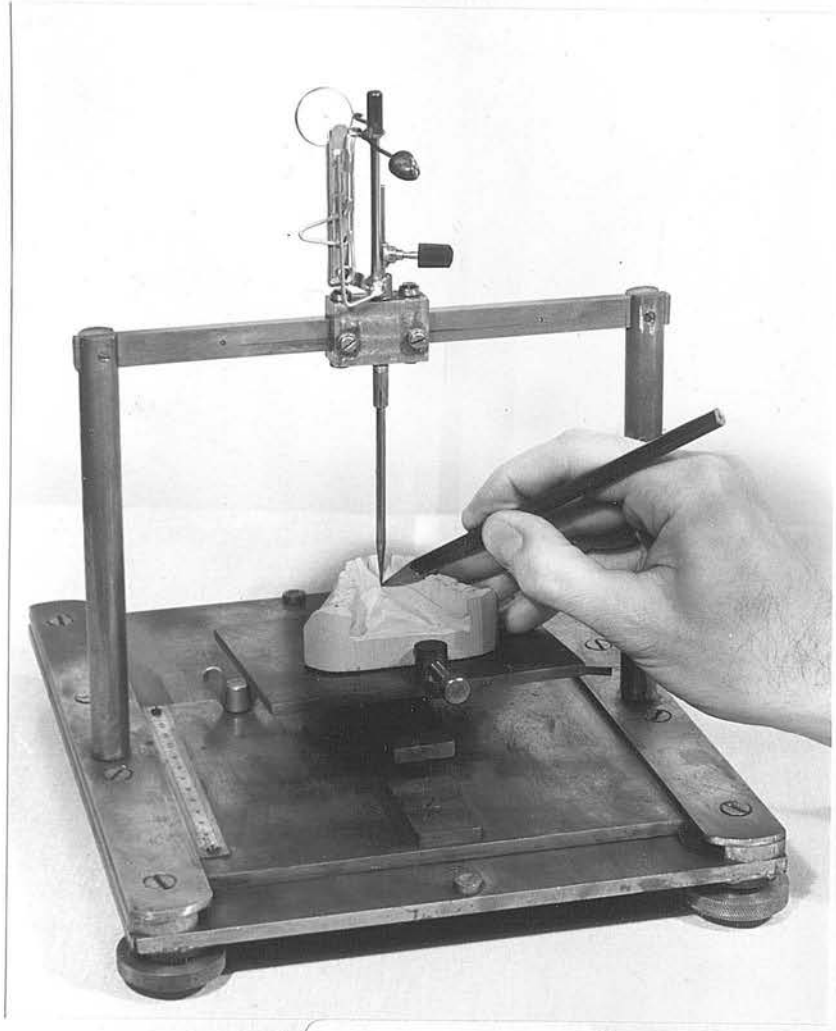
Fig. 41





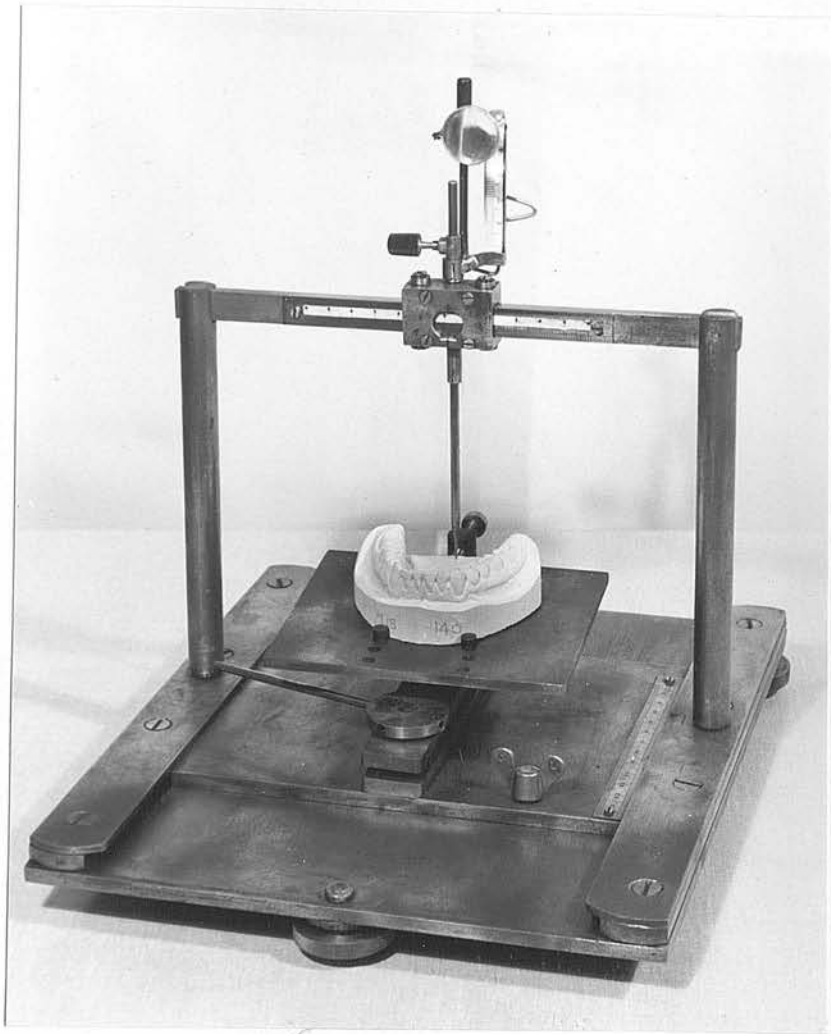
Locating the Posterior Midpoint.

Fig. 42



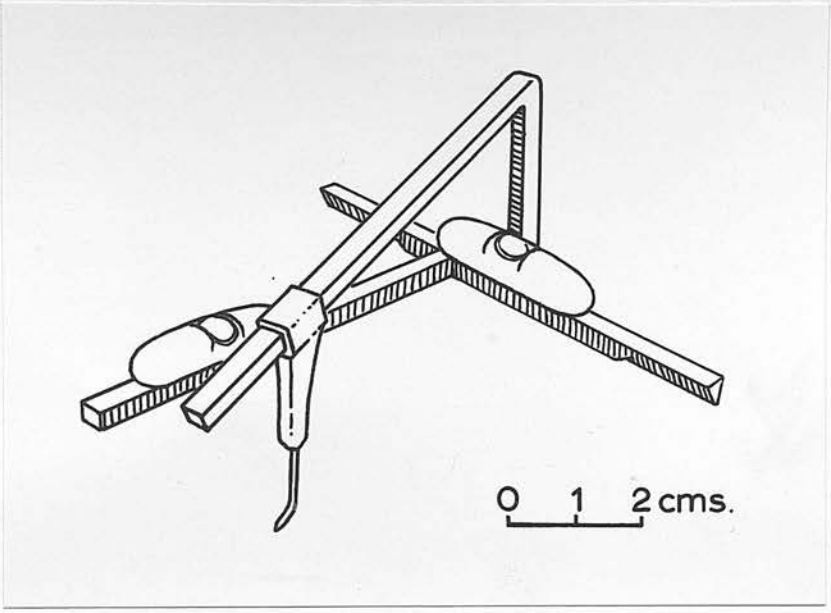
Marking the RL point.

Fig. 44



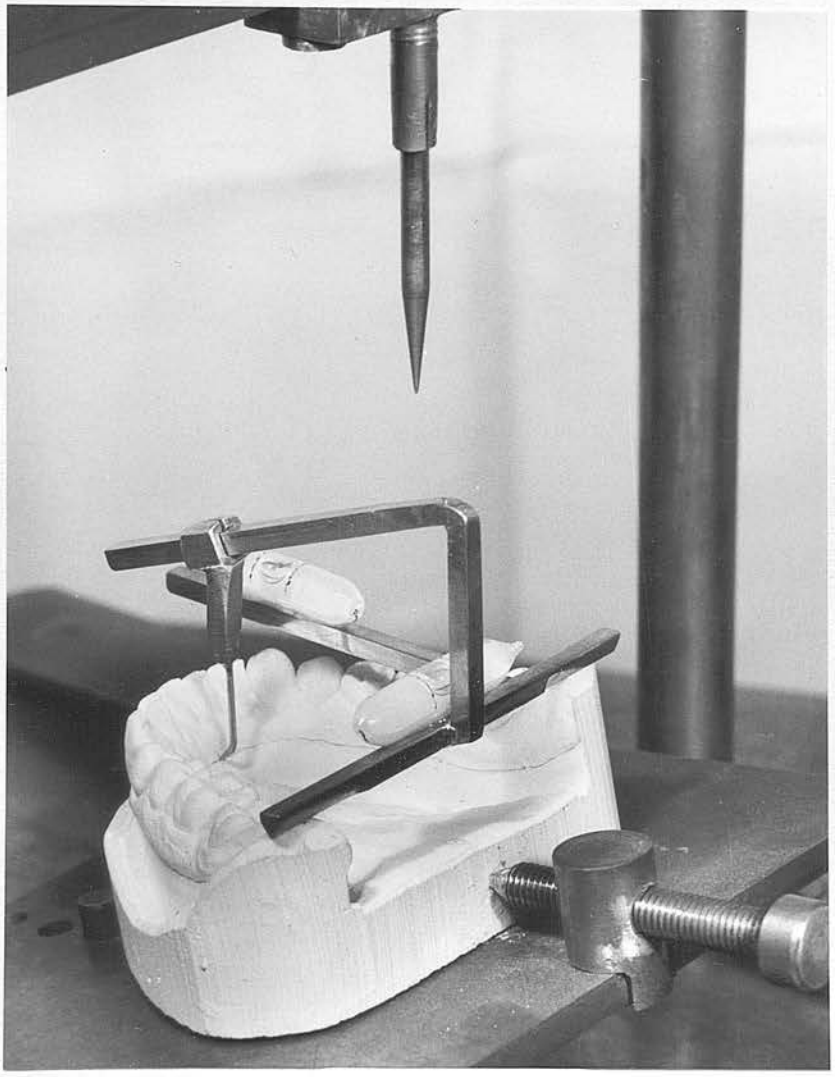
Point of stylus on the Posterior Midpoint.

Fig. 43



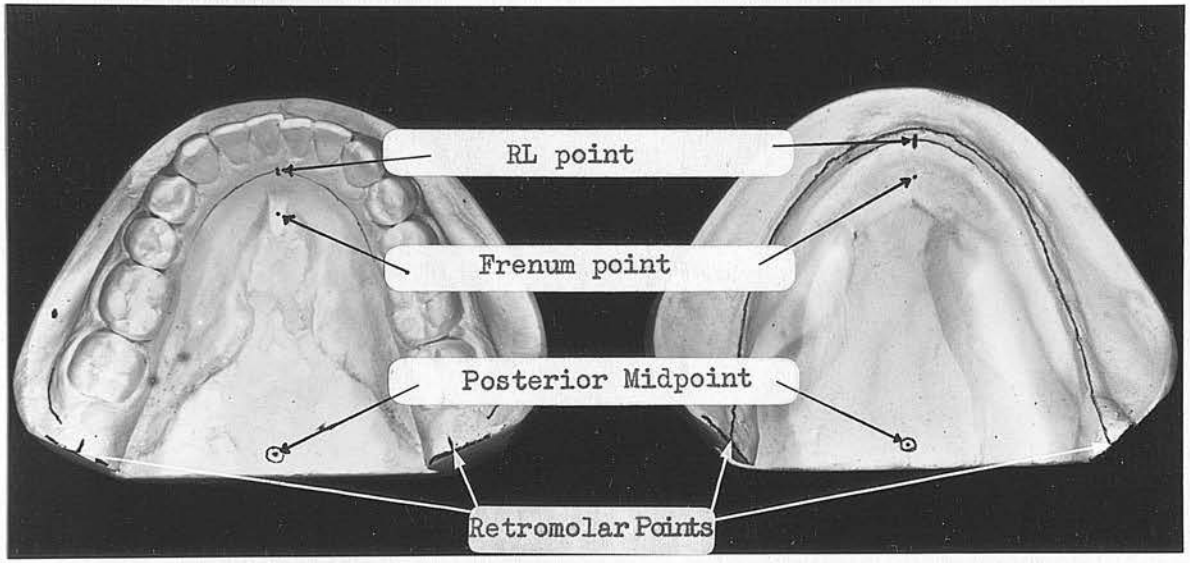
Spirit level used for orienting mandibular casts.

Fig. 45



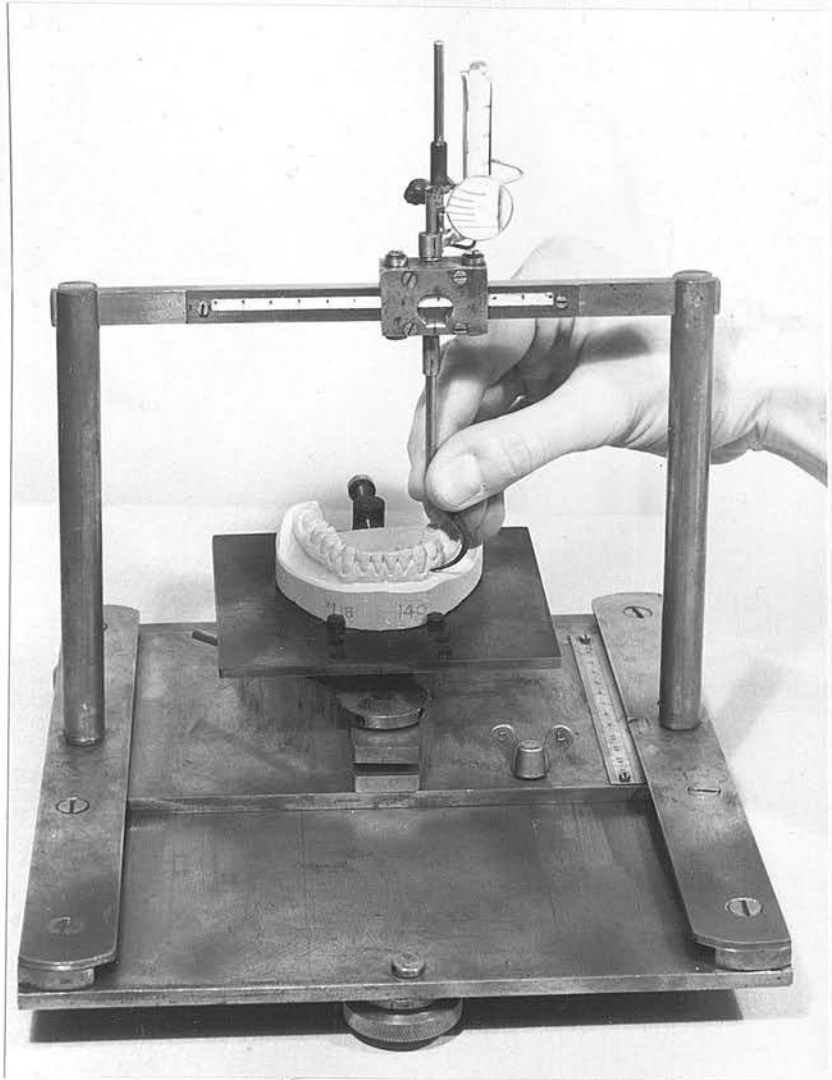
Spirit level on RL point and Retromolar points.

Fig. 46



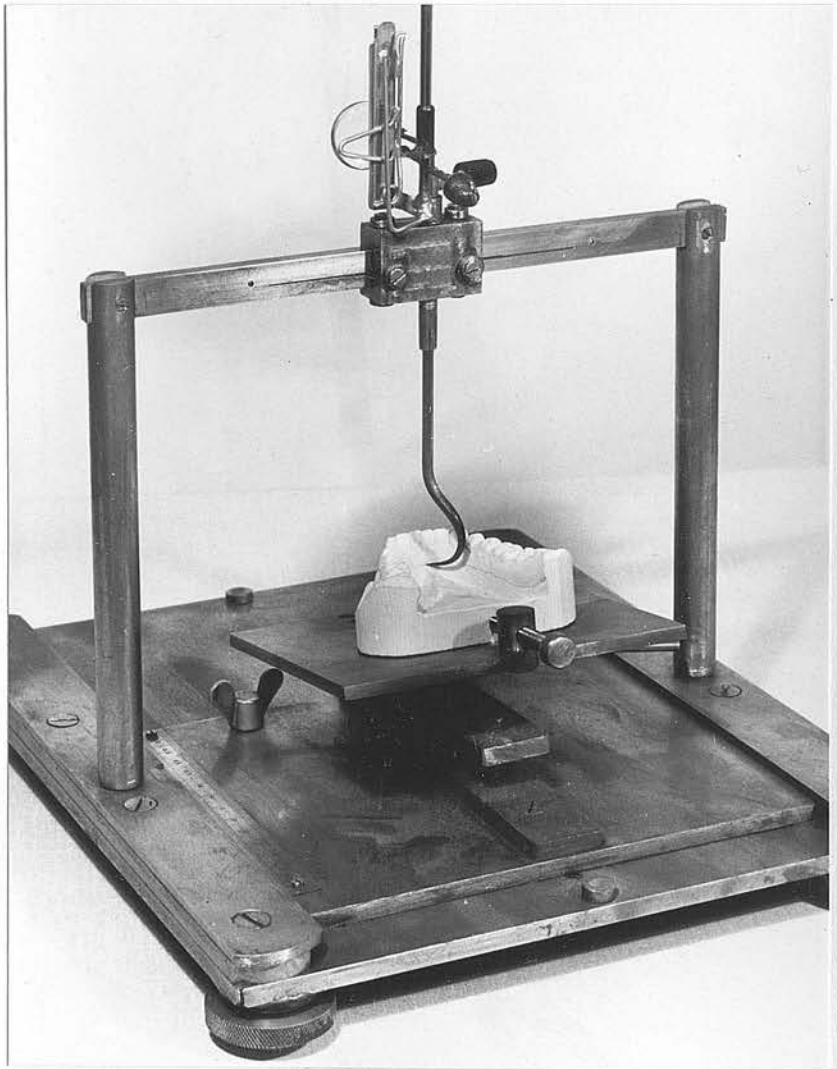
Points marked on mandibular casts.

Fig. 47



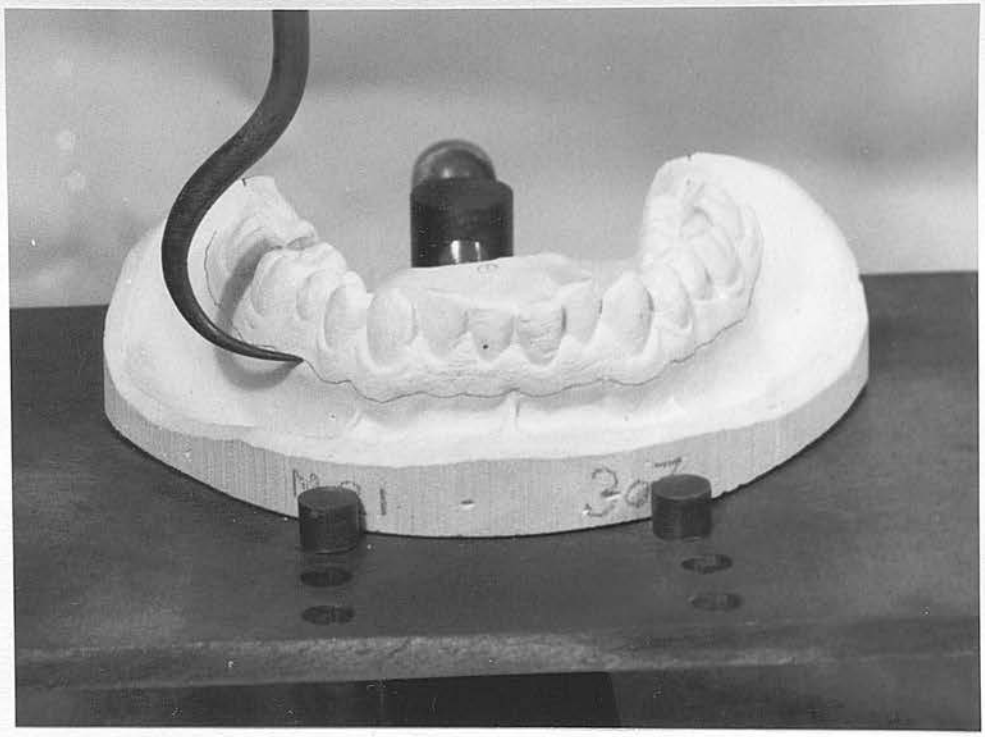
Point of stylus on the muco-gingival line.

Fig. 49



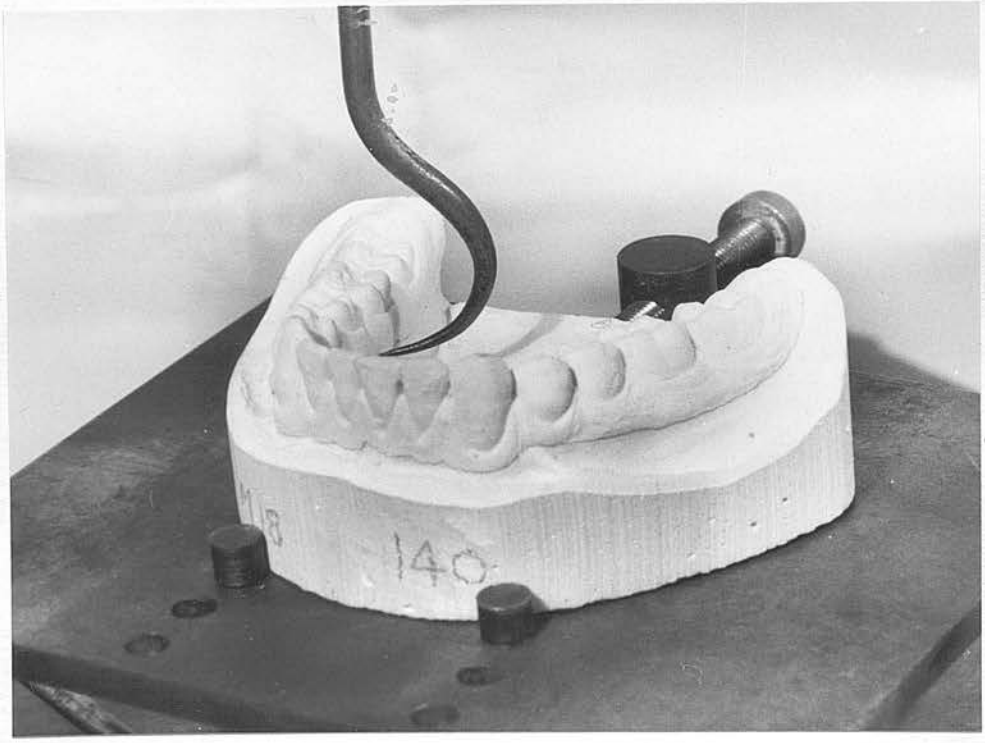
Point of stylus on RL point.

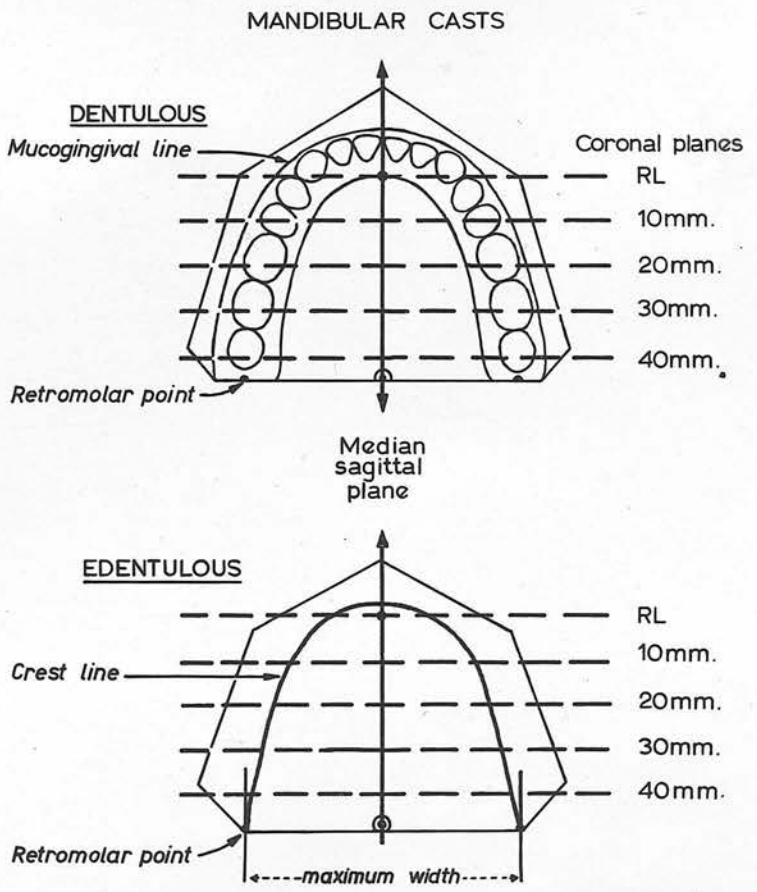
Fig. 48



Point of stylus on the buccal and lingual mucogingival line.

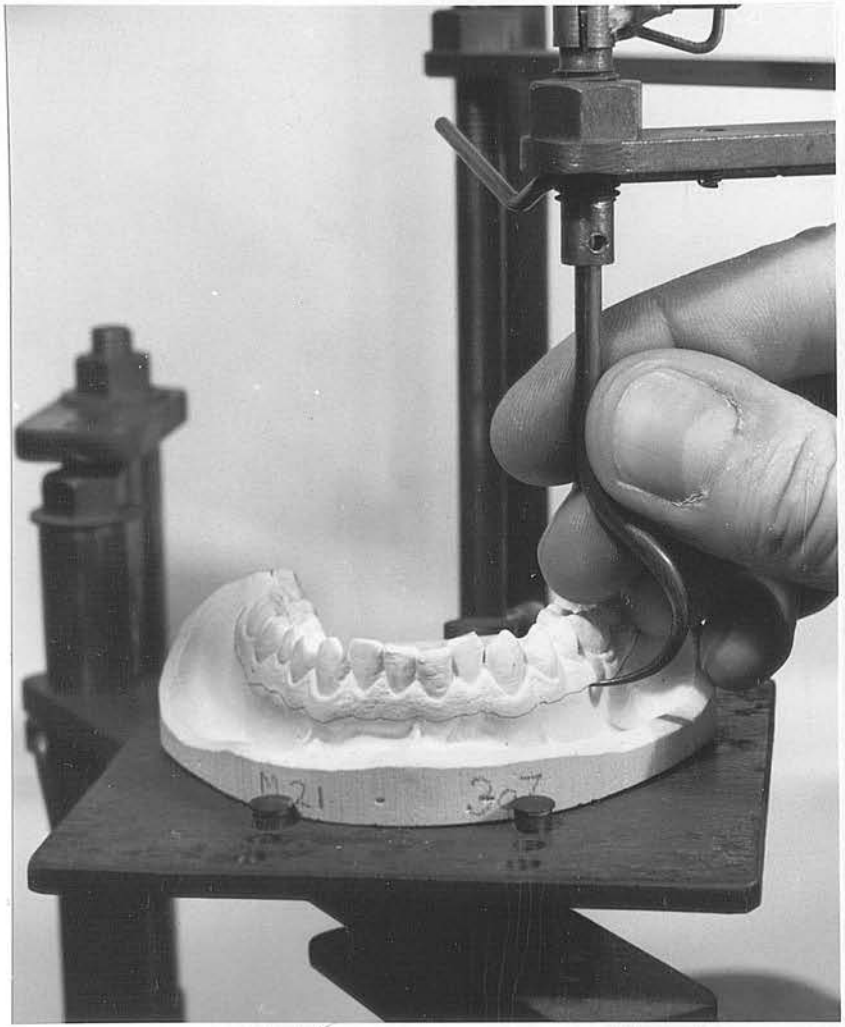
Fig. 50





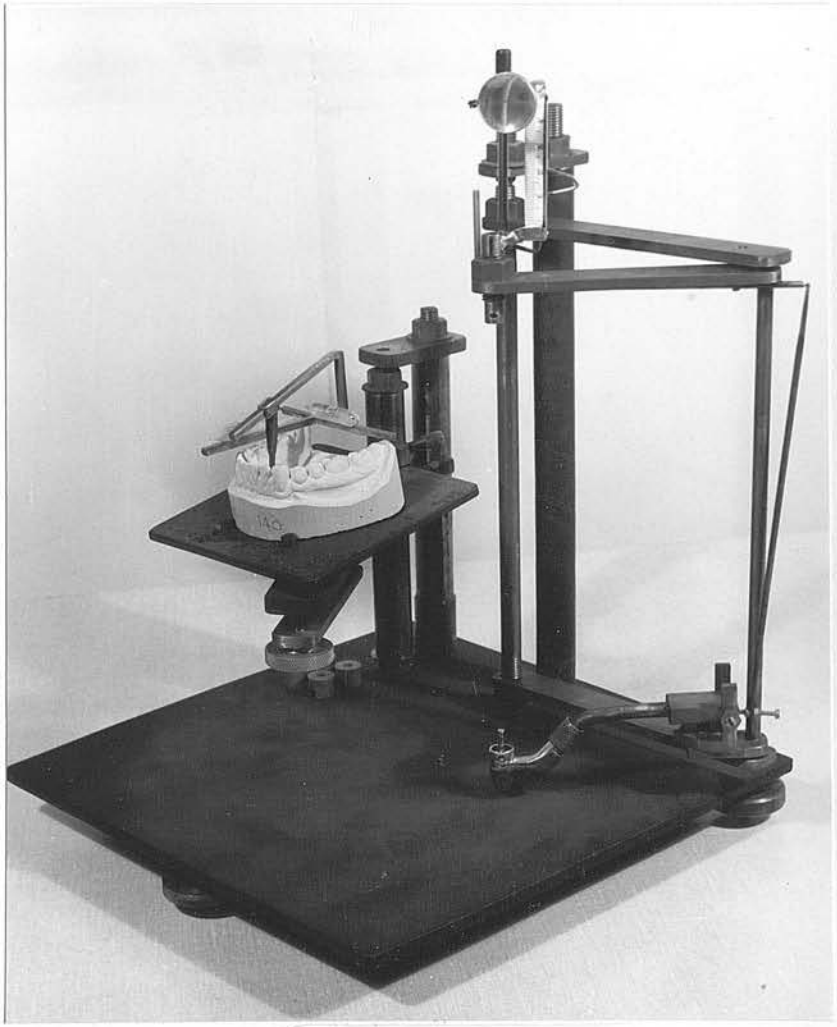
DIAGRAMS SHOWING SAGITTAL & CORONAL PLANES IN WHICH DIRECT MEASUREMENTS WERE MADE

Fig. 51



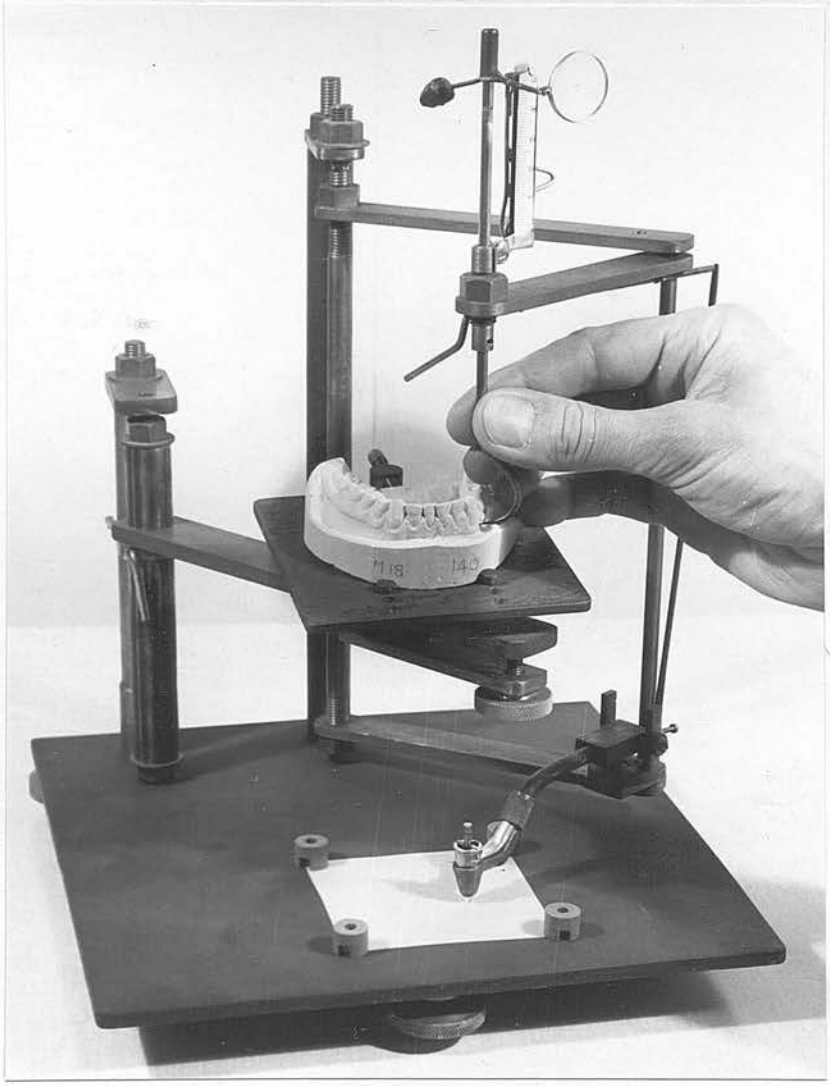
Point of stylus on the muco-gingival line.

Fig. 53



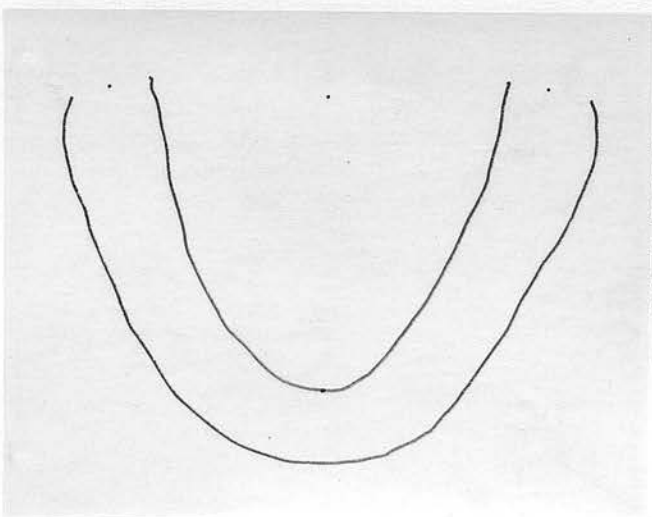
Dentulous mandibular cast secured to tracing instrument.

Fig. 52



Tracing along the mucogingival line

Fig. 54



Trace of the projection of the buccal and lingual mucogingival lines of a dentulous mandibular cast on the horizontal plane.

Fig. 55

EDENTULOUS MANDIBULAR CASTS

Direct measurement of the casts

Direct measurements were made of each of the 300 edentulous mandibular casts. The following procedure was used :

On each cast the position of the Mucogingival Line in the anterior lingual region was marked with a sharp pencil. The Frenum Point was marked on the crest of the lingual frenum.

The horizontal level of the measuring instrument base was checked by spirit levels and the cast was secured to the adjustable platform. The transverse spirit level was used to correct the lateral tilt of the cast (Fig. 56). The cross-piece was laid in contact with the trimmed distal edge of each retromolar region. The platform was adjusted until the spirit level read zero. The Retromolar Points and the Posterior Midpoint were located and marked in the same way as on dentulous mandibular casts (Figs. 57 58).

The platform, to which the cast was secured, was now adjusted until the median sagittal plane of the cast coincided with the sagittal plane of the instrument. This was ensured by moving the sliding plate and checking that the point of a stylus contacted first the Posterior Midpoint and then the Frenum Point. The transverse spirit level was again used to check the lateral tilt of the cast. The sliding plate was then moved until the point of the stylus contacted the pencilled lingual mucogingival line. At the point of contact, a pencil mark was made (Fig. 59). This mark was the Reference Point (the RL point).

The cast was finally oriented by means of the offset spirit level (Fig. 60) which ensured that the reference plane through the RL point and the Retromolar Points of each cast was oriented at an angle of 19.6° to the horizontal plane.

The crest of the residual alveolar ridge was then marked by means of the horizontal graphite rod mounted on a stylus. The sliding plate was moved so that the graphite marked the crest of the ridge (Fig. 61). The line made by the graphite rod was known as the Crest Line.

The horizontal graphite rod was replaced by the stylus and the sliding plate was again moved to check that the point of the stylus lay on both the RL point and the Posterior Midpoint, thus ensuring that the median sagittal plane of the cast coincided with the sagittal plane of the instrument.

The point of the stylus was returned to the RL point and readings from the three millimetre scales on the instrument were made and recorded on a specially prepared printed sheet. Thus the horizontal, sagittal and coronal co-ordinates of the RL point were recorded and all subsequent readings were made relative to this point.

The following measurements of each cast were then made :

1. Vertical measurements from the horizontal plane through the RL point to :
   - i. the point of intersection of the Crest Line with the median sagittal plane.
   - ii. the points of intersection of the Crest Line on the right and left sides of the cast with the coronal plane through the RL point and coronal planes at 10 mm. horizontal intervals from the RL point (Fig. 62).

2. Width measurements

   i. between the points of intersection of the Crest Line with the coronal plane through the RL point and with coronal planes at 10 mm. horizontal intervals from the RL point.

   ii. maximum width, defined as the maximum measurement between sagittal planes which cut the Crest Line on the right and left sides of the cast. The measurement was made in the coronal plane.

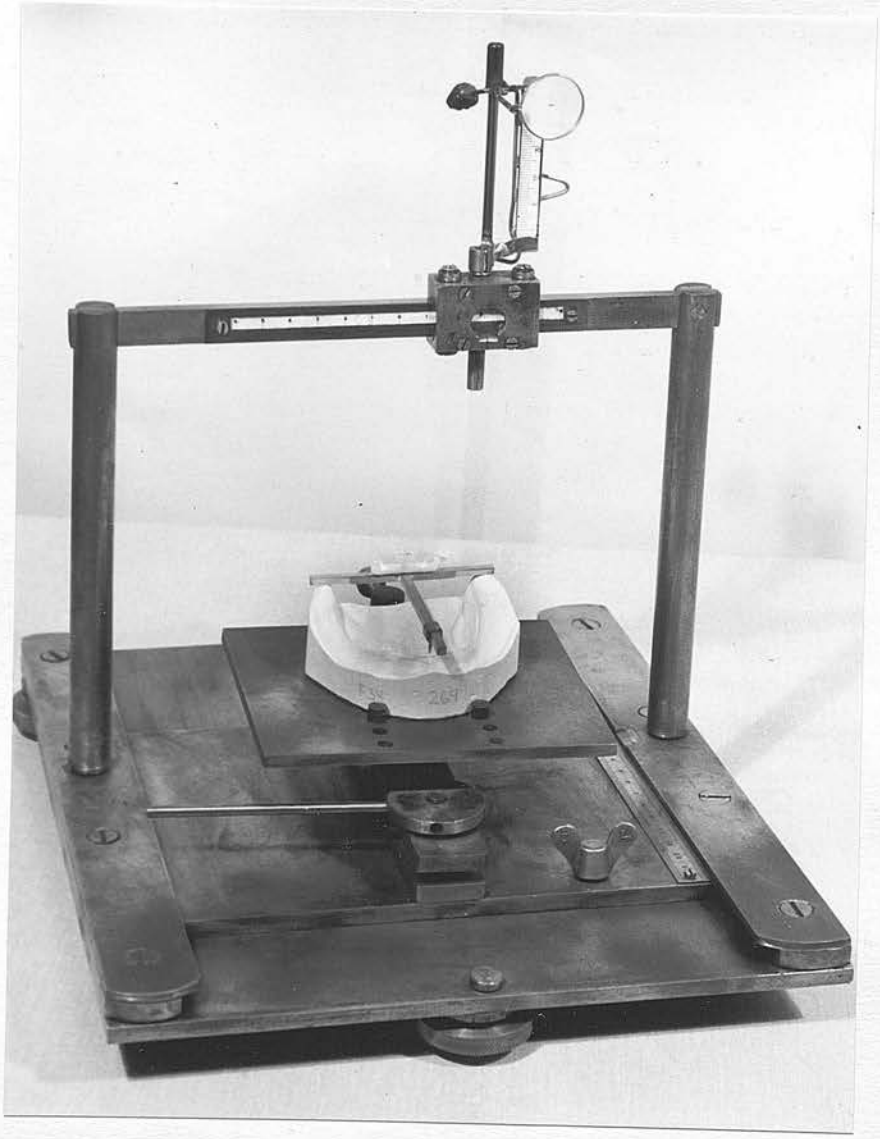
3. Length measurements in the median sagittal plane from the point of intersection of the Crest Line with the median sagittal plane to :

   i. the coronal plane through the RL point.

   ii. the coronal plane through the more posterior of the two Retromolar Points. This measurement was called the maximum length of the cast.

Vertical measurements were made to the nearest 0.5 mm.; width and length measurements were made to the nearest whole millimetre (.5 mm. read as 1 mm.).

The sagittal and coronal planes in which the above measurements were made are shown diagrammatically in Fig. 51 .



The transverse spirit level used to correct the lateral tilt of a mandibular cast.

Fig. 56

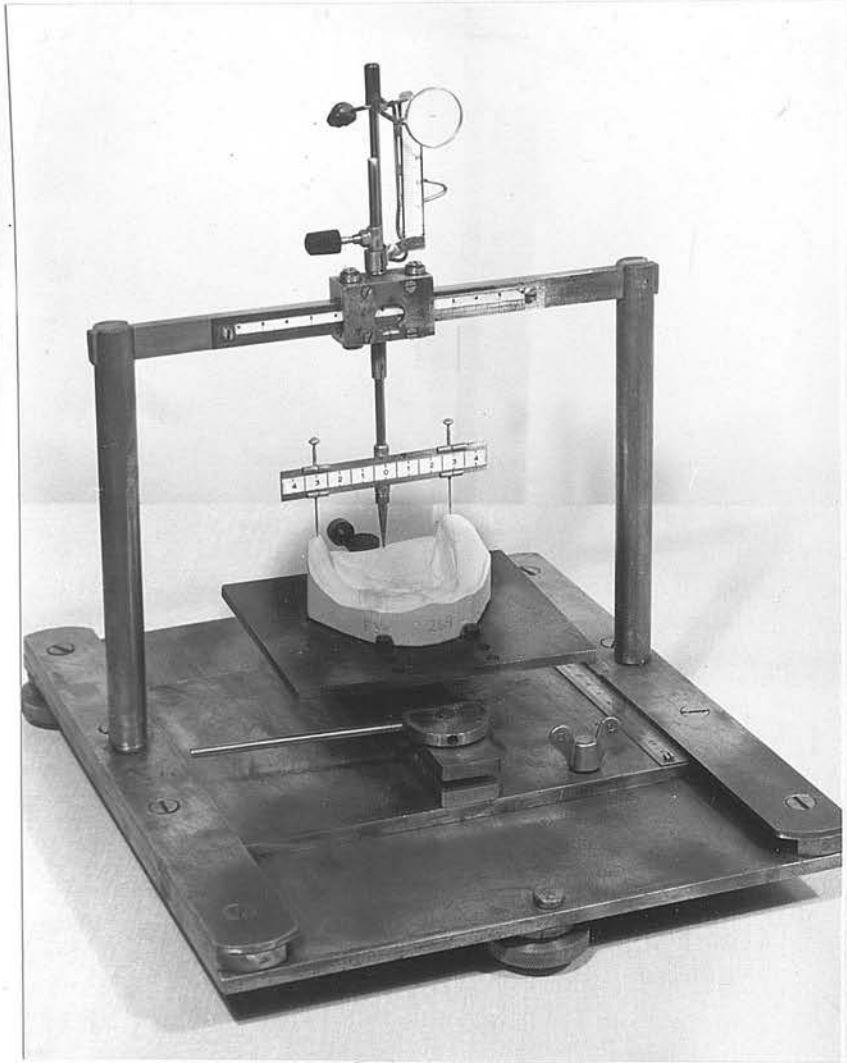
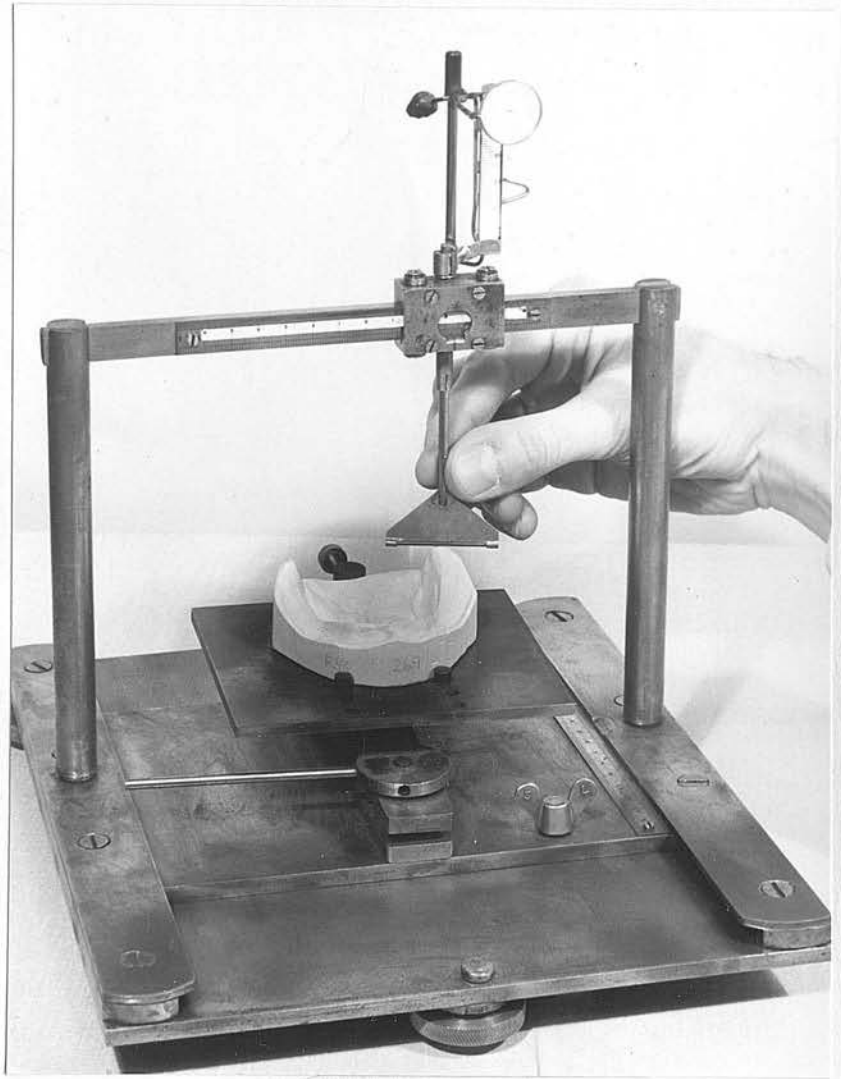


Fig. 58

Locating the Posterior Midpoint.



Marking the distal edge of the retromolar region prior to locating the Retromolar Point.

Fig. 57

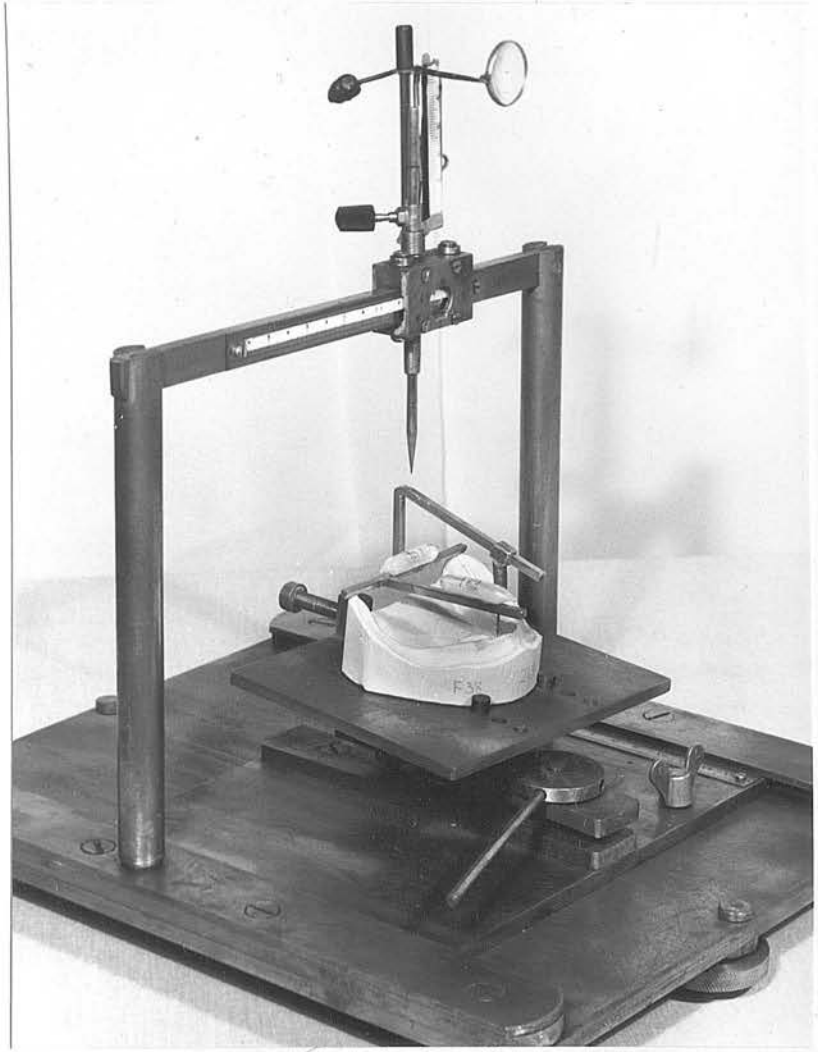
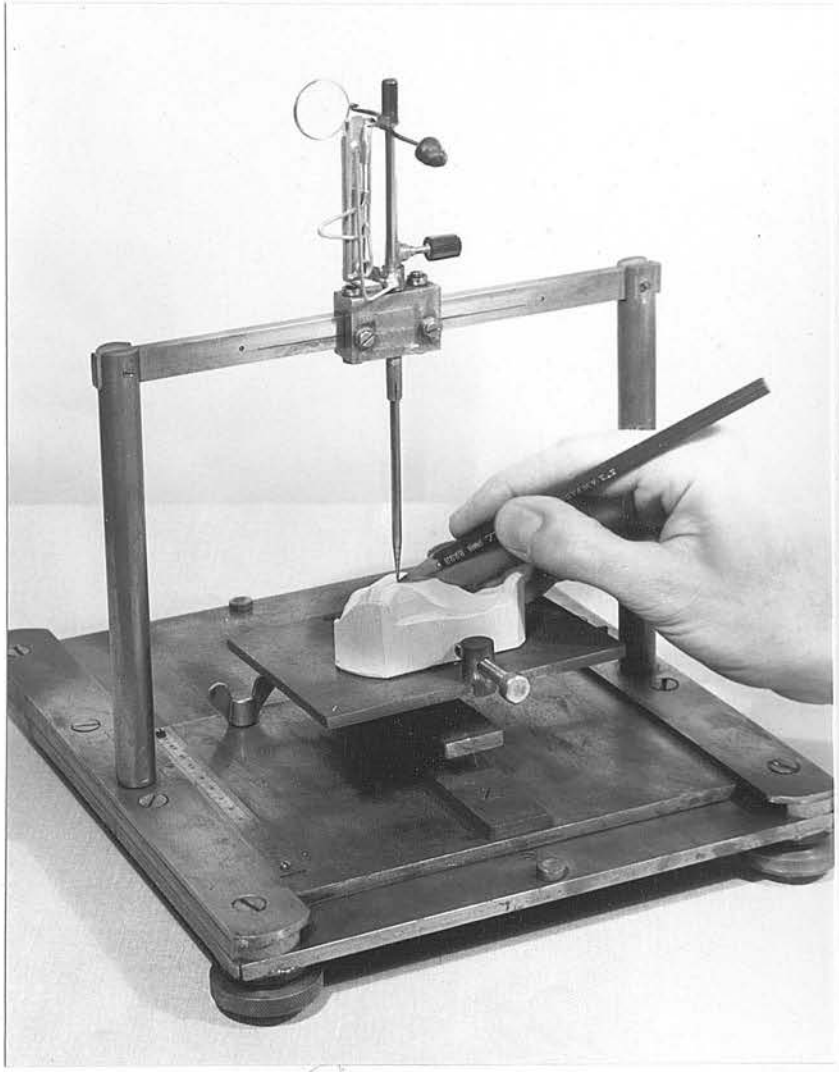


Fig. 60 Spirit level on RL point and Retromolar Points.



Marking the RL point. Fig. 59

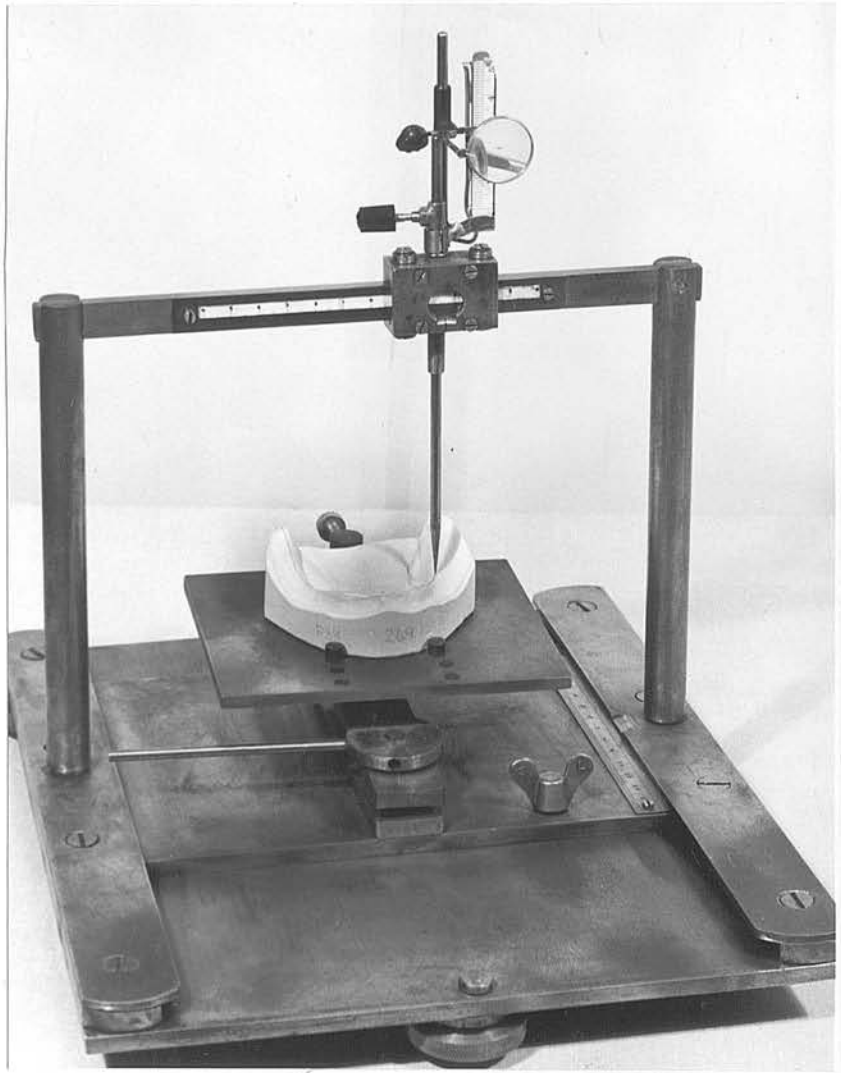
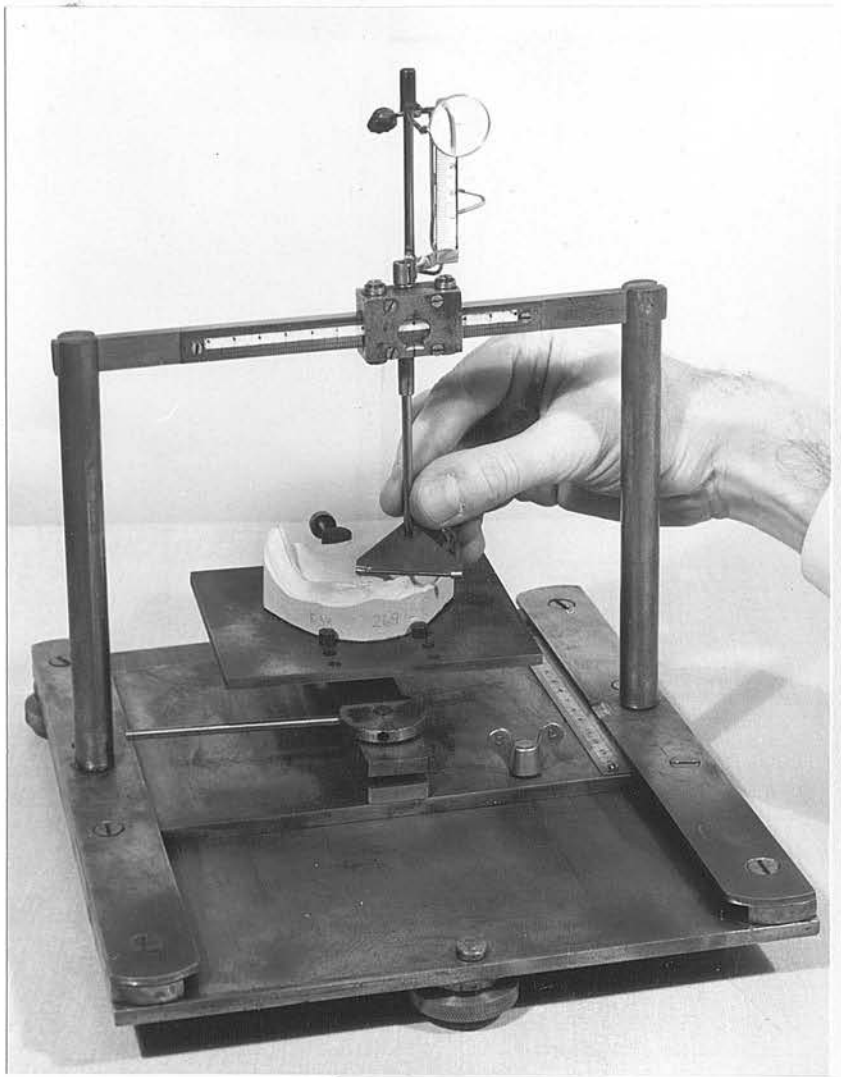


Fig. 62

Point of stylus on the Crest Line.



Marking the Crest Line.

Fig. 61

EDENTULOUS CASTS

TRACES and ADDITIONAL MEASUREMENTS

Out of the total edentulous sample of 300 pairs of casts it was found possible to locate and mark the position of the entire buccal mucogingival line on only 99 pairs of casts.

Each of the 300 maxillary edentulous casts and the 300 mandibular edentulous casts was examined carefully under a strong light and magnifying glass. Only those casts on which the entire mucogingival line was located with reasonable certainty were marked. Casts on which only parts of the line were located were rejected. The casts were marked or rejected in pairs i.e. if the position of the line was located on the maxillary cast but not in the mandibular cast, or vice versa, then both casts were rejected.

The position of the line was marked with a sharp pencil on the buccal surface of each cast.

The ability of an observer to locate and mark the position of the mucogingival line on the surface of maxillary and mandibular edentulous casts was investigated. This investigation is reported fully in the Appendix on page 201 .

Trace of maxillary casts

Each cast was mounted on the tracing instrument and the reference plane of the cast oriented to the horizontal plane by means of the spirit level. A stylus was tracked along the mucogingival line (Fig. 63) and the pen scribed a trace

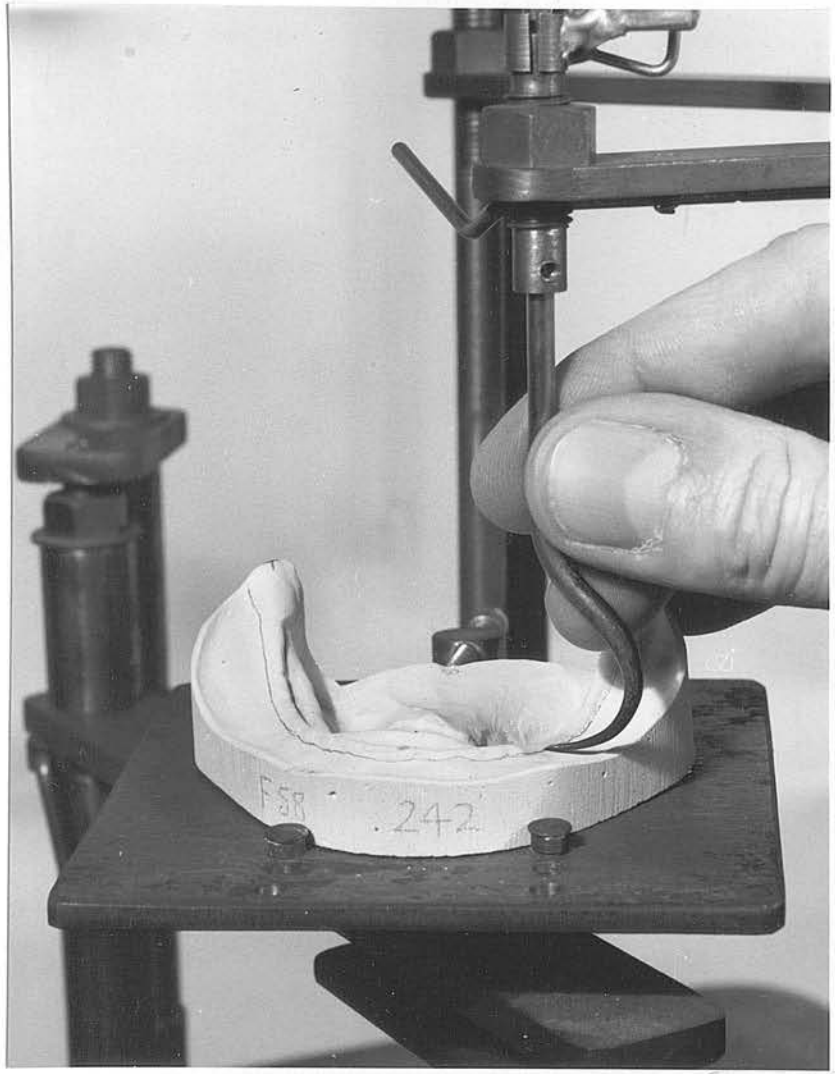
on tracing paper. The stylus was laid in turn on the RU point, Posterior Midpoint and the Notch Points and these points were marked on the tracing paper. The trace was a projection of the mucogingival line on the horizontal plane.

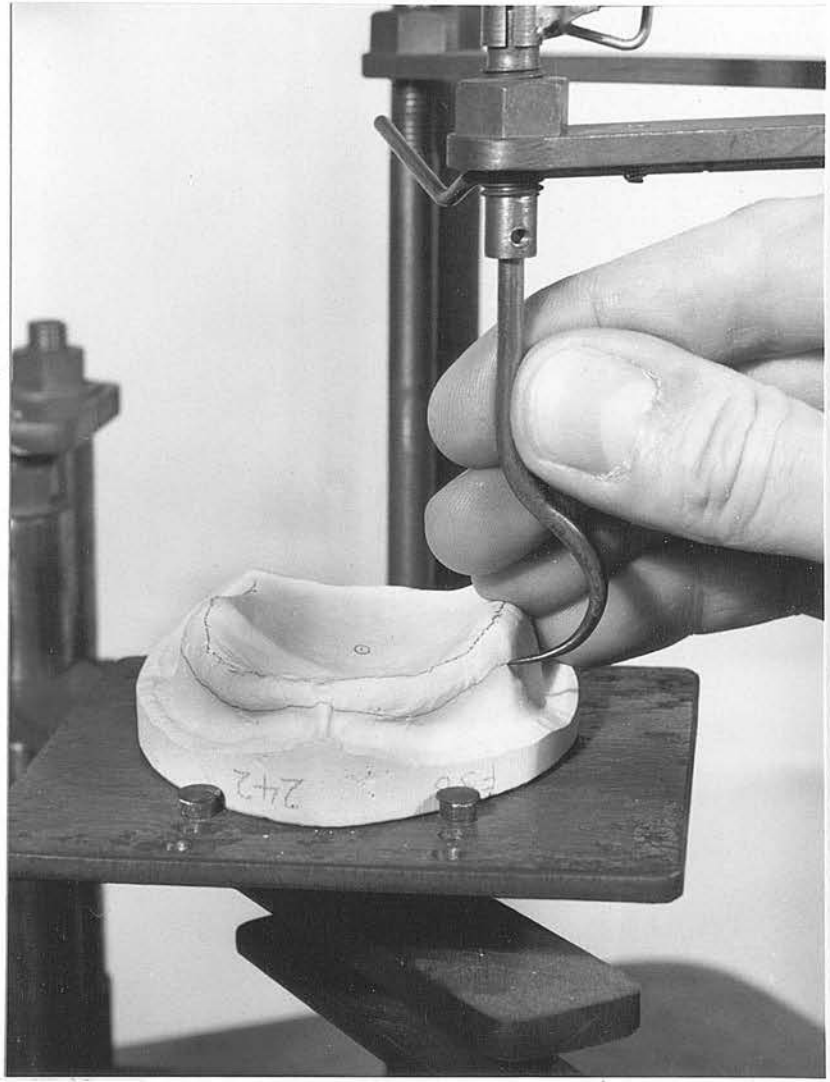
Vertical measurement of maxillary casts

Each cast was mounted on the measuring instrument and the reference plane of the cast oriented to the horizontal plane by means of the spirit level. The median sagittal plane of the cast was coincided with the sagittal plane of the instrument. The stylus was laid on the RU point and readings from the three millimetre scales were made and recorded. All subsequent readings were made relative to this point. Vertical measurements were then made from the mucogingival line on each side of the cast in a coronal plane through the RU point and in coronal planes at 10 mm. intervals from the RU point.

Trace of mandibular casts

Each cast was mounted on the tracing instrument and the horizontal plane through the RL point of the cast was oriented by means of the offset spirit level laid on the RL point and Retromolar Points. A stylus was tracked along the buccal mucogingival line (Fig. 63) and the pen scribed a trace on tracing paper. The stylus was laid in turn on the RL point, Posterior Midpoint and the Retromolar Points and those points were marked on the tracing paper. The trace was a projection of the buccal mucogingival line on the horizontal plane.





Tracing along the buccal mucogingival lines of edentulous casts.

Fig. 63

EDENTULOUS MANDIBULAR CASTS

Trace of Crest Line

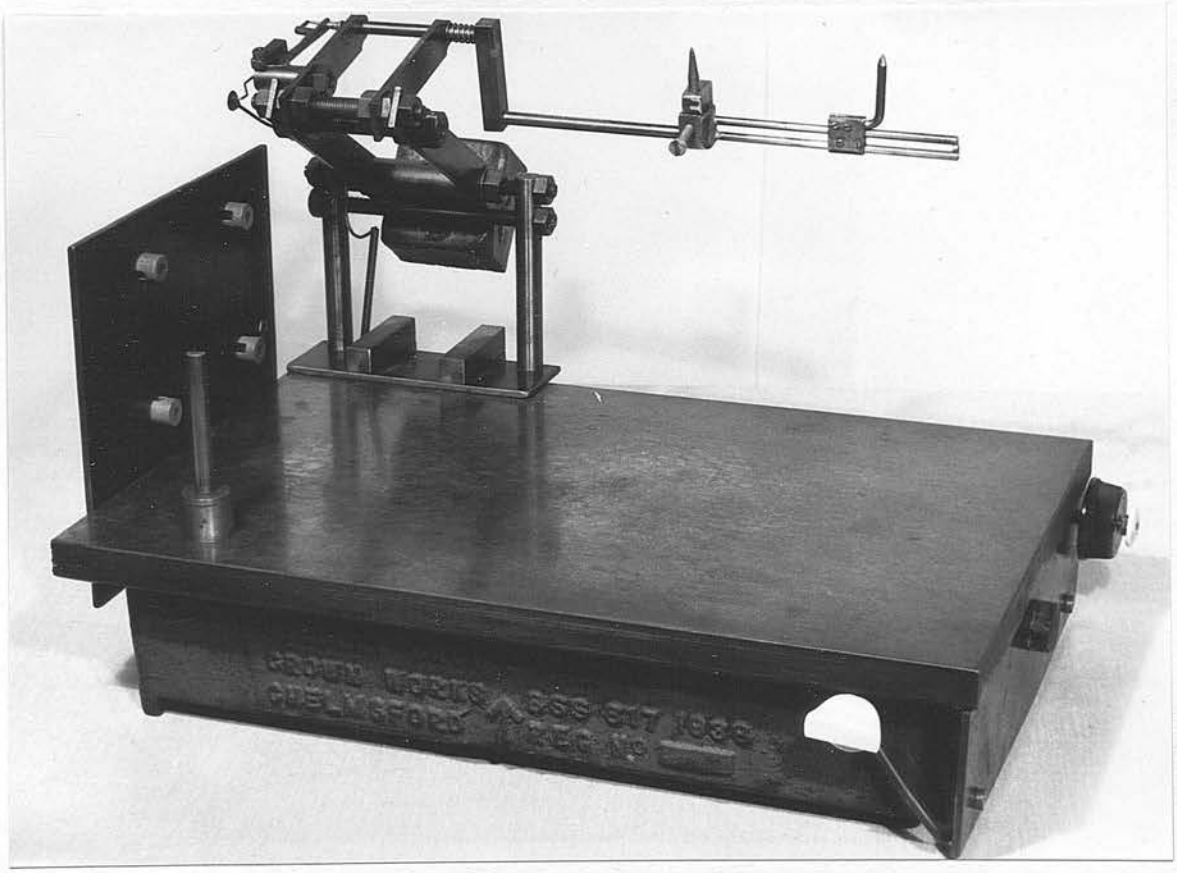
A trace of the projection of the Crest Line on a sagittal plane was made of each of the 300 edentulous mandibular casts in the sample. The traces were made of the Crest Line on one side of the cast only, the left side being selected on even-numbered casts, the right side on odd-numbered casts. (On a number of casts, superimposed tracing of the Crest Lines on both sides of the cast was attempted but the resultant double trace was confused and difficult to interpret.)

The following procedure was used with each cast : The cast was mounted on a machined Perspex block by means of three pillars of Plasticine. A spirit level was laid in contact with the Retromolar Points to ensure that these Points were on the same horizontal plane. The antero-posterior tilt of the cast was not important as this tilt did not affect the resultant trace. The Perspex block was held on the table of an instrument for making vertical traces (Fig. 64) by means of inserted pot magnets. An addition was made to this instrument for the present investigation. This consisted of a horizontal double bar bolted to the stem of the tracing stylus of the instrument. The double bar carried a second stylus which travelled freely along it. The point of the second stylus lay in the same horizontal axis as the tracing stylus of the instrument and the point of the tracing pen.

The Perspex block was shifted so that the median sagittal plane of the cast was parallel to the vertical plate to which the tracing paper was fastened. This position was checked by ensuring that the point of the fixed stylus lay on both the RL point and the Posterior Midpoint of the mounted cast (Figs. 65 66).

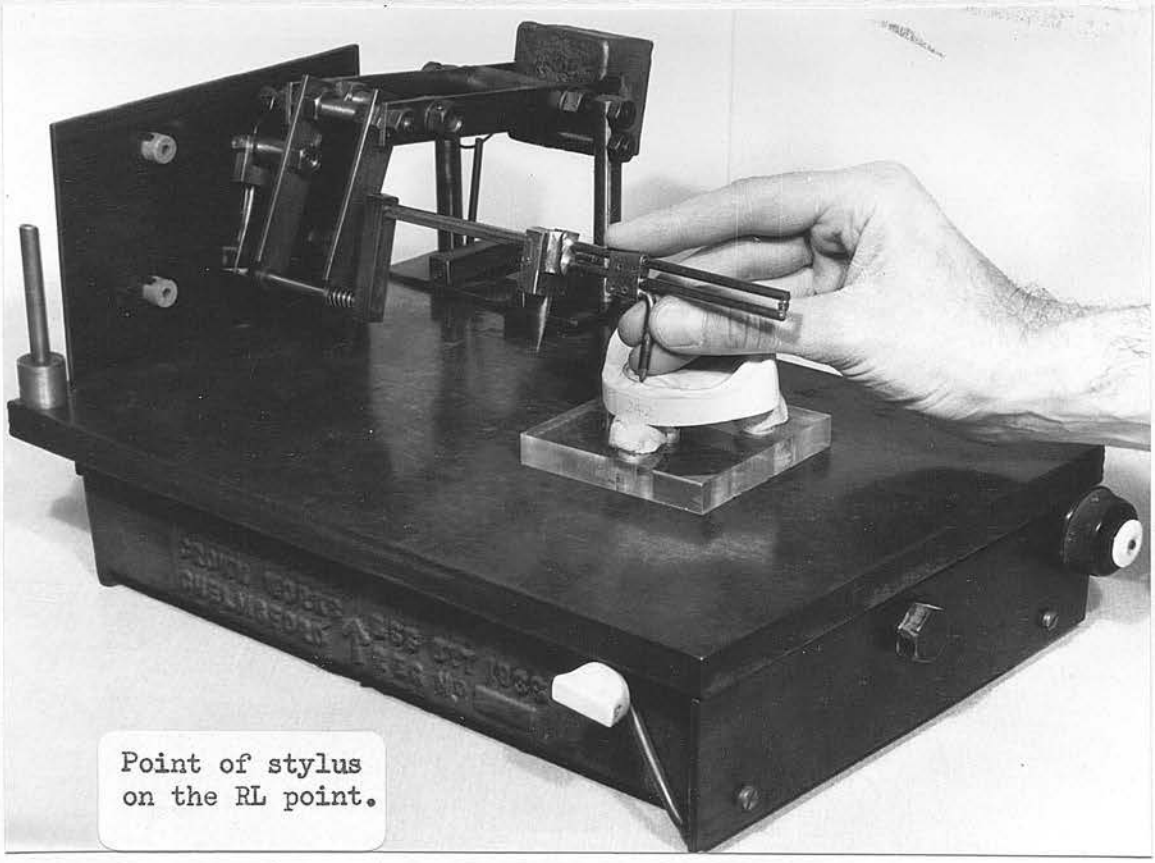
A trace of the cast was then made in the following way : The stylus was held in the median sagittal plane of the cast and moved lingually, in contact with the cast surface, from the buccal sulcus to the RL point. The position of the RL point was clearly marked on the tracing paper. The stylus was then laid on the Crest Line in the median sagittal plane and moved along the Crest Line (either right or left depending on the number of the cast) to the Retromolar Point on that side of the cast (Fig. 67). The position of the Retromolar Point was clearly marked on the tracing paper.

This trace (Fig. 68) was a projection of the Crest Line on the sagittal plane.



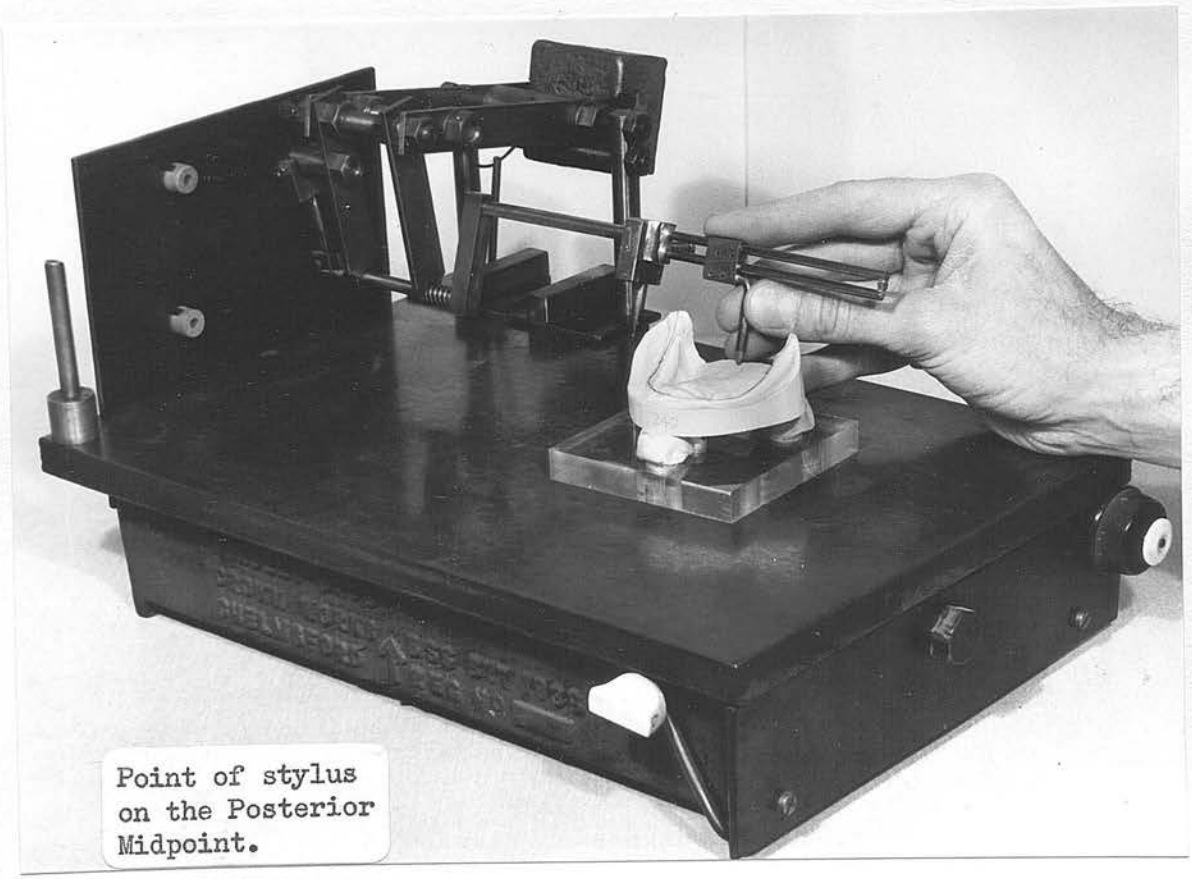
Instrument for making vertical traces showing the second stylus bolted to the stem of the tracing stylus.

Fig. 64



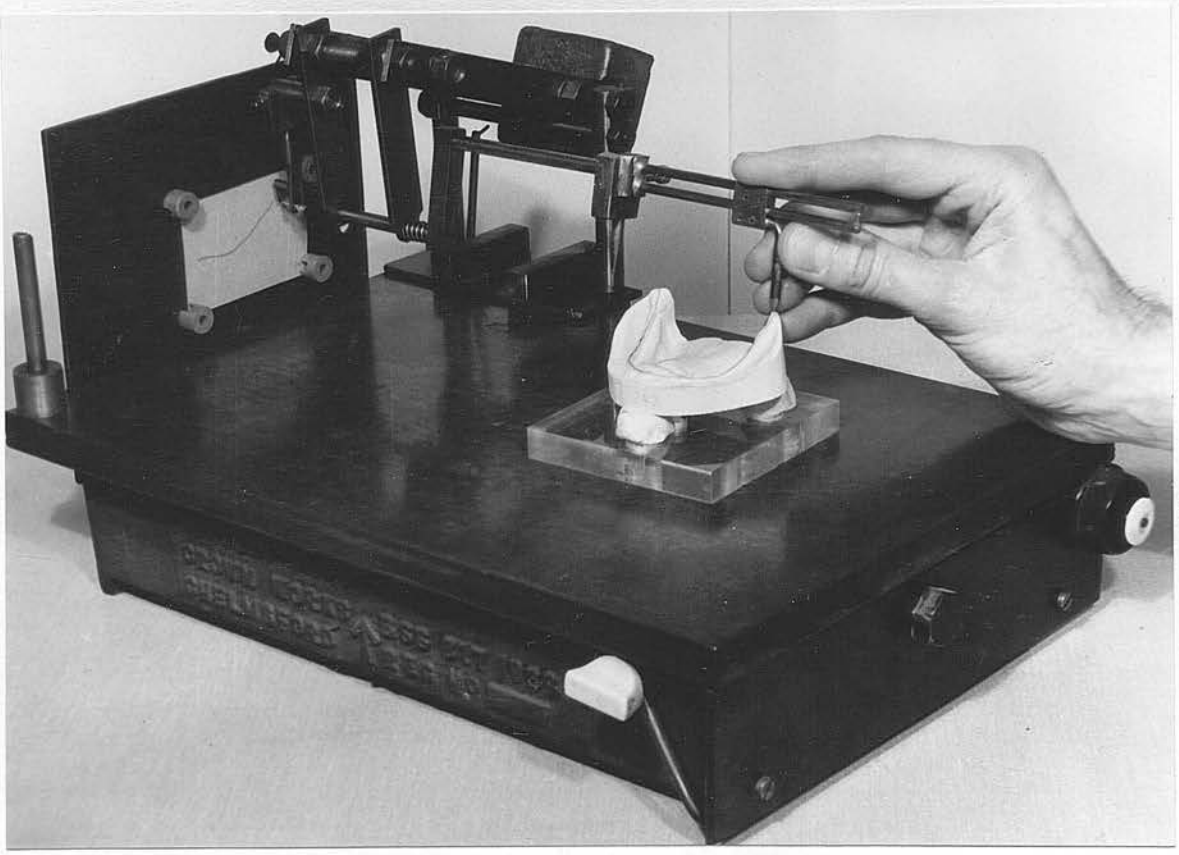
Point of stylus on the RL point.

Fig. 65



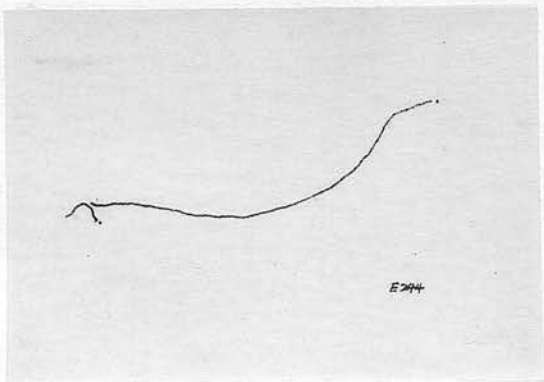
Point of stylus on the Posterior Midpoint.

Fig. 66



Tracing along the Crest Line.

Fig. 67



Trace of the projection of the Crest Line on the sagittal plane. The RL point and Retromolar Point marked on the tracing paper.

Fig. 68

INVESTIGATION of ERRORS

1. Impressions and Casts.

2. Instruments.

3. Measuring errors.

4. Selection and Location of Points.

5. Errors in orientation of casts.

6. Random errors.

1. IMPRESSIONS and CASTS

The main source of inaccuracy in the casts used in the present study was likely to be found in the casts of the edentulous sample. This was due to the fact that 62% of the total number of these casts were obtained from preliminary impression compound (Kemdent) taken in manufactured standard trays and poured in plaster of Paris or equal parts of the latter and artificial stone. The impressions were taken by both staff and students of the Edinburgh Dental Hospital and the casts were stored for a number of years.

Sources of Error

(a) The average linear thermal contraction of impression compound from mouth to room temperature is in the order of 0.4%. Such an error is unavoidable (SKINNER & PHILLIPS 1960).

(b) Distortion of a compound impression may also be due to stress relaxation, the error of which is difficult to assess.

Two experiments were carried out to assess the amount of dimensional error which might be expected in the edentulous casts used in this study :

(i) Laboratory experiment

Six impressions were taken of a U-shaped metal die (Fig. 69). The impressions were taken in manufactured standard metal trays using impression compound (Kemdent). The impressions were taken at 37°C, removed from the die and chilled in water at room-temperature. Four impressions were poured in plaster of Paris and two in equal parts of

plaster of Paris and artificial stone. The W/P ratios were not standardised.

The distance between the outer edges of two reference points on the die (Fig. 69) was measured by two observers by means of a travelling microscope. The mean of six readings was 60.33 mm. (range 60.30 mm. to 60.35 mm.).

Similar measurements were made of each cast 30 minutes after final set. The results ranged from 60.13 mm. to 60.77 mm. (mean 60.50 mm.). This showed a mean linear expansion of + 0.17 mm. (+ 0.28%).

These dimensional changes were due to the distortion of the impression compound and the setting expansion of the cast materials.

(ii) Clinical experiment

Four mandibular impressions of an edentulous patient were taken by two observers. Impression compound (Kemdent) was used in four identical manufactured standard metal trays. The impressions were poured in plaster of Paris. The W/P ratio was not standardised. A single self-polymerising acrylic veneer, which fitted the crest regions of the residual alveolar ridges of all four casts, was used for mounting the casts on Perspex bases by the method already described on page 55 . Each cast and its base was laid into a set square on the table of the vertical tracing instrument (Fig. 64). A crest line was marked along the residual alveolar ridge by means of a horizontal graphite rod held in the stylus of the instrument.

A trace of the projection of the crest line on the sagittal plane was then made of the right side of the cast.

Without moving the set square, the other casts and their bases were laid into the same position and traces were made. Thus the four traces of the right sides of the casts were superimposed to show the variation between the traces. A similar combined trace was produced for the left side (Fig. 7o).

The variation between individual traces in each combined trace was measured by an eyepiece micrometer at centimetre intervals from the crest of the ridge in the midline. The variation in the four lines at the position of measurement was found by subtracting the width of one line (0.3 mm.) from the measurement. From these measurements a mean variation between the lines was calculated. The range was 0.2 mm. to 1.2 mm. with a mean of 0.66 mm.

These combined traces showed a reasonable accuracy in the use of impression compound as an impression material for an edentulous person, but neither this experiment nor the laboratory experiment provided accurate estimates of the random dimensional errors which may have arisen in the routine clinical use of this material. It was likely that such errors were considerable in certain cases but were inevitable in a study of this kind.

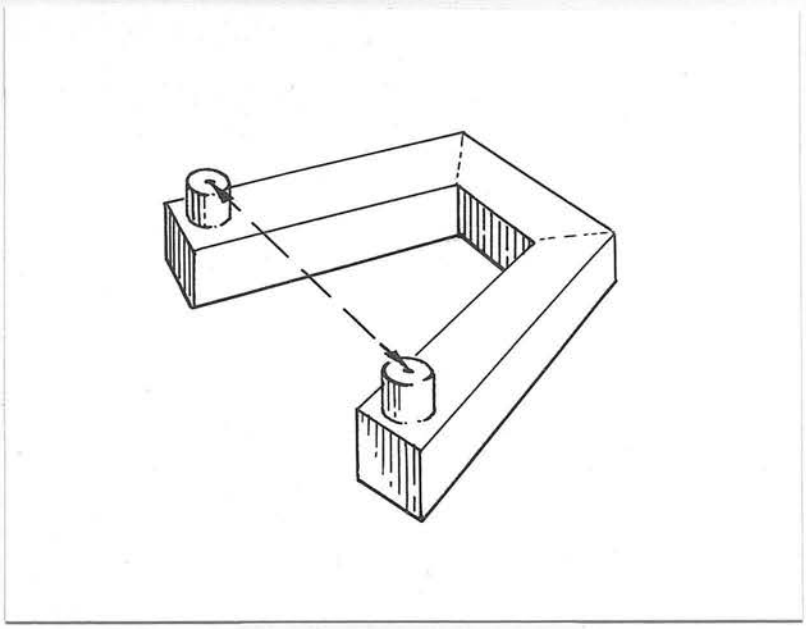
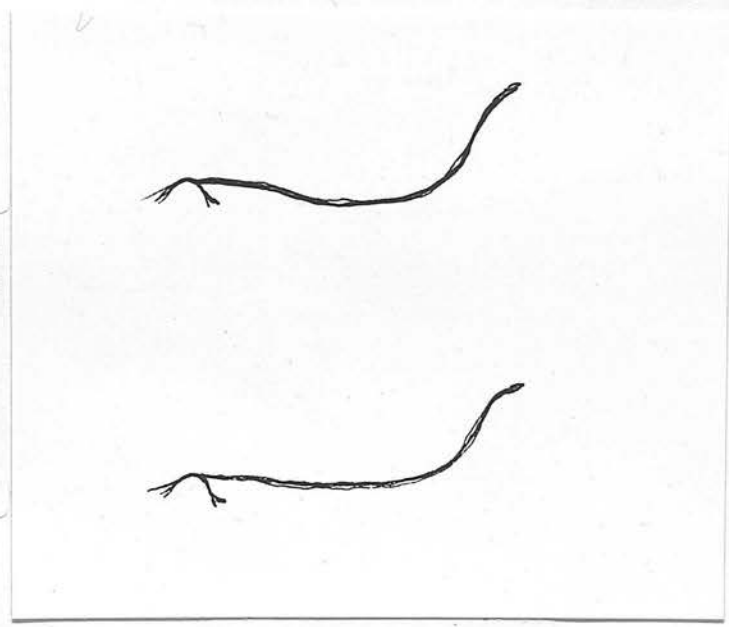


Diagram of metal die with two reference points marked on the vertical pillars.

Fig. 69



Combined traces of the projections of the crest lines on the sagittal plane.

Fig. 70

2. INSTRUMENT ERRORS

(a) Tracing instrument

A midline was scribed on the surface of a machined metal block. The length was measured between the outer faces of the block with sliding calipers laid along the midline. The mean of six measurements made by two observers was 88.8 mm.

The block was mounted on the adjustable platform of the tracing instrument and oriented to the horizontal plane by means of spirit levels.

Four separate traces of the block perimeter were made and marks were made on the traces indicating the position of the midline.

Two observers measured the length of the traces with sliding calipers from the outside of one line to the inside of the opposite line. The results ranged from 88.7 mm. to 88.1 mm. with a mean of 88.42 mm. (a mean percentage error of - 0.43%).

(b) Measuring instrument

The same block was used to assess the accuracy of the measuring instrument. The block was mounted on the adjustable platform, oriented to the horizontal plane and checked that the midline coincided with the sagittal plane of the instrument. The length of the block was measured with the sickle-shaped stylus in contact with the outer faces of the block.

Six measurements made by two observers ranged from 88.5 mm. to 88.9 mm. with a mean of 88.64 mm. (a mean percentage error of - 0.18 %).

The block was then rotated so that its midline coincided with the coronal plane of the instrument. Measurements made in this plane ranged from 88.6 mm. to 90.0 mm. with a mean of 88.7 mm. (a mean percentage error of - 0.11%).

3. MEASURING ERRORS

The errors in the use of the measuring instrument were investigated by comparison of measurements of the same casts by two observers (the author and one other).

Twenty four casts were selected by random numbers from the total cast sample. These casts comprised six pairs of dentulous casts and six pairs of edentulous casts. The various points and lines were already marked on the cast surfaces.

An observer was asked to orient each cast on the measuring instrument and to make direct measurements of the casts according to the method employed in this study. The observer made a total of 399 separate measurements.

These measurements were tabulated against the measurements made previously by the author on the same 24 casts. The results are given in Table 8 .

Measurements (mm.)		Dentulous maxillary and mandibular (12 casts)	Edentulous maxillary and mandibular (12 casts)	Total number of measurements	% of total number of measurements
Total		167	232	399	
Identical		104	157	261	65.41 %
0.5	+	15	23	38	21.06 %
	-	29	17	46	
1.0	+	5	9	14	10.03 %
	-	8	18	26	
1.5	+	1	2	3	1.75 %
	-	3	1	4	
2.0	+	2	3	5	1.50 %
	-		1	1	
2.5	+		1	1	0.25 %
	-				

TABLE 8.

Errors of direct measurement of 24 casts found by comparison of measurements of the same casts by 2 observers. (Observer I (the author) was taken as standard. A + sign signified the measurement made by Observer II was greater than that of Observer I; a - sign signified the measurement was less.)

4. SELECTION and LOCATION of POINTS

(A) Errors in the selection and location of points on the casts were investigated by two observers (the author and one other).

Twenty four casts were selected by random numbers from the total cast sample. These comprised six pairs of dentulous casts and six pairs of edentulous casts. These were termed the master casts.

The base of each cast was laid on an engineers' surface table and a fine groove was scribed around the outer wall of the cast by means of a surface gauge. At three points on this groove a mark was made at right angles to the groove. These three points served as "marker" points.

Each cast was then duplicated in artificial stone (Kaffir D) with a $^{W}/_{P}$ ratio of approximately 0.35 from a "Duplit" impression contained in a "Duplit" flask. The "marker" points were located on the duplicate casts and ringed with pencil for future identification.

An observer was asked to orient the duplicate casts and locate and mark the various points according to the methods employed in this study.

Each of the 48 casts (24 master casts and 24 duplicate casts) was then mounted on the tracing instrument. A flat plate, which carried spirit levels, was laid on the incisal edges and occlusal surfaces of all the teeth. (In the case of the edentulous casts the flat plate was laid on the residual alveolar ridge.) The cast was oriented so that the flat plate was horizontal.

The positions of the following points on each cast were then marked on tracing paper :

(a) Maxillary casts : RU point
Notch Points
3 "marker" points

(b) Mandibular casts : RL point
Retromolar Points
3 "marker" points

The positions of the points which were marked on the master casts by the author were now compared with the points marked on the duplicate casts by the observer. This was done in the following way :

The trace of the master cast and the trace of the duplicate cast were stapled together in such a way that the 3 "marker" points superimposed. The variation in position of the various points was measured by an eyepiece micrometer which was also used to check the superimposition of the "marker" points. The variation in position between two points was found by measuring from the farthest edges of the points and subtracting from this measurement the mean diameter (0.4 mm.) of the ink spot made by the pen of the tracing instrument. A note was also made of the direction that the observer mark varied relative to the master mark.

Results showed that :

i. the range of variation in position between points was 0.1 mm. to 1.7 mm. with a mean variation of 0.53 mm.

ii. the direction in which the two marks varied appeared to be quite random.

(B) Errors in the selection and location of points, the orientation of casts by means of these points, and the subsequent measuring and tracing of the casts were investigated by double determinations by one and the same observer.

Forty casts were selected by random numbers from the total cast sample. These casts comprised 10 pairs of dentulous casts and 10 pairs of edentulous casts.

The pencil marks were washed off the cast surfaces and the casts were allowed to dry for a few days.

The various reference marks and lines were then marked on each cast according to the methods employed in this study.

i. Direct measurement of casts

Each cast was mounted on the measuring instrument and direct measurements were made. A total of 596 separate measurements were made on the 40 casts.

These measurements were tabulated against the direct measurements made previously on the same 40 casts. The results are given in Table 9 .

Measurements (mm.)	Dentulous maxillary and mandibular (20 casts)	Edentulous maxillary and mandibular (20 casts)	Total number of measurements	% of total number of measurements
Total	267	329	596	
Identical	200	245	445	74.66 %
0.5 +	29	20	49	18.12 %
0.5 -	26	33	59	
1.0 +	8	15	23	6.37 %
1.0 -	3	12	15	
1.5 +		1	1	0.67 %
1.5 -	1	2	3	
2.0 +		1	1	0.18 %
2.0 -				

TABLE 9.

Errors of direct measurement of 40 casts found by means of double determinations by one and the same observer. (1st measurement was taken as standard. A + sign signified the 2nd measurement was greater than the 1st; a - sign signified the 2nd measurement was less.)

ii. Tracing of casts

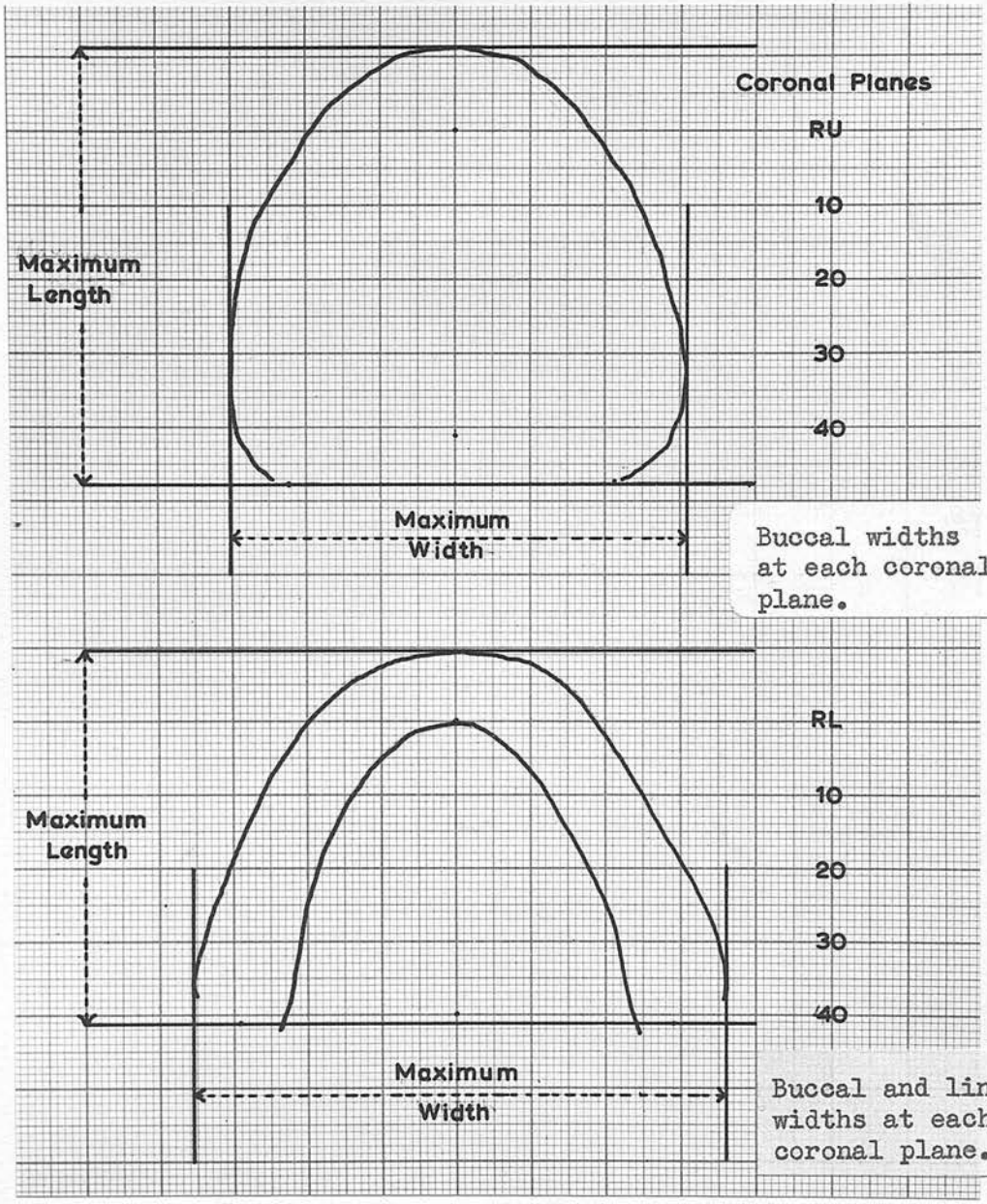
Each of the dentulous casts (20 casts) was then mounted on the tracing instrument, oriented and a trace made of the projection of the mucogingival line on the horizontal plane. The various reference points and marks were also marked on the tracing paper. Each trace was then placed under a transparent millimetre grid and measurements of length and width were made, to the nearest whole millimetre, at the positions shown in Fig. 71 .

The measurements of these traces were tabulated against measurements made on previous traces of the same 20 casts. The results are given in Table 10 .

Measurements	Dentulous Maxillary (10 casts)	Dentulous Mandibular (10 casts)	Total number of measurements	% of total number of measurements
Total	77	101	178	
Identical	65	89	154	86.52 %
1 mm. +	6	7	13	11.79 %
1 mm. -	5	3	8	
2 mm. +	1	1	2	1.69 %
2 mm. -		1	1	

TABLE 10 .

Errors of traces of 20 dentulous casts found by means of double determinations by one and the same observer. (Measurement of 1st trace taken as standard ; a + sign signified the measurement of the 2nd trace was greater than the 1st ; a - sign signified the 2nd measurement was less.)



Measurements made on traces of dentulous casts.

Fig. 71

5. ERRORS in ORIENTATION of CASTS

The effect on the measurements and traces of the casts produced by errors in cast orientation were investigated.

(a) Errors in orientation of Maxillary Casts

Possible errors in orientation of maxillary casts due to changes in position of the RU point and the Notch Points after the loss of teeth were investigated.

Vertical measurements were made from the horizontal reference plane to the palatal surface of each dentulous and edentulous maxillary cast in the median sagittal plane. These measurements were made at 10 mm. horizontal intervals from the RU point.

The mean results of these measurements for the total maxillary cast sample are given in the following table :

	Numbers of casts	Coronal planes			
		10 mm.	20 mm.	30 mm.	40 mm.
Dentulous	351	10.57	13.55	12.77	10.14
Edentulous	300	8.58	11.65	11.03	8.90

(measurements in millimetres)

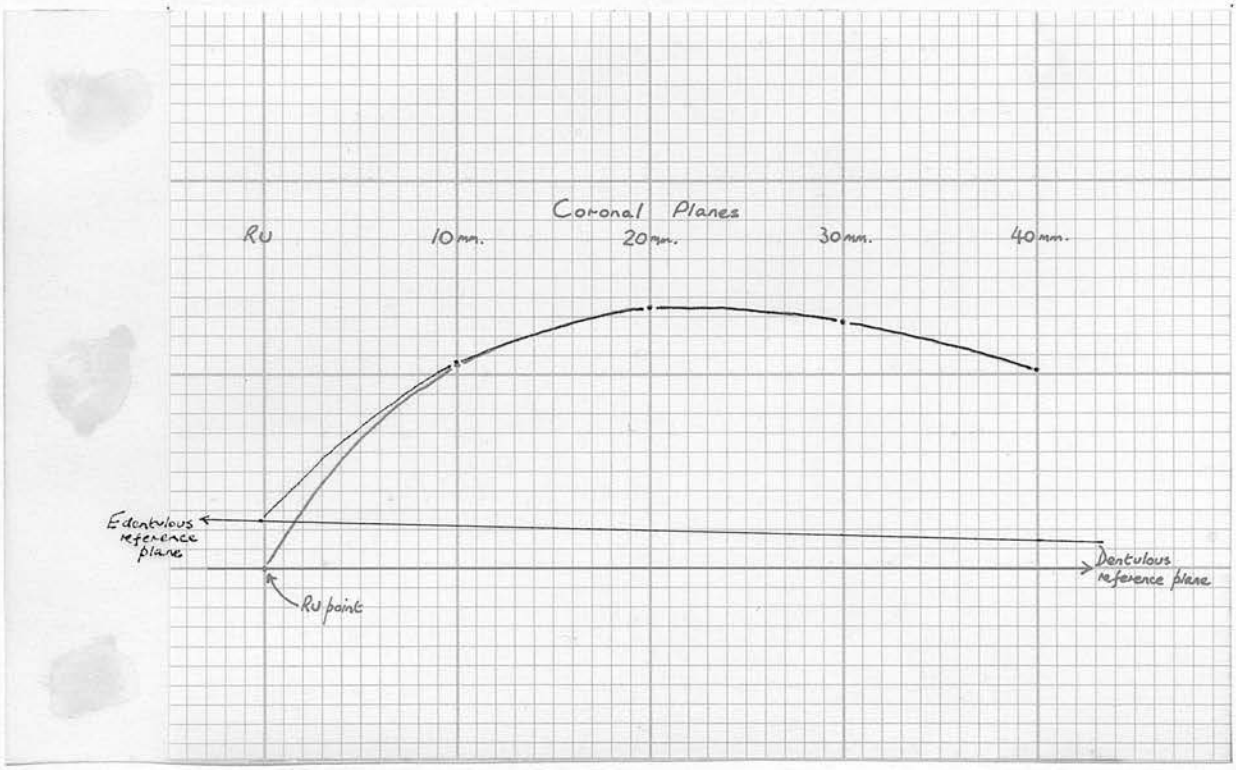
The positions of these points were plotted on squared paper and related to horizontal reference planes. The points were joined by smooth curves to form mean dentulous and edentulous palate curves.

Evidence presented by the work of WATT (1960), HEDEGARD (1962), ATKINSON & JOHNSON (1962 a & b) and JOHNSON (1963) showed that the central and posterior parts of the palate, in the region of the midline, appeared to remain relatively stable after the loss of teeth and that changes in this region of casts were minimal.

Therefore, the mean palate curves of the dentulous and edentulous samples were superimposed in this region to find the possible effect on the dentulous and edentulous reference planes.

It was found that, by shifting the edentulous curve, superimposition of the points occurred in the 20 mm., 30 mm. and 40 mm. coronal planes (Fig. 72). The points in the 10 mm. coronal plane did not superimpose, but this was expected because all the workers in this field showed that changes occurred in this region of the palate after the loss of teeth. Shifting of the edentulous curve in this manner caused a change in position of the edentulous reference plane relative to the position of the dentulous reference plane. This change was in the order of 2 mm. with an angulation of about 1° (Fig. 72).

By shifting the curves it was possible to superimpose the curves in a number of different positions. The exact position could not be known with certainty, however, because of the variable movement of the RU point after the loss of teeth and variations in antero-posterior length of the casts within the sample. Nevertheless, it was seen that whichever position the curves were superimposed, the vertical measurement between the reference planes of the dentulous and edentulous casts remained about 2 mm. with only slight alterations in the 1° angulation.



Superimposing the mean palatal curves of the dentulous and edentulous casts.

Fig. 72

The importance of this vertical difference between the reference planes was in the relating of the dentulous and edentulous measurements to a common reference plane which was necessary for the design and construction of the impression trays.

In order to relate the vertical measurements of dentulous and edentulous casts to a common reference plane, a mean compensation factor of 2 mm. was applied to the edentulous measurements. This compensation factor was applied only to the vertical measurements from the edentulous reference plane to the crest line and the palatal surface. This matter is discussed further on page 178 where the method of impression tray design is described.

With regard to the 1° antero-posterior angulation between the reference planes, it was appreciated that this might have produced errors in the horizontal measurements i.e. the measurements of width and length of the edentulous casts. It was concluded, however, that with this small degree of angulation, the errors were negligible.

(b) Errors in orientation of Mandibular casts

The difficulties encountered in this study of locating points which were subject to least change following the loss of mandibular teeth have already been discussed on page 54 .

Evidence was presented to suggest that the RL point and Retromolar Points were located in regions of the mandibular casts where post-extraction changes were small compared with changes in other regions. Because this

evidence was based almost entirely on the results of short term longitudinal samples before and after the loss of teeth, it was likely that the points selected on a number of edentulous casts were situated at different anatomical positions than the points on the dentulous casts. This is due to the progressive alveolar changes which appear to take place after the loss of teeth. It has already been pointed out, however, that the RL point and Retromolar Points were selected for the purpose of this study because, although they were not ideal, these points were the best that could be found on both dentulous and edentulous casts.

The location of the Retromolar Point was particularly liable to error. This was due to the different anatomy of the retromolar region in dentulous and edentulous mouths and to variations in the casts, the lengths of which were influenced by both the impressions and the laboratory trimming. For these reasons, the location of the Retromolar Point was not an exact anatomical position, but rather a point defined for a particular cast i.e. the most distal point on the superior surface of the retromolar region. However, the criteria of selection of the casts ensured that the retromolar regions were clearly visible on both dentulous and edentulous casts. This implied that the length of the casts was adequate for the construction of full dentures and that impression trays, designed from measurement of these casts, would also be of adequate length, for the reason that the trays would extend to the Retromolar Points and cover the retromolar regions. In addition, it was probable that variations in position of the Retromolar Point would be random throughout the

dentulous and edentulous sample, and errors of measurement resulting from these variations would be such that both positive and negative errors would tend to cancel out.

The Reference Plane selected on mandibular casts was the plane through the RL point and the Retromolar Points. If a mandibular cast was oriented in such a way that this plane was horizontal, then the cast was abnormally tilted in the sagittal plane. It was for this reason that another method of orientation was sought and finally selected for the dentulous and edentulous casts.

All the mandibular casts were oriented by means of a spirit level mounted on an angled base which ensured that the Reference Plane subtended an angle of 19.6° to the horizontal plane. Variations in the position of the RL point and Retromolar Points, or faults in the location of these points, would therefore have the effect of altering the selected orientation of the casts, in particular the orientation of the casts in the sagittal plane. This was investigated :

1. Position of RL points and Retromolar Points

Length of a cast was defined as a measurement along the line of intersection of a sagittal plane with the horizontal plane. From the measurements made in the study, the length of each mandibular cast in the median sagittal plane from the coronal plane through the RL point to the coronal plane through the more posterior of the Retromolar Points was calculated (Fig. 73). The results of these length measurements were as follows :

	Number of casts	Mean	S.D.
Edentulous	300	39.48 mm.	3.84
Dentulous	351	38.92 mm.	3.41

Difference between means : 0.56 mm.

S.E. of difference : 0.29

This difference was not significant at the 5% level.

The 95% confidence limits for the true difference were :

$0.56 \pm 1.96 \times 0.29$

i.e. 0.56 ± 0.57

i.e. -0.01 to + 1.13

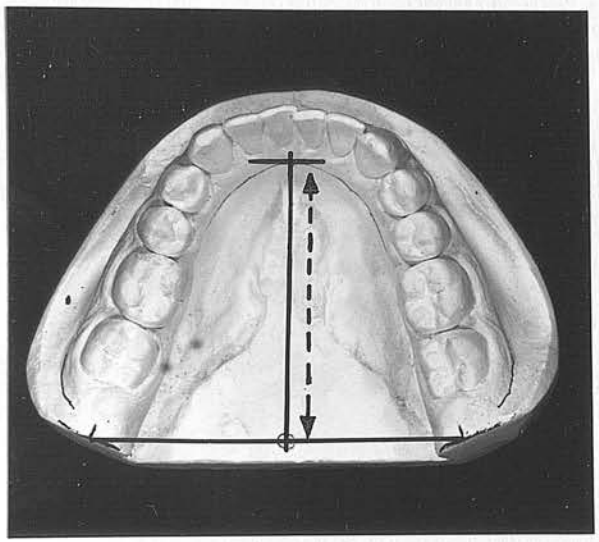
i.e. it was very unlikely that the real difference exceeded 1.2 mm.

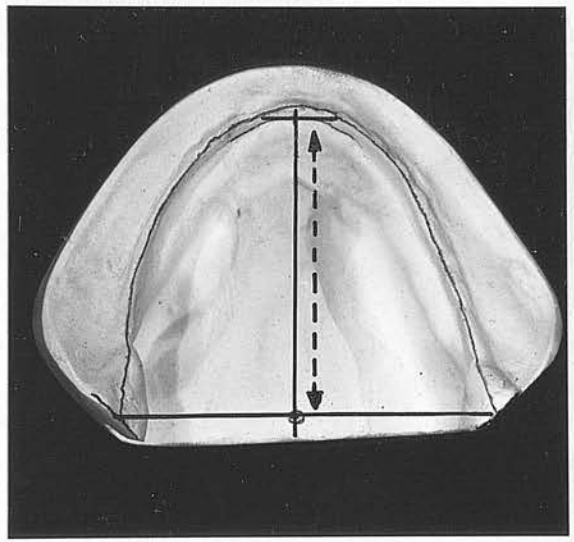
This measurement of length of the dentulous and edentulous casts would have been affected not only by differences in position of the RL point and Retromolar Points but also by different orientations of the casts in the sagittal plane.

The small difference between the means seemed to indicate that the positions of the RL points and Retromolar Points on dentulous and edentulous casts were reasonably comparable for the purpose of this study.

2. Orientation of edentulous mandibular casts

Direct vertical measurements of the edentulous mandibular casts were made from the horizontal plane through the RL point to the Crest Line on both sides of the cast. The measurements were made in coronal planes through the RL point and at 10 mm. intervals from that point.





Mandibular casts

The length from the coronal plane through the RL point to the coronal plane through the more posterior of the Retromolar Points.

Fig. 73

These measurements were important in the design of the impression trays as they were used to determine the antero-posterior curves of the trays. Such measurements were obviously affected by errors in orientation of the edentulous casts as seen in Fig. 74A. This showed the effect on the position of the vertical measurements and the curve of the Crest Line caused by different angles of orientation of an edentulous cast. It was also seen, however, that although the form of the curves appeared to be very different, there was sufficient similarity to allow reasonable superimposition (Fig. 74B).

Nevertheless, because of the importance of these measurements, direct traces of all 300 edentulous casts in the sample were also made (see page 89). The traces were projections of the Crest Lines on the sagittal plane. The positions of the RL point and the Retromolar Points were also recorded on the tracing paper. The curves of these traces were unaffected by the antero-posterior orientation of the casts and thus represented the true curves of the Crest Lines.

One group of edentulous casts was selected for comparison of the direct measurements with the traces of the Crest Lines. This group comprised 66 casts of approximately the same length (range 45 - 48 mm.). *

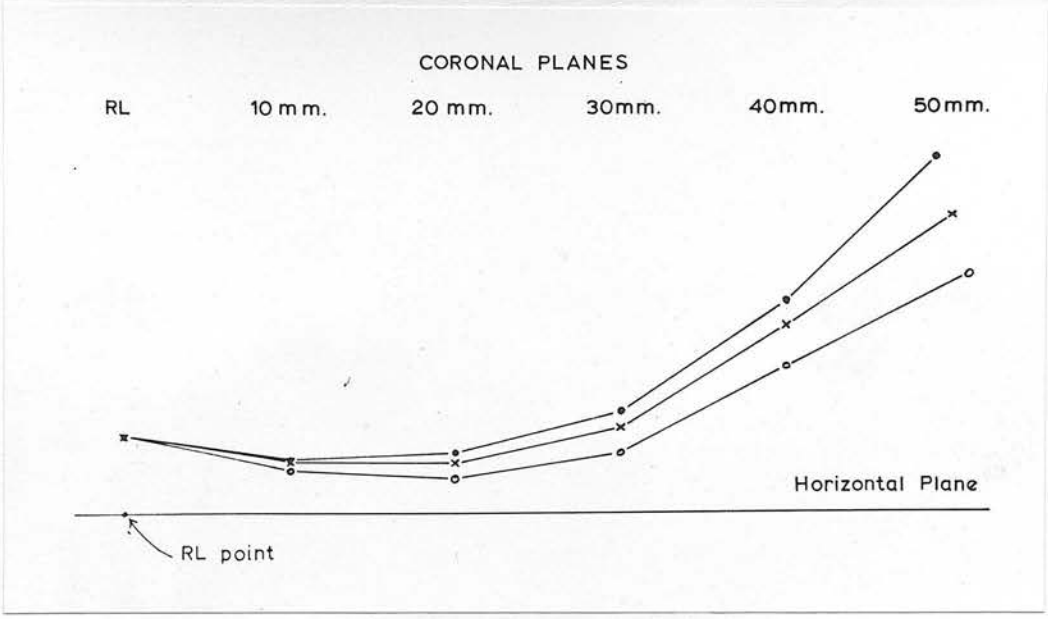
The results of the direct vertical measurements were plotted on squared paper and showed the range and means at each 10 mm. coronal plane (Fig. 75). The measurements were related to the horizontal plane through the RL point.

* The method of grouping casts by length is discussed under "Presentation of Findings" (page 113).

In this diagram the measurements of right and left sides of the casts were combined.

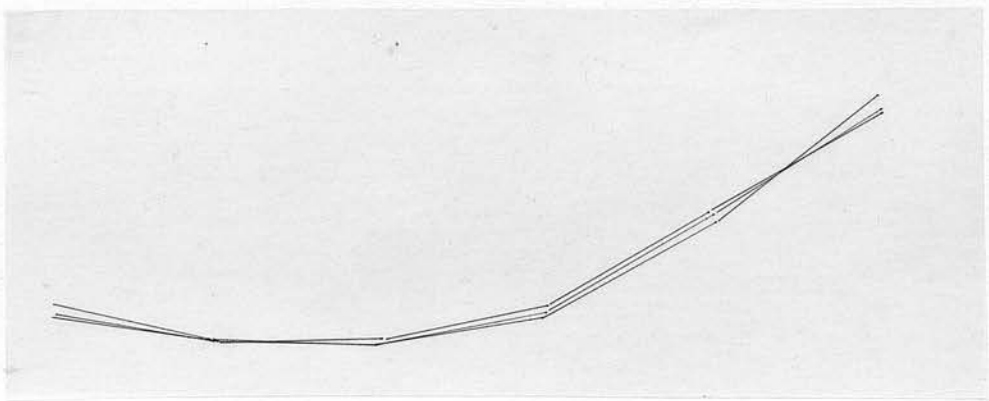
A composite trace of the individual traces was made by superimposing the RL point and Retromolar Point of each trace on a line representing the reference plane through the RL point and the Retromolar Point (Fig. 76). This composite trace thus represented the true curves of this group of casts in relation to the reference plane. It should be recalled that the individual traces were made of one side of the cast, either left or right depending on the sample number of the cast. Thus the composite trace, while representing the curves of both sides of the casts, was only approximate as some of the more extreme curves of the left or right sides of the casts may not have been traced due to the method employed.

It was seen that superimposition of the composite trace and the plotted direct measurements (Fig. 76) was reasonably accurate, and the angle subtended between the reference plane and the horizontal plane was between 19° and 20°. This supported the conclusion that the method selected for orienting the mandibular edentulous casts was sufficiently accurate for the purpose of this study.



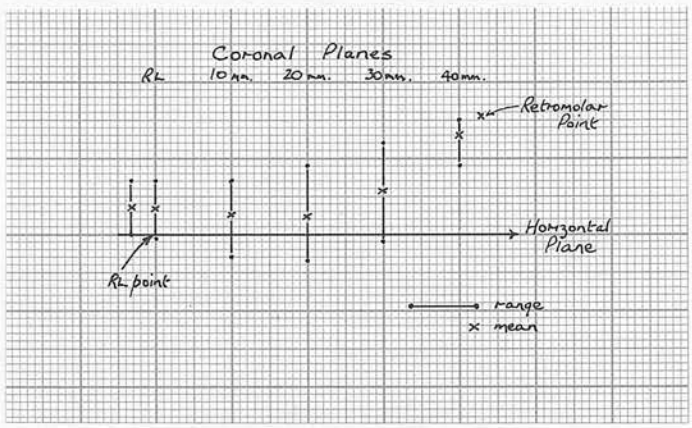
The effect on the curve of the Crest Line caused by different angles of orientation of the cast.

Fig. 74A



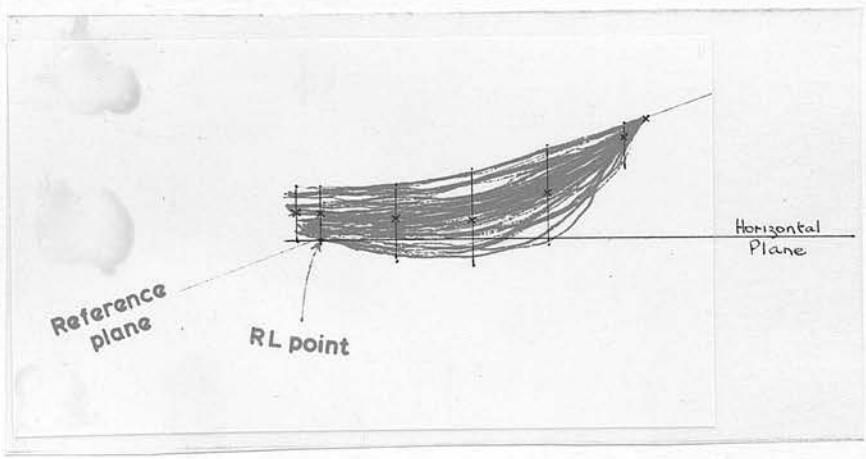
Superimposition of the three curves to show similarity in form of the curves.

Fig. 74B



Vertical measurements of 66 edentulous mandibular casts showing the range and mean at each coronal plane (right & left sides combined).

Fig. 75



Composite trace of individual traces of the Crest Lines of 66 edentulous mandibular casts with the vertical measurements of the same group of casts superimposed.

Fig. 76

6. RANDOM ERRORS

In addition to the errors already discussed, random errors were bound to occur in a cross-section study of this kind and were unavoidable. The magnitude of such errors could not be estimated but it was likely that nearly equal numbers of positive and negative values occurred and tended to cancel out.

(a) Distal extension of impressions and casts

Such variations affected only the mandibular casts and in particular, the location of the Retromolar Points. This has already been mentioned on page 59 .

(b) Distortion of impressions

Apart from the dimensional changes of impression materials which have already been discussed, a number of factors may lead to gross distortion of impressions. These factors, which apply particularly to alginate impressions, include partial separation of the material from the impression tray, drying before casting, careless handling, distortion on the laboratory bench, etc.

(c) Distortion of tissue

i. Caused by dentures : morphologic changes in the denture bearing tissues caused by wearing dentures are not fully understood, but it is likely that soft tissue displacement or distortion occurred in a number of persons in the edentulous sample. Such distortion may have affected the location of points on the cast surfaces.

ii. Caused by impressions : it is likely that distortion or displacement of soft tissue occurred in some dentulous and edentulous persons in the sample, due to

contact with parts of impression trays or variations in plasticity of the impression material.

(d) The samples

The dentulous and edentulous samples were selected and could not be considered representative of the general population.

i. The dentulous sample was selected by certain specified criteria (see page 40) from persons, who were fairly easily accessible, from the age of 18 or more years. An older age group might have been expected to present a stage of more complete dental development but, with increase of age, changes resulting from caries, periodontal disease and loss of teeth are more liable to occur. Such changes make the collection of "dentulous" material difficult.

ii. The edentulous sample of 300 pairs of casts was selected by random numbers from the casts of persons who had attended the Edinburgh Dental Hospital for prosthetic treatment.

Conclusion

It was concluded that the methods employed were sufficiently accurate for the purpose of this study.

PRESENTATION of FINDINGS

The Dentulous Casts

1. Measurement and grouping of casts

   i. Maxillary casts : BUCCAL OUTLINES.

   ii. Mandibular casts : BUCCAL & LINGUAL OUTLINES.

2. Vertical measurements

   i. Maxillary casts : VERTICAL BUCCAL MEASUREMENTS.
   PALATE MEASUREMENTS.

   ii. Mandibular casts : VERTICAL BUCCAL MEASUREMENTS.
   VERTICAL LINGUAL MEASUREMENTS.

The Edentulous Casts

1. Horizontal measurements and grouping of casts

   i. Maxillary casts : RIDGE OUTLINES.

   ii. Mandibular casts : RIDGE OUTLINES.

2. Vertical measurements

   i. Maxillary casts : VERTICAL RIDGE MEASUREMENTS.
   PALATE MEASUREMENTS.

   ii. Mandibular casts : VERTICAL RIDGE MEASUREMENTS.

PRESENTATION of FINDINGS

The measurements and traces made on the 1302 dentulous and edentulous casts which comprised the sample, provided the data which was used to design a range of impression trays for taking impressions of edentulous patients.

In dentulous persons, the lips and cheeks lie in contact with almost the whole buccal alveolar process and thus derive part of their support from the dentulous jaws.

After the loss of teeth, and the subsequent changes in the dental alveolar tissues, the lips and cheeks are deprived of some of their underlying support and the facial contours are altered. It is desirable that full dentures should restore the lips and cheeks of edentulous patients to positions approximating the pre-extraction facial contours.

This restoration, accomplished in the various stages of the construction of full dentures, is begun at the stage of taking maxillary and mandibular impressions. Such impressions contribute to facial restoration by recording the form of the vestibule. Vestibular form of an edentulous person, however, varies according to the activity of the muscles of the face and the position of the lips and cheeks. As completed full dentures are intended to restore the lips and cheeks to their approximate pre-extraction position, it seems that the form of the vestibule should be recorded, at the stage of taking impressions, with the lips and cheeks supported in this position.

The pre-extraction position of the lips and cheeks of an edentulous person, however, is seldom known with certainty.

It was the intention in this study, therefore, that the impression trays should be designed from measurement of the dentulous casts in order that the trays might contribute to the approximate pre-extraction restoration of edentulous mouths. In this respect, it was important that the size and shape of the tray outlines conformed as precisely as possible to the measurements and traces of the maxillary and mandibular dentulous casts.

In addition, measurements of edentulous casts were made for incorporation into the tray design in order that the impression trays matched the variations in form and size of the edentulous jaws.

The Dentulous Casts

A trace of the projection of the mucogingival line on the horizontal plane was made of each of the 702 dentulous casts in the sample. The traces were contour lines of the buccal and lingual surfaces of the alveolar processes of the dentulous casts at the level of the mucogingival lines. The traces were made for the purpose of determining the design of the buccal and lingual outlines of the impression trays.

Study of the traces showed great diversity in their size and outline form. A number of traces were found in which measurements of maximum length and maximum width were identical, but the form of these traces varied because of differences of width in other parts of the traces. Similarity in outline form occurred more frequently, but no two traces were found in which it was possible to superimpose the whole trace of one upon the other.

These great differences in the traces presented many difficulties in devising a method of grouping them. The object of grouping the traces was to examine the range of variation of their size and form and to assist in the design of a range of impression trays, with different buccal and lingual outlines, which would represent the dentulous cast sample.

The method finally adopted was as follows :

(a) the maximum length and maximum width of each trace were measured.

(b) traces of similar length and width were placed into the same group.

(c) a composite trace was made by superimposition of the individual traces within each group.

(d) a single outline was then made from the composite trace, with reference to other measurements of the individual traces in the group.

It will be shown that this method of grouping the dentulous casts, which is described in greater detail in the following sections, resulted in a number of different buccal and lingual outlines, each of which represented the approximate form and size of the casts in the different groups. Such approximation was found to be necessary because of the complex variations of the dentulous casts in the sample. It was also felt that, in devising a method of grouping the casts, the number of groups should be as few as possible in order to reduce the number of impression trays in the range to practical limits.

It will also be shown that this method of grouping the dentulous casts by means of their maximum length was particularly useful when handling the vertical measurements made on each cast from the horizontal plane through the reference point to the mucogingival line. (On the maxillary casts, measurements were also made to the palate surface.) These measurements were made in coronal planes at 10 mm. horizontal intervals from the reference point. Measurements made in this way present a problem in cross-section studies because the coronal planes cross casts of different lengths at different anatomical positions and, therefore, comparison of the measurements are difficult to interpret. For this reason, the vertical measurements were more relevant when tabulated for groups of casts of similar length.

1. Measurement of Traces of Dentulous Casts

Each trace of the 702 dentulous casts was measured under a transparent millimetre grid (Fig. 77). The median line of the grid was superimposed on the Reference Point and the Posterior Midpoint of the trace and the following 4 measurements were made and recorded to the nearest whole millimetre (0.5 mm. read as 1) :

Length measurements, in the median sagittal plane, from the point of intersection of the trace of the buccal mucogingival line with the median sagittal plane to :

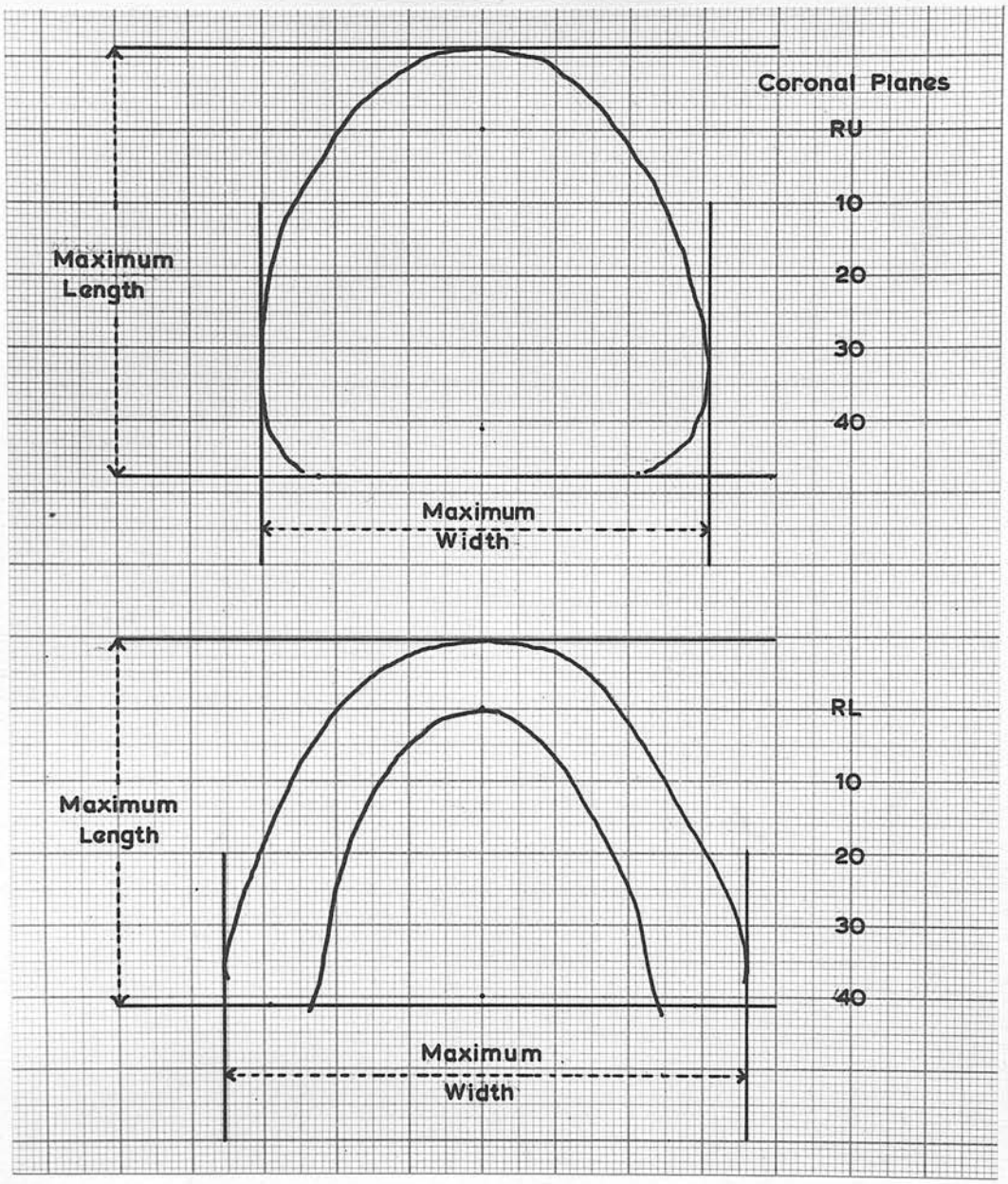
i. the coronal plane through the Reference Point. This measurement was defined as the anterior length of the cast.

ii. the coronal plane through the more posterior of the two Notch Points (or, in the case of mandibular traces, the Retromolar Points). This measurement was defined as the maximum length of the cast.

Width measurements

i. between the points of intersection of the trace of the buccal mucogingival line with the coronal plane through the Reference Point. This measurement was defined as the Width at RU point (or, in the case of mandibular traces, the Width at RL point).

ii. maximum width defined as the maximum measurement between sagittal planes which cut the trace of the buccal mucogingival line on the right and left sides of the trace. The measurement was made in the coronal plane.



Measurement of traces of dentulous casts.

Fig. 77

2. Method of grouping the Dentulous Maxillary Casts

The measurements of Maximum Length of the casts were arranged as a frequency distribution (Table 11). The range was 43 to 65 mm. (mean 52.73 mm.; S.D. 3.55). This standard deviation of 3.55 was used as a method of dividing the casts into 5 groups. Owing to the presence of skewness in the distribution it was realised that the standard deviation, or multiples thereof, could not be used to cut off exactly the same proportions above and below the mean. This was not intended. The method was used because the amount of the standard deviation was considered to be an acceptable difference of length between the various impression trays subsequently designed from these measurements. The 5 groups were designated as follows :

Group	Length	Group borders
Extra Long : mean + 2 S.D.	= 59.83 mm.	59 mm.
Long : mean + 1 S.D.	= 56.28 mm.	55 to 58 mm.
Mean :	52.73 mm.	51 to 54 mm.
Short: mean - 1 S.D.	= 49.18 mm.	47 to 50 mm.
Extra Short: mean - 2 S.D.	= 45.63 mm.	46 mm.

Each cast was allocated into one of the 5 Length Groups according to the maximum length of that cast (Table 12).

TABLE 12.

351 DENTULOUS MAXILLARY CASTS : MAXIMUM LENGTH

Mean 52.73 mm.

S.D. 3.55

Division of casts into 5 groups

45.63 mm.	49.18 mm.	52.73 mm.	56.28 mm.	59.83 mm.
EXTRA SHORT	SHORT	MEAN	LONG	EXTRA LONG
46 mm. or below	47-50 mm.	51-54 mm.	55-58 mm.	59 mm. or above
15 casts (4.3 %)	75 casts (21.3 %)	152 casts (43.3 %)	89 casts (25.4 %)	20 casts (5.7 %)

It followed from the method that differences of length between casts in adjacent groups were small at the points of demarcation. This was due to both the length measurements and the group borders being made to the nearest whole millimetre. Thus a cast which measured 50.4 mm. was given a length measurement of 50 mm. and grouped as Short, while a cast measuring 50.6 mm. was given a length measurement of 51 mm. and grouped as Mean.

Upper and lower borders were not fixed for the Extra Long and Extra Short groups respectively, because it was intended that all the casts of extreme length in the distribution should be included in these groups. It can be seen from Table 12 that 10% of the total sample of casts were placed in these groups.

The measurements of Maximum Width of the dentulous maxillary casts were also arranged as a frequency distribution (Table 13). The range was 52 to 75 mm. (mean 62.33 mm; S.D. 3.83). The standard deviation was again used as a method of dividing the casts into 5 groups which were designated as follows :

Group		Width	Group borders
Extra Wide	: mean + 2 S.D. =	69.99 mm.	69 mm.
Wide	: mean + 1 S.D. =	66.16 mm.	65 to 68 mm.
Mean	:	62.33 mm.	61 to 64 mm.
Narrow	: mean - 1 S.D. =	58.50 mm.	57 to 60 mm.
Extra Narrow	: mean - 2 S.D. =	54.67 mm.	56 mm.

Each cast was allocated into one of the 5 Width Groups according to the maximum width of that cast (Table 14).

TABLE 14 .

351 DENTULOUS MAXILLARY CASTS : MAXIMUM WIDTH

Mean 62.33 mm.

S.D. 3.83

Division of casts into 5 groups

54.67 mm.	58.50 mm.	62.33 mm.	66.16 mm.	69.99 mm.
EXTRA NARROW	NARROW	MEAN	WIDE	EXTRA WIDE
56 mm. or below	57-60 mm.	61-64 mm.	65-68 mm.	69 mm. or above
20 casts (5.7 %)	100 casts (28.5 %)	123 casts (35.1 %)	91 casts (25.9 %)	17 casts (4.8 %)

Each dentulous maxillary cast was thus placed into one of 25 groups according to the maximum length and maximum width of the cast.

It was found that 94.9% of the total number of casts were placed in 13 of the 25 groups. The remaining 5.1% (18 casts) were distributed in 7 groups, while in 5 groups no casts were placed.

The frequency distribution of the groups, and the 13 groups which contained the majority of the casts of the sample, are listed in Table 15 .

In each of these 13 groups a composite trace was made comprising all the individual traces within that group. This was done by laying each trace on a viewing screen and copying the trace on tracing paper with a pen which produced a line width of 0.2 mm. The tracing paper was superimposed on the RU point of each trace and on a line through the RU point and Posterior Midpoint (Fig. 78).

Each of the composite traces was made for the purpose of indicating the general outline form of each group but, as can be seen from Fig. 78 , a greater variation occurred among the individual traces than seemed likely from the superimposition of traces of similar length and width. This was due to three main factors :

(i) Superimposition of the traces was made in relation to a common reference point and median sagittal plane. Thus, asymmetry between the right and left sides, which occurred in a number of traces, had the effect of increasing the width of the composite trace. It was noted, however, that the direction of this asymmetry appeared to be quite random and neither side was affected more than the other.

(ii) The anterior lengths of the traces were not identical, and this produced a variation between the individual traces because of the method of superimposing each trace on a common reference point. This effect is shown in Fig. 79 in which two traces with different anterior lengths, but in other respects identical, are superimposed on a common reference point.

It was important, however, that the composite trace was made in this way for the reason that, in the later design and construction of the impression trays, all other measurements of dentulous and edentulous casts were also related to a common reference point and median sagittal plane.

(iii) The greatest variation in the composite trace occurred in the region of the coronal plane through the RU point. This, of course, was expected because the method of grouping traces of similar maximum length and width did not imply similarity in other parts of the traces.

This variation in form is seen in Fig. 80 in which two traces of identical maximum length and maximum width, but different width at the RU point, are shown superimposed.

It was seen, therefore, that this measurement of width at the RU point had a special value in each composite trace since, in conjunction with the maximum length and maximum width measurements, it gave a further indication to the selection of an outline form as representative of each group.

However, it was found that if the mean measurement of this width in each composite trace was selected to indicate the outline form of each group, then the resultant outline forms of all 13 groups all tended to be similar, and obviously did not represent the variation of outline form of the maxillary cast sample.

For this reason the measurements of the width at the RU point of the traces of the total sample were arranged as a frequency distribution (Table 16). The range was 23 to 49 mm. (mean 38.05 ; S.D. 3.92). The traces were divided into 5 groups :

Group		Width at RU point	Group borders
Extra Wide	: mean + 2 S.D. =	45.89 mm.	45 mm.
Wide	: mean + 1 S.D. =	41.97 mm.	41 to 44 mm.
Mean	:	38.05 mm.	37 to 40 mm.
Narrow	: mean - 1 S.D. =	34.13 mm.	33 to 36 mm.
Extra Narrow	: mean - 2 S.D. =	30.21 mm.	32 mm.

and each trace was allocated into one of these groups according to the width at the RU point of the trace (Table 17).

TABLE 17 .

351 DENTULOUS MAXILLARY CASTS : WIDTH at RU point

Mean 38.05 mm.

S.D. 3.92

Division of casts into 5 groups

30.21 mm.	34.13 mm.	38.05 mm.	41.97 mm.	45.89 mm.
EXTRA NARROW	NARROW	MEAN	WIDE	EXTRA WIDE
32 mm. or below	33-36 mm.	37-40 mm.	41-44 mm.	45 mm. or above
25 casts (7.1 %)	90 casts (25.6 %)	147 casts (41.9 %)	74 casts (21.1 %)	15 casts (4.3 %)

The traces were then arranged to show the frequency distribution of the width at the RU point throughout the total sample (Tables 18 to 20).

The width at the RU point selected in the 13 groups was the width which occurred most frequently in each of the groups. When widths occurred with equal frequency then the wider of the two was used. Thus the 13 groups were further designated as in Table 21 .

TABLE 21 .

Designation of 13 groups of Dentulous Maxillary casts.

	Maximum Length	Maximum Width	Width at RU point
1	EXTRA LONG	Wide	Extra Wide
2	LONG	Extra Wide	Wide
3	"	Wide	Wide
4	"	Mean	Mean
5	"	Narrow	Narrow
6	MEAN	Wide	Mean
7	"	Mean	Mean
8	"	Narrow	Mean
9	SHORT	Wide	Mean
10	"	Mean	Mean
11	"	Narrow	Narrow
12	"	Extra Narrow	Narrow
13	EXTRA SHORT	Narrow	Narrow

It has already been explained that the anterior lengths of the individual traces were not identical and that this produced variation at the front of each composite trace.

It was found, however, that the range of measurement of the anterior lengths of the traces was small and, therefore, the mean anterior length of each length group, was used to indicate the outline form of this part of each composite trace. The range and mean of this measurement of the traces of each Length Group were as follows :

Length Group	Anterior Length (mm.)	
	Mean	Range
EXTRA LONG	11.25	9 - 14
LONG	10.30	6 - 13
MEAN	9.98	5 - 13
SHORT	9.32	6 - 13
EXTRA SHORT	9.26	7 - 12

Thus in each of the 13 composite traces, 4 measurements were known :

i. maximum length

ii. maximum width

iii. width at the RU point

iv. anterior length.

These 4 measurements were marked out on tracing paper in relation to a reference point and a median sagittal plane and this tracing paper was superimposed on the composite trace. A trace was made through the points laid out on the tracing paper and the main mass of the composite trace (Fig. 81).

This trace, which represented the size and form of the individual traces comprising the composite trace, was known as the BUCCAL OUTLINE. The 13 Buccal Outlines of the maxillary cast sample are shown in Figs. 82 to 85 .

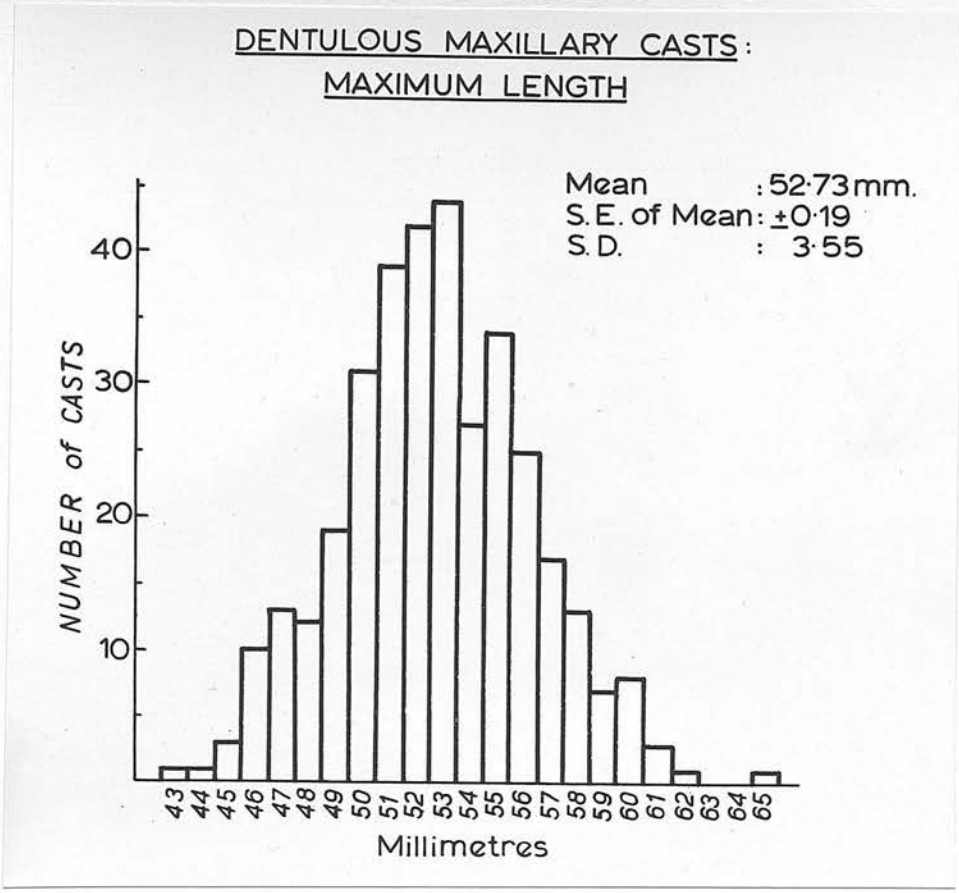


Table 11

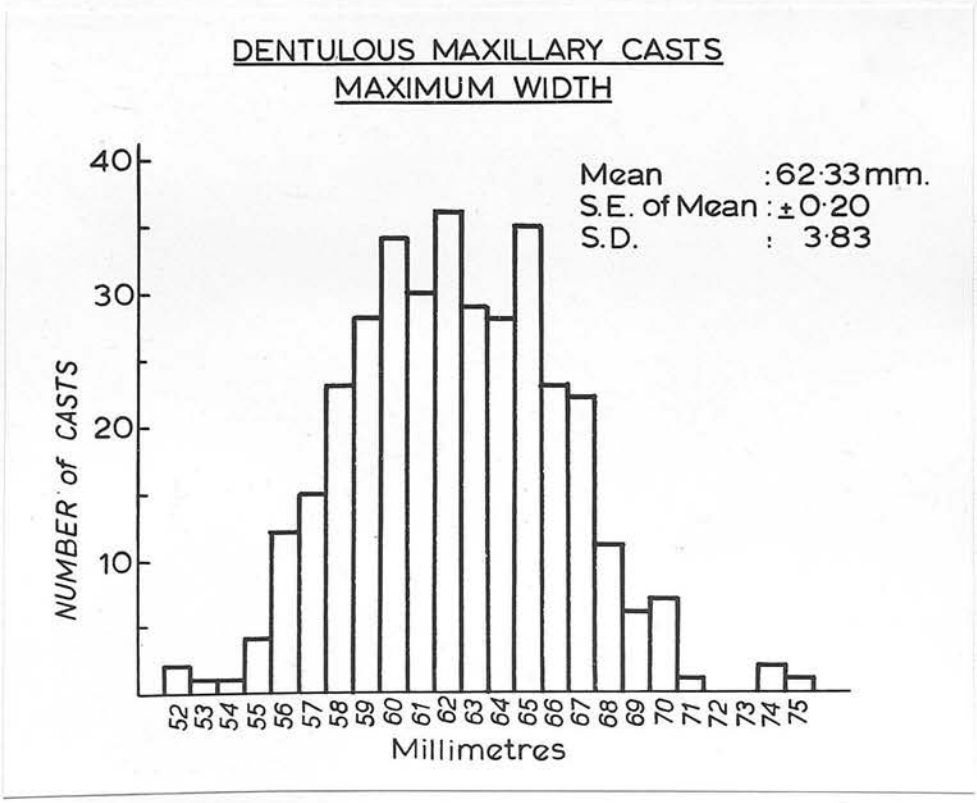


Table 13

GROUPING OF 351 DENTULOUS MAXILLARY CASTS
BY MAXIMUM LENGTH and MAXIMUM WIDTH

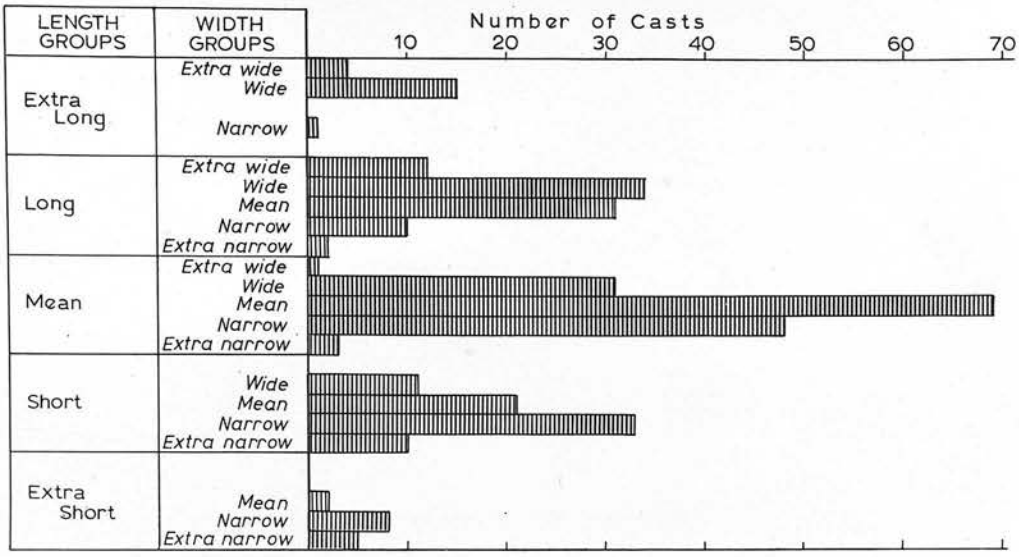


Table 15

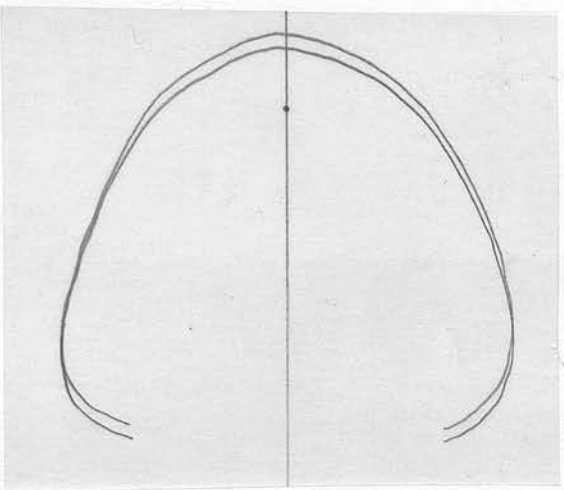
13 groups :

	Maximum Length	Maximum Width
1	EXTRA LONG	Wide
2	LONG	Extra Wide
3	"	Wide
4	"	Mean
5	"	Narrow
6	MEAN	Wide
7	"	Mean
8	"	Narrow
9	SHORT	Wide
10	"	Mean
11	"	Narrow
12	"	Extra Narrow
13	EXTRA SHORT	Narrow

DENTULOUS MAXILLARY CASTS

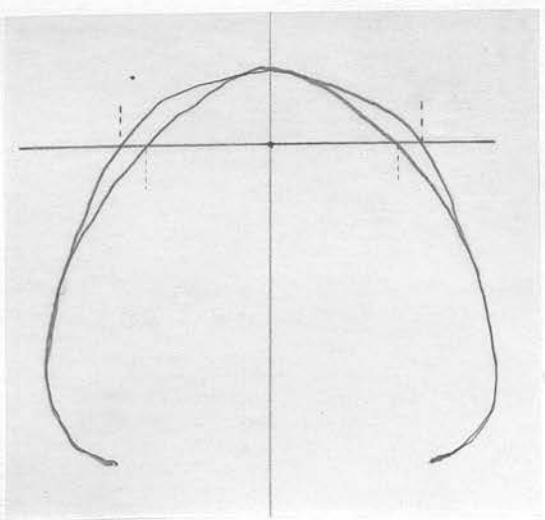
Composite trace of 69 individual traces of Mean Length : Mean Width group.

Fig. 78



Two traces with different anterior lengths superimposed on a common reference point.

Fig. 79



Two traces, of different width at the RU point, superimposed.

Fig. 80

DENTULOUS MAXILLARY CASTS:
WIDTH at RU point

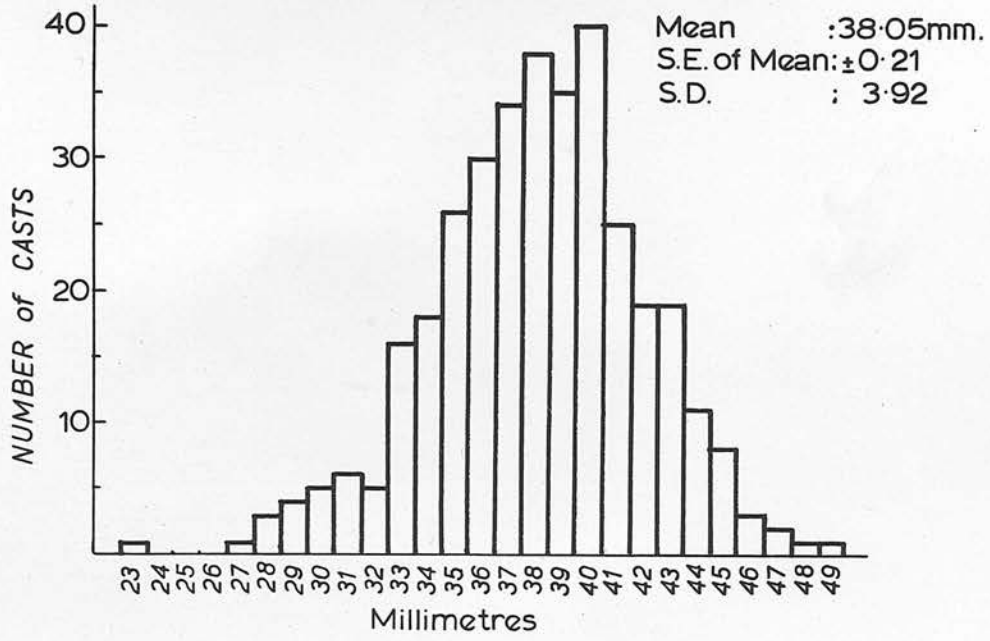
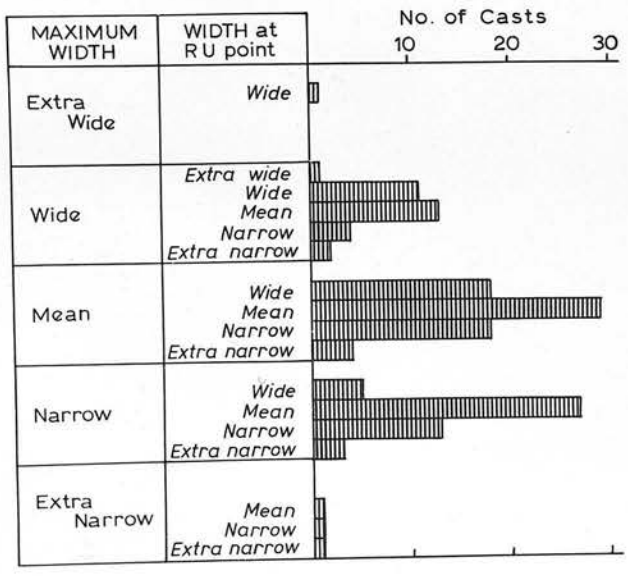


Table 16

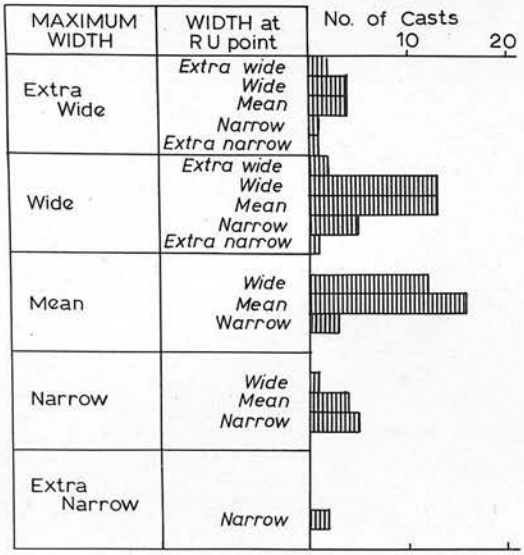
DENTULOUS MAXILLARY CASTS
Length Group : MEAN (52·73mm.)
152 casts (43·3% of total)



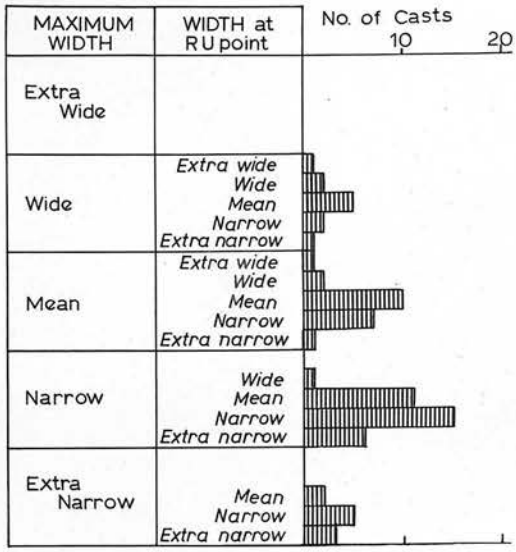
Frequency distribution of the width at the RU point.

Table 18

DENTULOUS MAXILLARY CASTS
Length Group: LONG (56·28mm.)
89 casts (25·4% of total)



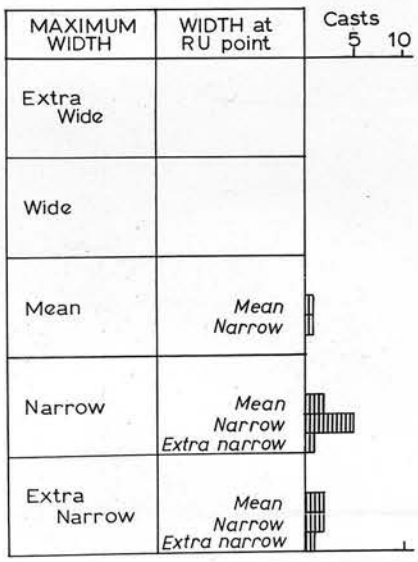
DENTULOUS MAXILLARY CASTS
Length Group: SHORT (49·18mm.)
75 casts (21·3% of total)



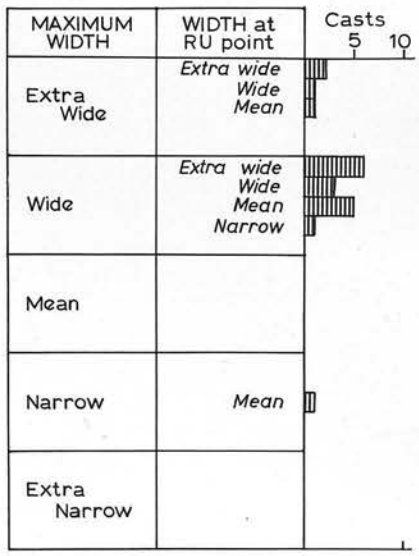
Frequency distribution of the width at the RU point.

Table 19

DENTULOUS MAXILLARY CASTS
Length Group: EXTRA SHORT (45·63 mm.)
15 casts (4·3% of total)

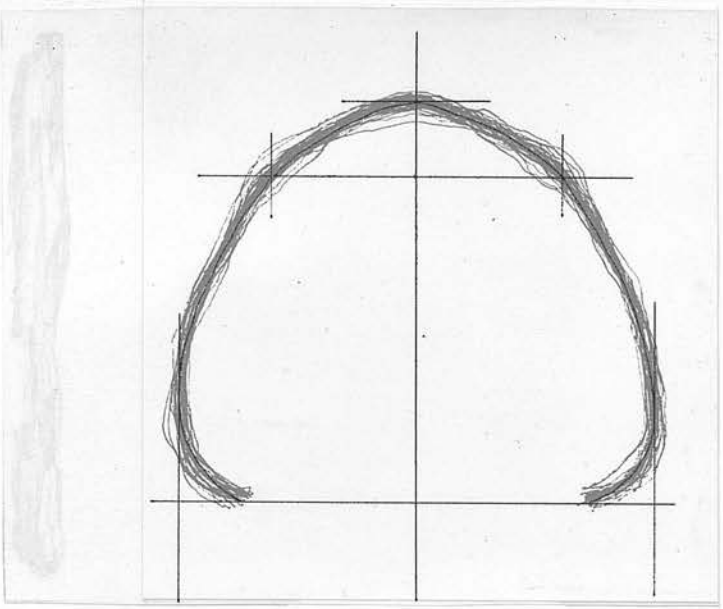


DENTULOUS MAXILLARY CASTS
Length Group: EXTRA LONG (59·83mm.)
20 casts (5·7% of total)



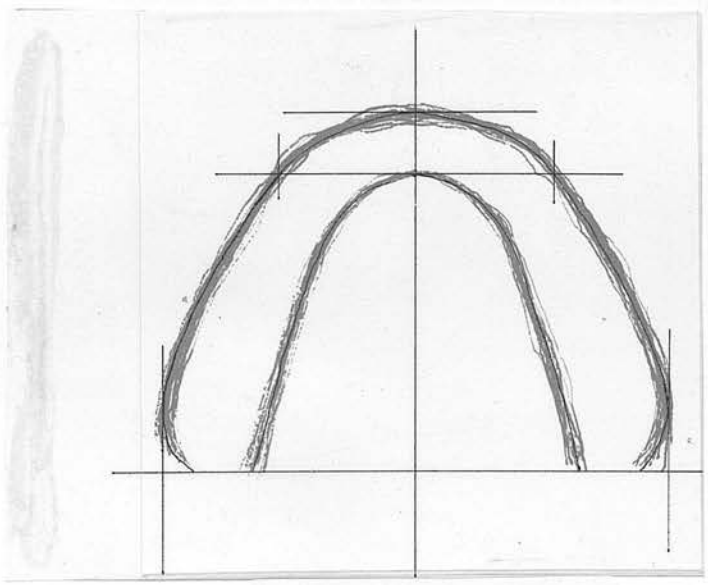
Frequency distribution of the width at the RU point.

Table 20



Tracing of
BUCCAL OUTLINE on
composite trace.

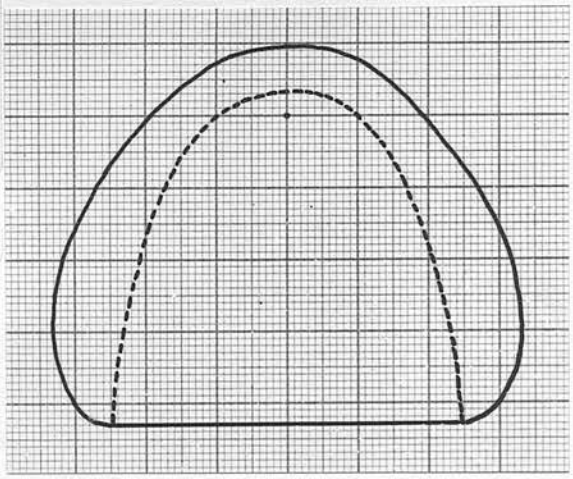
Fig. 81



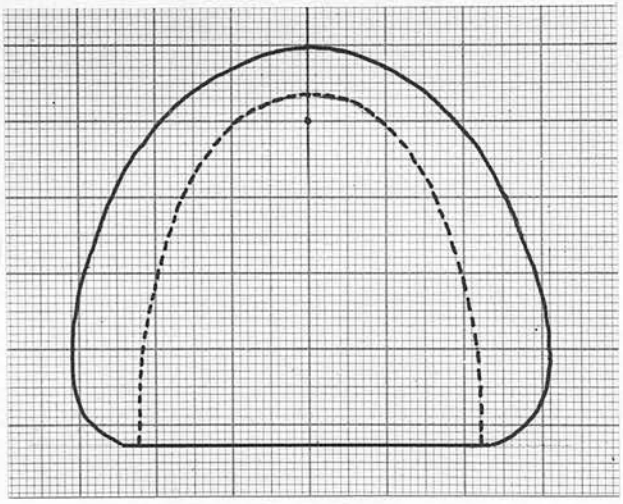
Tracing of BUCCAL
& LINGUAL OUTLINE
on composite trace.

The solid lines represent the BUCCAL OUTLINES; the broken lines represent the RIDGE OUTLINES which are discussed later.

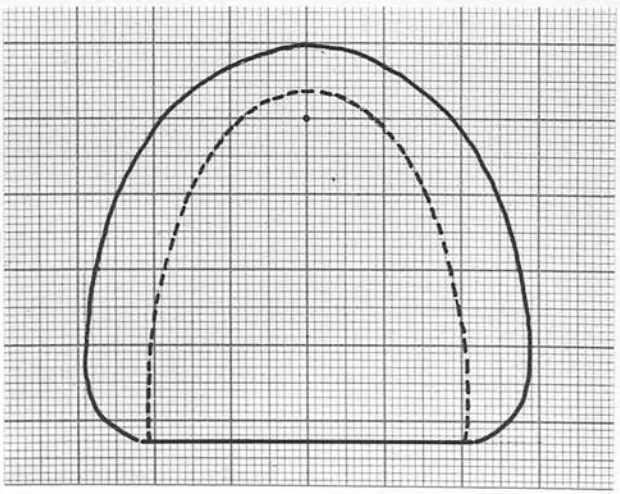
6. WIDE



7. MEAN



8. NARROW

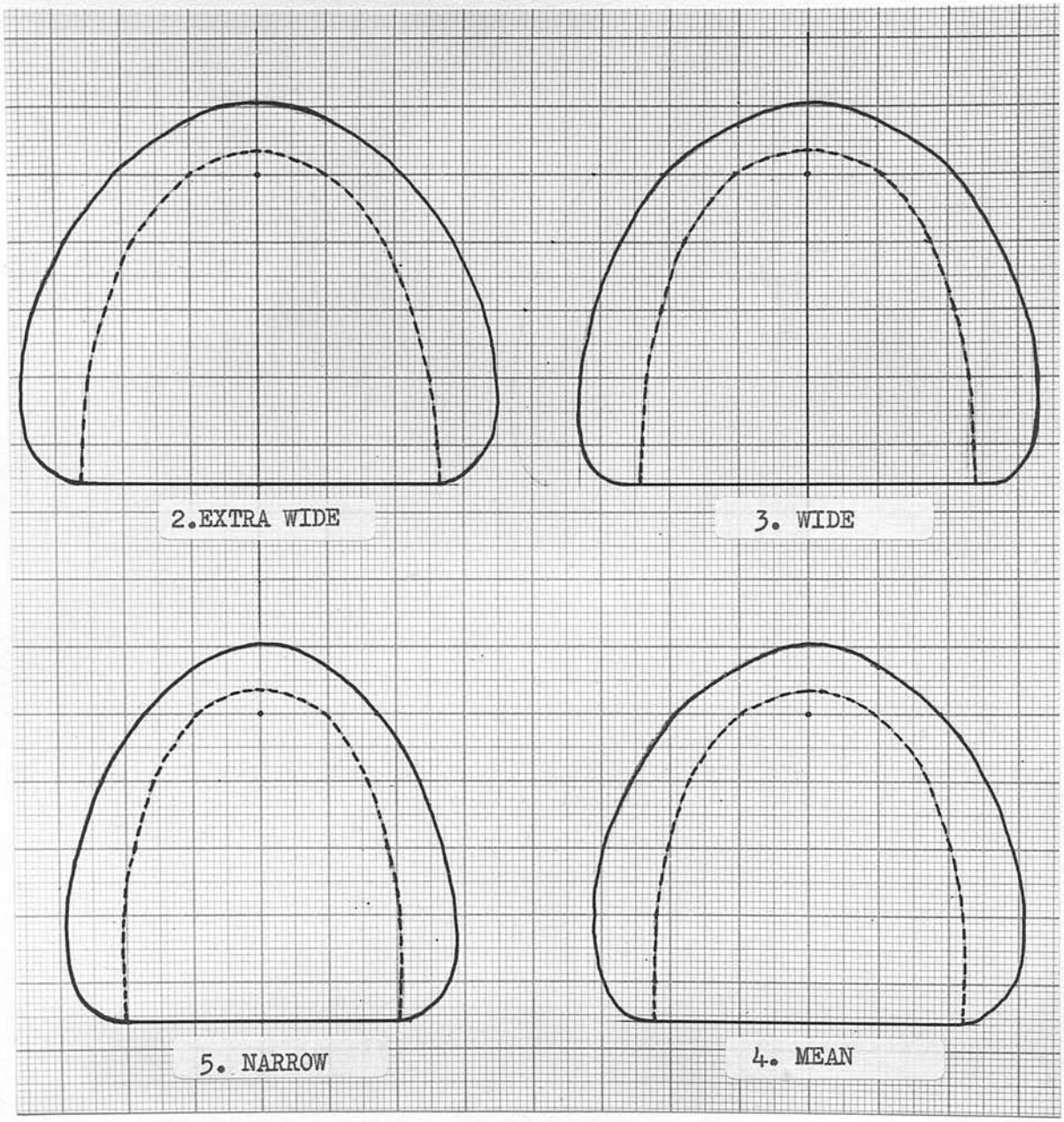


A number of the OUTLINES are reduced in size due to photographic distortion.

MAXILLARY
BUCCAL OUTLINES

Length group : MEAN

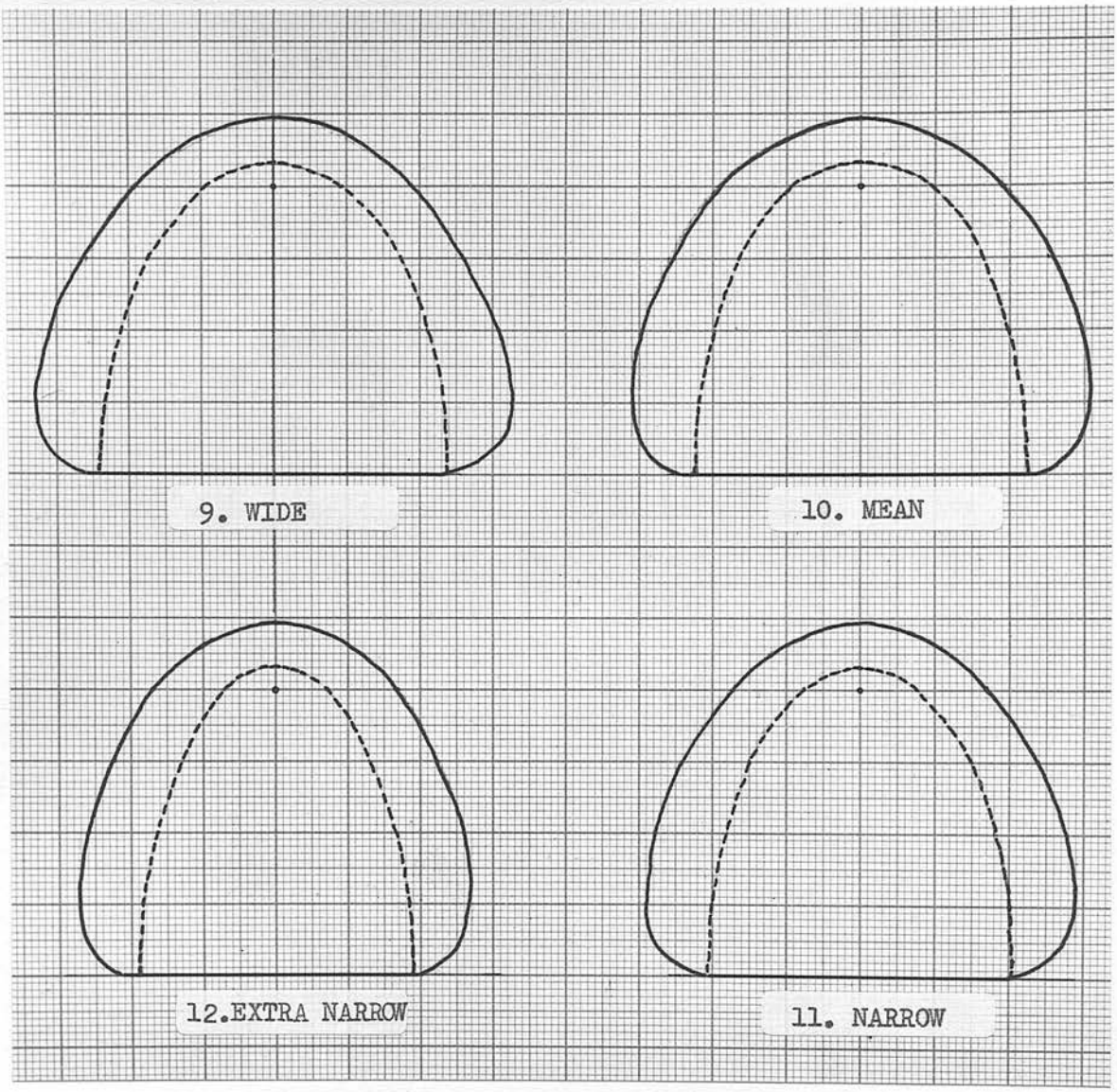
Fig. 82



MAXILLARY
BUCCAL OUTLINES

Length group : LONG

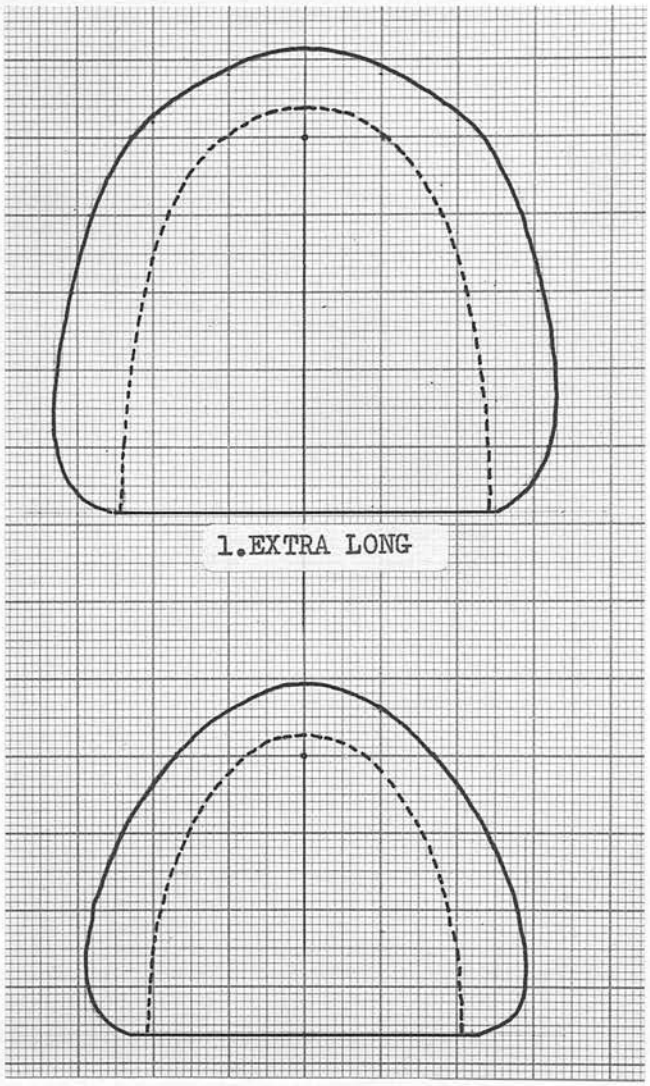
Fig. 83



MAXILLARY
BUCCAL OUTLINES

Length group : SHORT

Fig. 84



Maxillary
Buccal
Outlines

Fig. 85

3. Method of grouping the Dentulous Mandibular Casts

The method of grouping the dentulous mandibular casts was similar to that described for the maxillary casts and only the essential points of difference between the results are listed.

The measurements of Maximum Length of the casts were arranged as a frequency distribution (Table 22). The range was 37 to 55 mm. (mean 47.00 mm.; S.D. 3.49). This standard deviation was used as a method of dividing the casts into 5 groups which were designated as follows :

Group		Length	Group borders
Extra Long	: mean + 2 S.D. =	53.98 mm.	53 mm.
Long	: mean + 1 S.D. =	50.49 mm.	49 to 52 mm.
Mean	:	47.00 mm.	45 to 48 mm.
Short	: mean - 1 S.D. =	43.51 mm.	41 to 44 mm.
Extra Short	: mean - 2 S.D. =	40.02 mm.	40 mm.

Each cast was allocated into one of the 5 Length Groups according to the maximum length of that cast (Table 23).

TABLE 23.

351 DENTULOUS MANDIBULAR CASTS : MAXIMUM LENGTH

Mean 47.00 mm.

S.D. 3.49

Division of casts into 5 groups

40.02 mm.	43.51 mm.	47.00 mm.	50.49 mm.	53.98 mm.
EXTRA SHORT	SHORT	MEAN	LONG	EXTRA LONG
40 mm. or below	41-44 mm.	45-48 mm.	49-52 mm.	53 mm. or above
11 casts (3.4 %)	83 casts (23.6 %)	130 casts (37.0 %)	113 casts (32.0 %)	14 casts (4.0 %)

The measurements of Maximum Width were also arranged as a frequency distribution (Table 24). The range was 57 to 76 mm. (mean 66.70 mm.; S.D. 3.29) and 5 groups were designated as follows :

Group		Width	Group borders
Extra Wide	: mean + 2 S.D. =	73.28 mm.	73 mm.
Wide	: mean + 1 S.D. =	69.99 mm.	69 to 72 mm.
Mean	:	66.70 mm.	65 to 68 mm.
Narrow	: mean - 1 S.D. =	63.41 mm.	61 to 64 mm.
Extra Narrow	: mean - 2 S.D. =	60.12 mm.	60 mm.

and each cast was allocated into one of 5 Width Groups (Table 25).

TABLE 25 .

351 DENTULOUS MANDIBULAR CASTS : MAXIMUM WIDTH

Mean 66.70 mm.

S.D. 3.29

Division of casts into 5 groups

60.12 mm.	63.41 mm.	66.70 mm.	69.99 mm.	73.28 mm.
EXTRA NARROW	NARROW	MEAN	WIDE	EXTRA WIDE
60 mm. or below	61-64 mm.	65-68 mm.	69-72 mm.	73 mm. or above
12 casts (3.5 %)	78 casts (22.2 %)	156 casts (44.4 %)	96 casts (27.3 %)	9 casts (2.6 %)

Each dentulous mandibular cast was thus placed into one of 25 groups according to the maximum length and maximum width of the cast.

It was found that 94.6% of the total number of casts were placed in 13 of the 25 groups. The remaining 5.4% (19 casts) were distributed in 9 groups, while in 3 groups no casts were placed.

The frequency distribution of the groups, and the 13 groups which contained the majority of the casts of the sample, are listed in Table 26 .

A composite trace of each of the 13 groups was made by superimposition of the individual traces on the RL point and on a line through the RL point and Posterior Midpoint (Fig.86).

The measurements of the Width at the RL point were arranged as a frequency distribution (Table 27). The range was 29 to 47 mm. (mean 36.18; S.D. 2.45). The traces were divided into 5 groups :

Group		Width at RL point	Group borders
Extra Wide	: mean + 2 S.D. =	41.08 mm.	41 mm.
Wide	: mean + 1 S.D. =	38.63 mm.	38 to 40 mm.
Mean	:	36.18 mm.	35 to 37 mm.
Narrow	: mean - 1 S.D. =	33.73 mm.	32 to 34 mm.
Extra Narrow	: mean - 2 S.D. =	31.28 mm.	31 mm.

and each trace was allocated into one of these groups (Table 28).

TABLE 28.

351 DENTULOUS MANDIBULAR CASTS : WIDTH at RL point

Mean 36.18 mm.

S.D. 2.45

Division of casts into 5 groups

31.28 mm.	33.73 mm.	36.18 mm.	38.63 mm.	41.08 mm.
EXTRA NARROW	NARROW	MEAN	WIDE	EXTRA WIDE
31 mm. or below	32-34 mm.	35-37 mm.	38-40 mm.	41 mm. or above
5 casts (1.5 %)	83 casts (23.6 %)	167 casts (47.6 %)	82 casts (23.3 %)	14 casts (4.0 %)

The traces were then arranged to show the frequency distribution of the width at the RL point throughout the total sample (Tables 29 to 32). The width at the RL point selected in the 13 groups was the width which occurred most frequently in each of the groups.

Thus the 13 groups were further designated in Table 33 .

TABLE 33 .

Designation of 13 groups of Dentulous Mandibular casts.

	Maximum Length	Maximum Width	Width at RL point
1	EXTRA LONG	Mean	Mean
2	LONG	Extra Wide	Wide
3	"	Wide	Mean
4	"	Mean	Mean
5	"	Narrow	Mean
6	MEAN	Wide	Wide
7	"	Mean	Mean
8	"	Narrow	Narrow
9	SHORT	Wide	Mean
10	"	Mean	Mean
11	"	Narrow	Mean
12	"	Extra Narrow	Narrow
13	EXTRA SHORT	Narrow	Mean

The range and mean of the anterior length of the mandibular casts of each Length Group were as follows :

Length Group	Anterior Length (mm.)	
	Mean	Range
EXTRA LONG	8.57	7 - 11
LONG	8.34	7 - 10
MEAN	8.10	6 - 11
SHORT	8.01	7 - 10
EXTRA SHORT	8.00	7 - 9

Thus, in each of the 13 composite traces, 4 measurements were known :

i. maximum length

ii. maximum width

iii. width at the RL point

iv. anterior length

These 4 measurements were marked out on tracing paper and a trace was made through the points and the buccal and lingual outlines of the composite trace (Fig. 81). This trace was known as the BUCCAL & LINGUAL OUTLINE.

The 13 Buccal & Lingual Outlines of the mandibular cast sample are shown in Figs. 87 to 90 .

DENTULOUS MANDIBULAR CASTS:
MAXIMUM LENGTH.

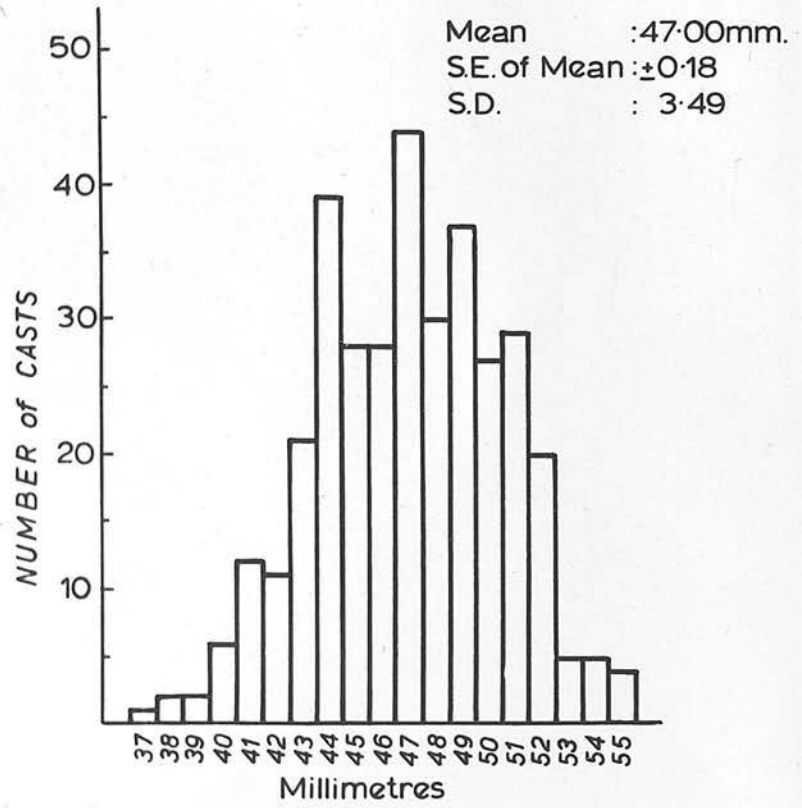


Table 22

DENTULOUS MANDIBULAR CASTS:
MAXIMUM WIDTH.

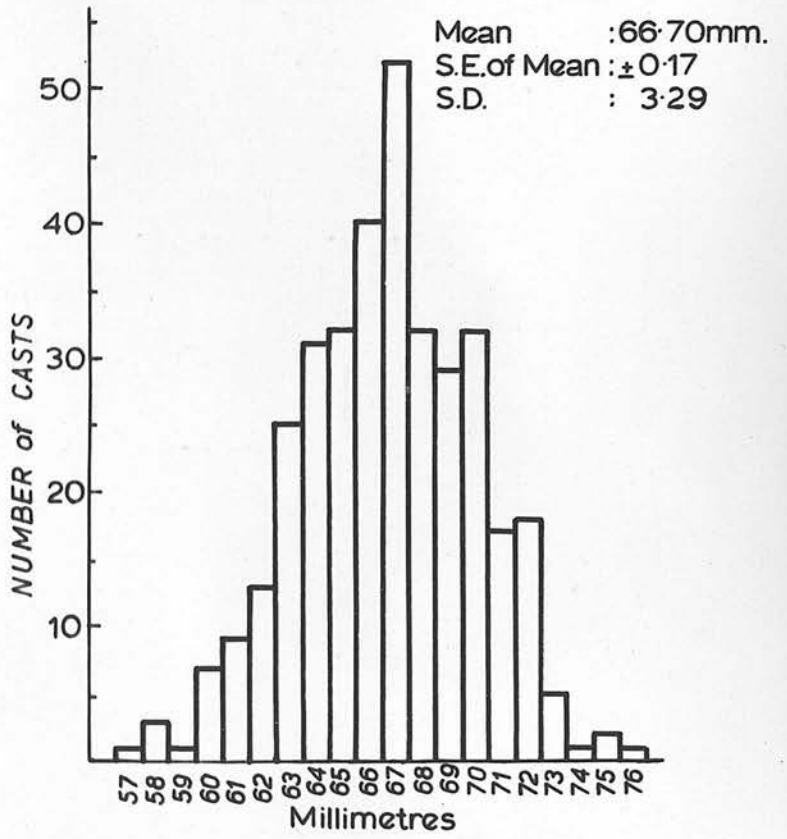


Table 24

GROUPING OF 351 DENTULOUS MANDIBULAR CASTS
BY MAXIMUM LENGTH and MAXIMUM WIDTH

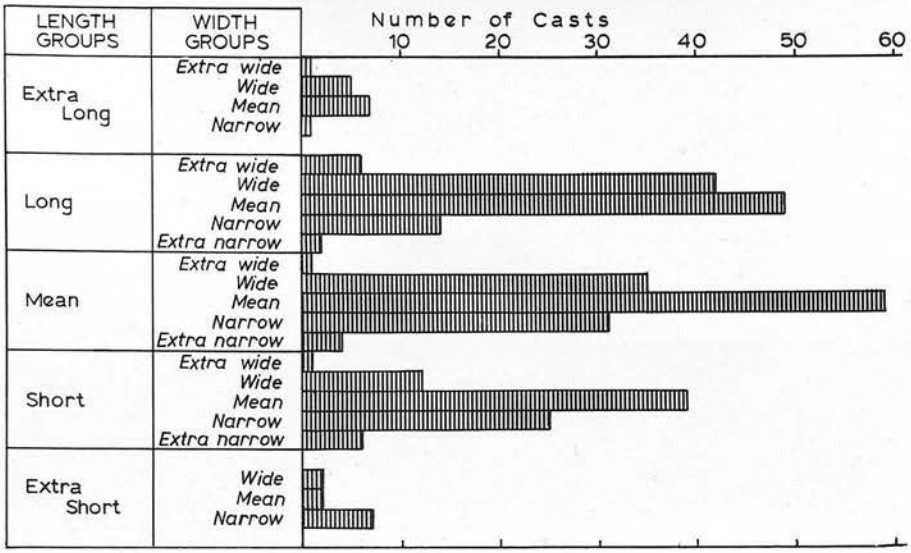
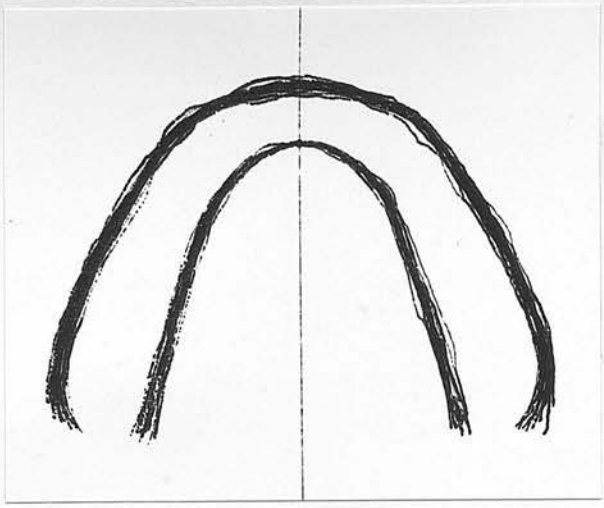


Table 26

13 groups :

	Maximum Length	Maximum Width
1	EXTRA LONG	Mean
2	LONG	Extra Wide
3	"	Wide
4	"	Mean
5	"	Narrow
6	MEAN	Wide
7	"	Mean
8	"	Narrow
9	SHORT	Wide
10	"	Mean
11	"	Narrow
12	"	Extra Narrow
13	EXTRA SHORT	Narrow



DENTULOUS MANDIBULAR CASTS

Composite trace of 59 individual traces of Mean Length : Mean Width group.

Fig. 86

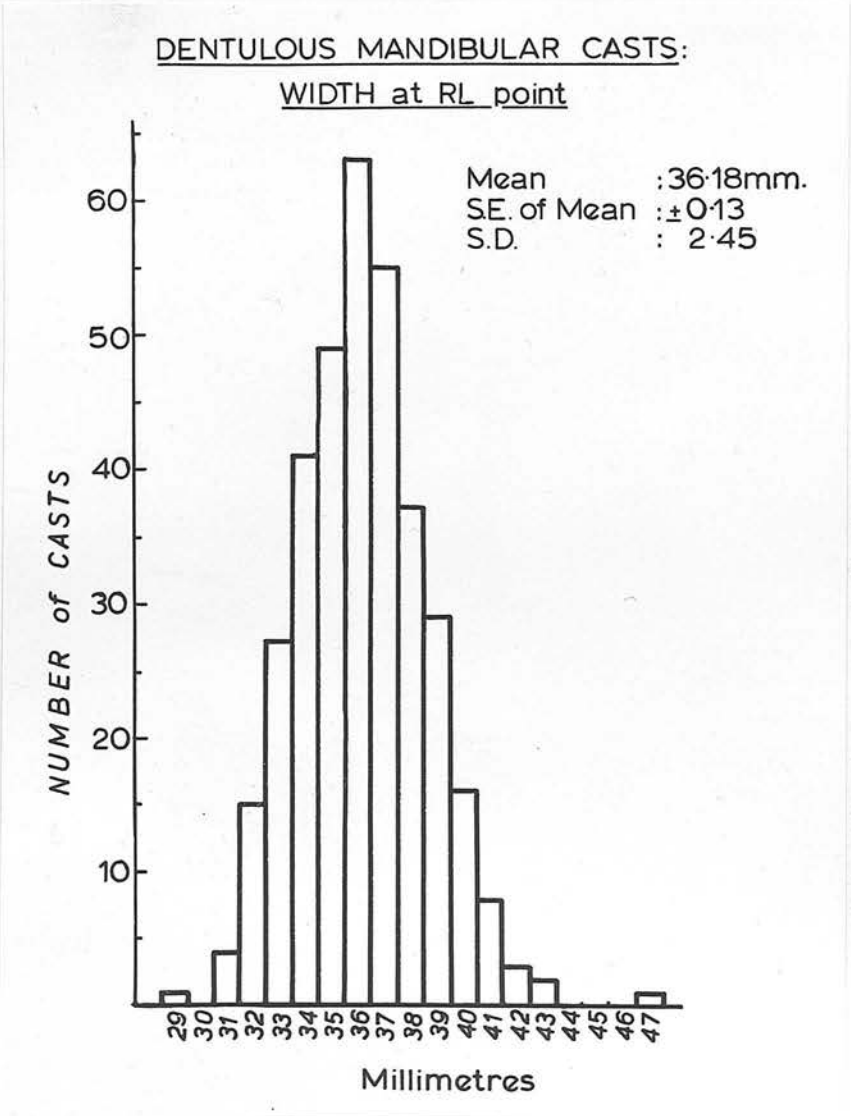
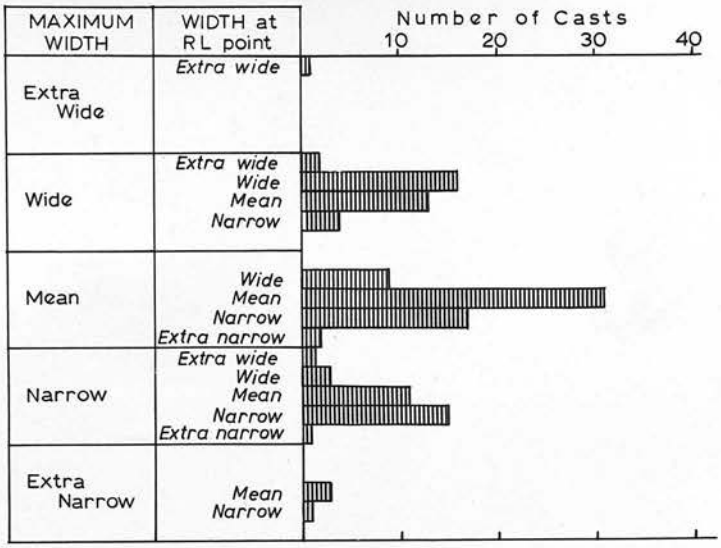


Table 27

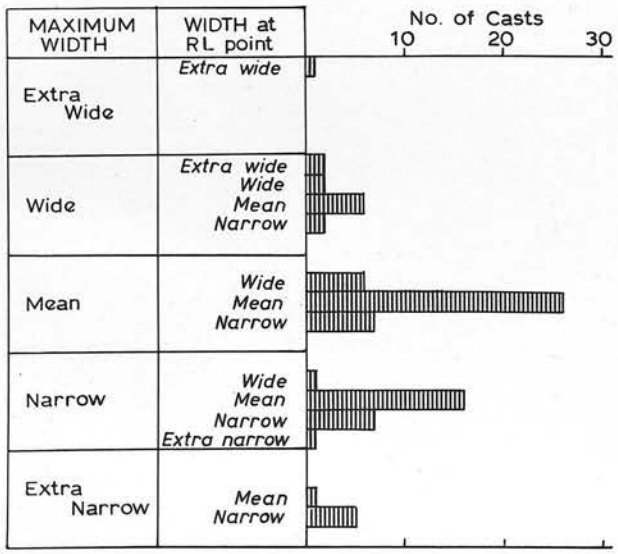
DENTULOUS MANDIBULAR CASTS
Length Group: MEAN (47·0mm.)
130 casts (37·0% of total)



Frequency distribution of the width at the RL point.

Table 29

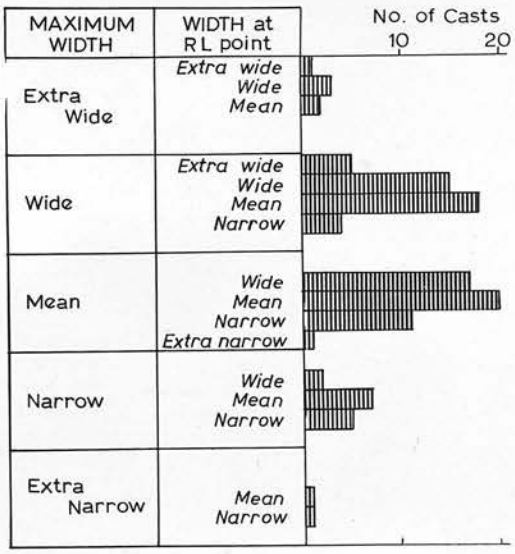
DENTULOUS MANDIBULAR CASTS
Length Group: SHORT (43·51mm.)
83 casts (23·6% of total)



Frequency distribution of the width at the RL point.

Table 30

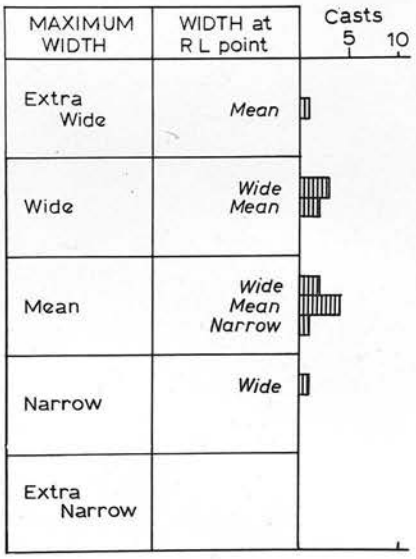
DENTULOUS MANDIBULAR CASTS
Length Group: LONG (50·49 mm.)
113 casts (32·0% of total)



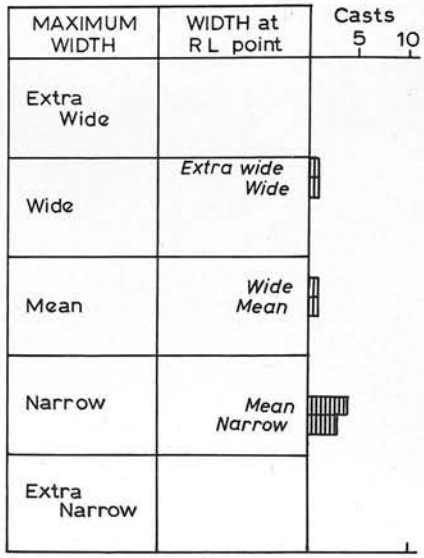
Frequency distribution of the width at the RL point.

Table 31

DENTULOUS MANDIBULAR CASTS
Length Group: EXTRA LONG (53·98 mm.)
14 casts (4·0% of total)



DENTULOUS MANDIBULAR CASTS
Length Group: EXTRA SHORT (40·02 mm.)
11 casts (3·4% of total)



Frequency distribution of the width at the RL point.

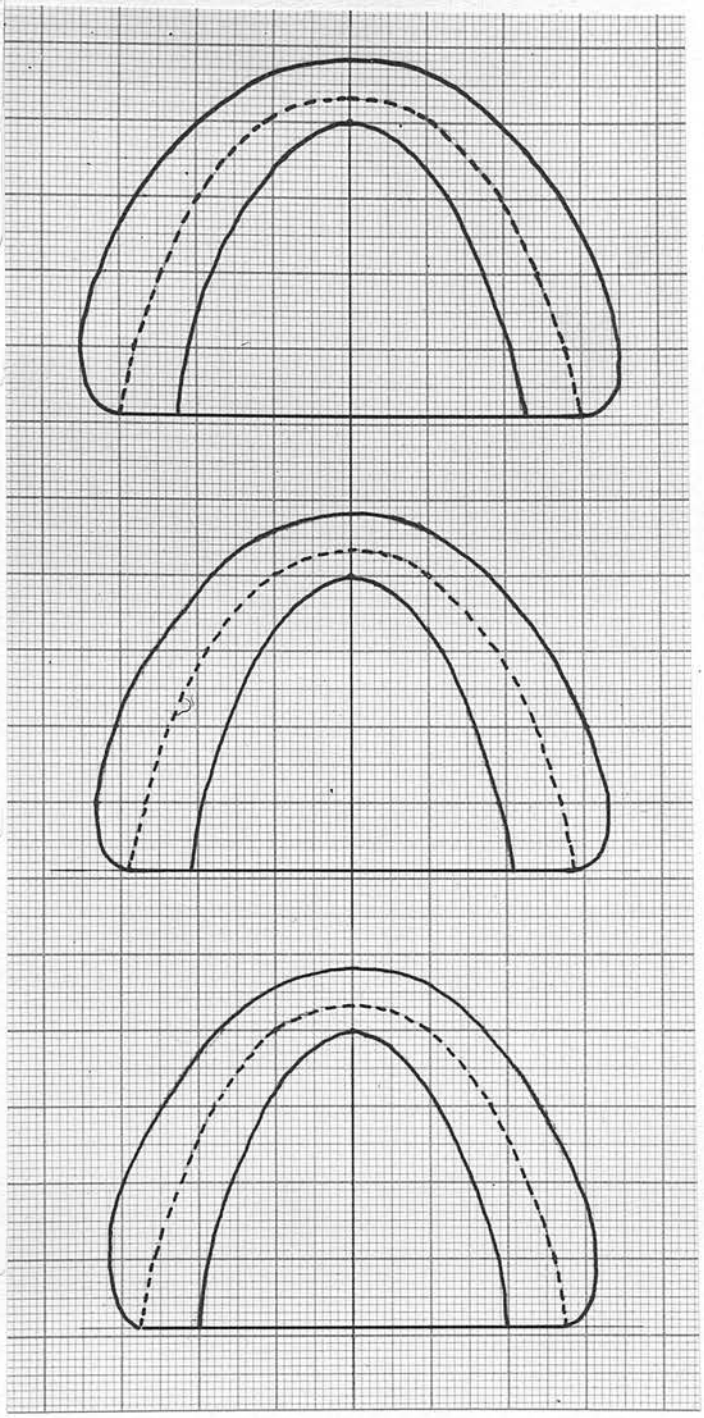
Table 32

The solid lines represent the BUCCAL & LINGUAL OUTLINES; the broken lines represent the RIDGE OUTLINES which are discussed later.

6. WIDE

7. MEAN

8. NARROW

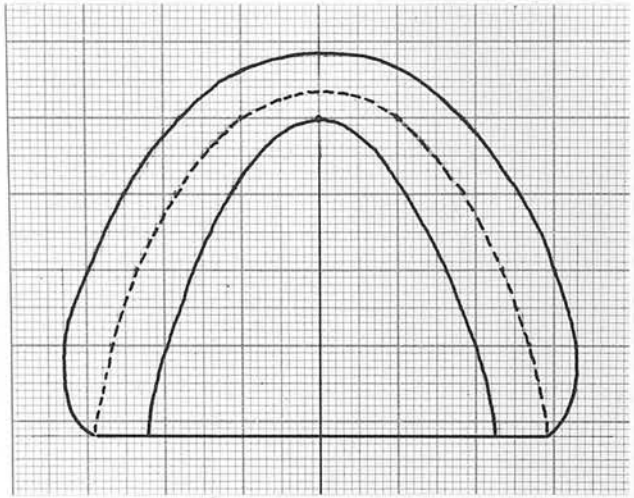


A number of the OUTLINES are reduced in size due to photographic distortion.

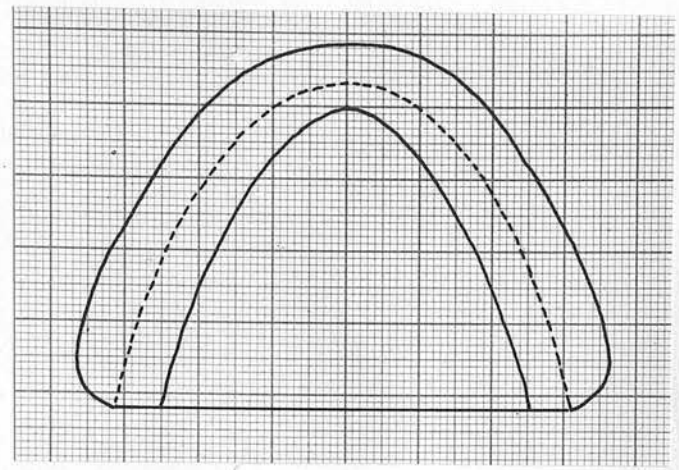
MANDIBULAR BUCCAL & LINGUAL OUTLINES.

Length group : MEAN

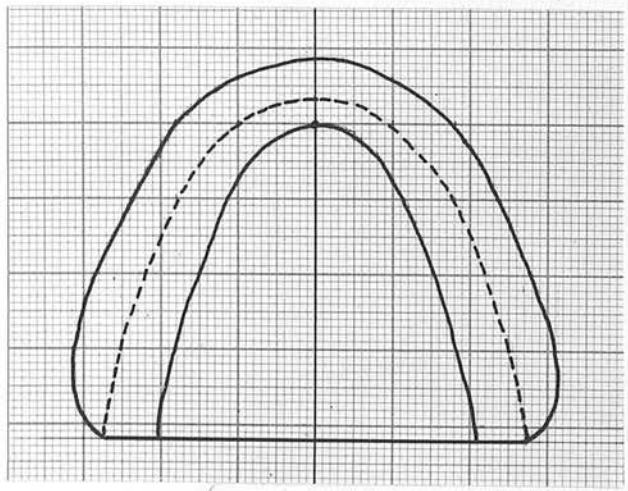
Fig. 87



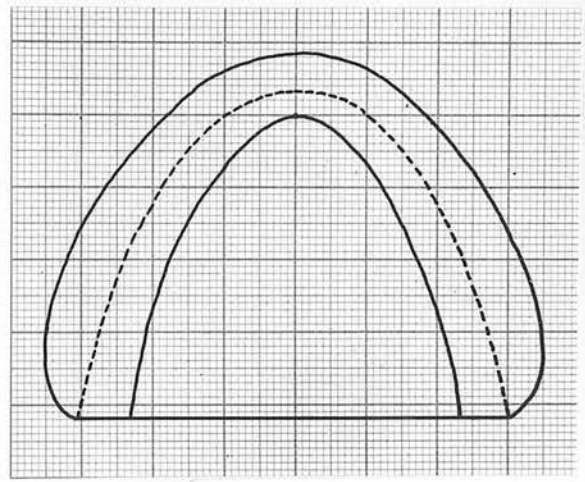
4. MEAN



2.EXTRA WIDE



5. NARROW

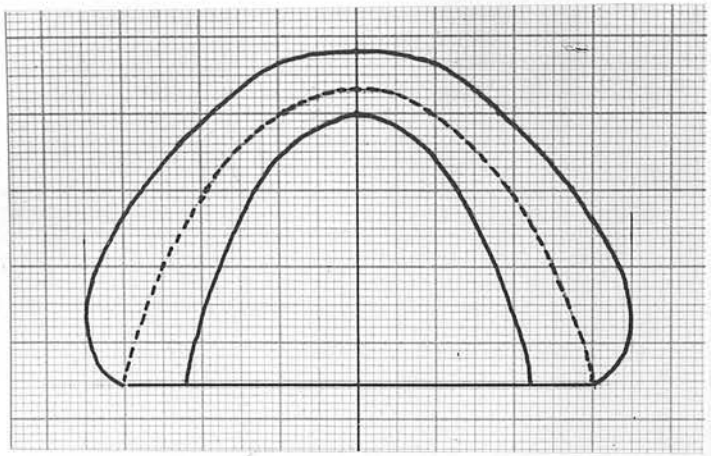


3. WIDE

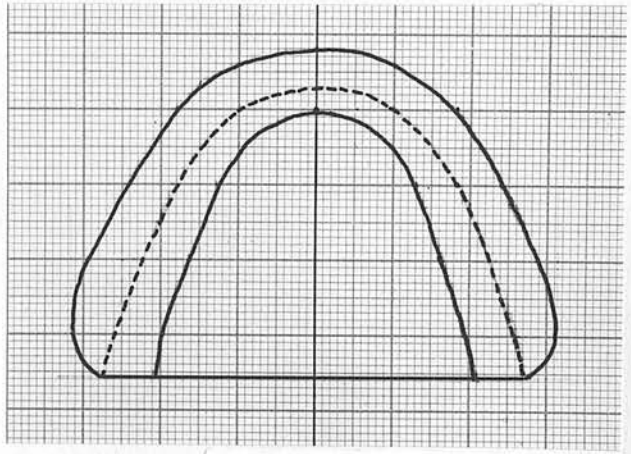
Fig. 88

MANDIBULAR
BUCCAL & LINGUAL
OUTLINES.

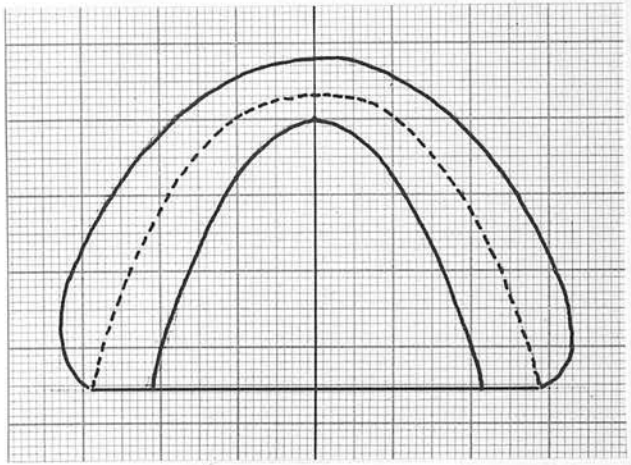
Length group : LONG



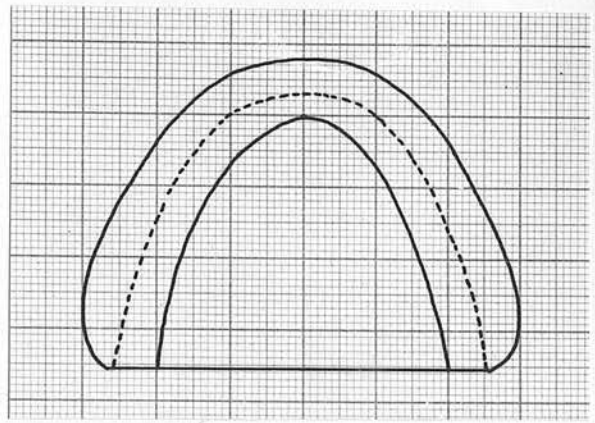
9. WIDE



11. NARROW



10. MEAN

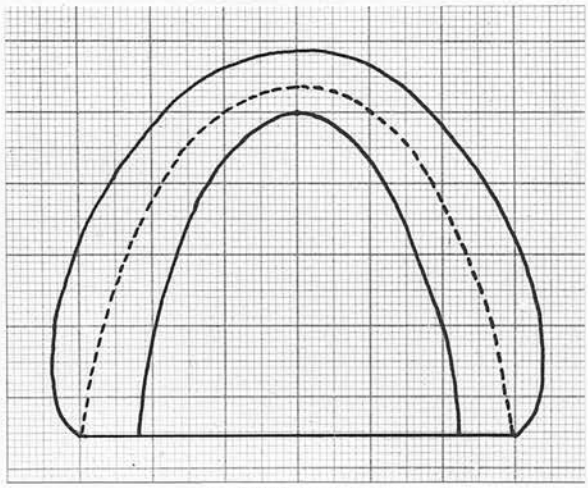


12.EXTRA NARROW

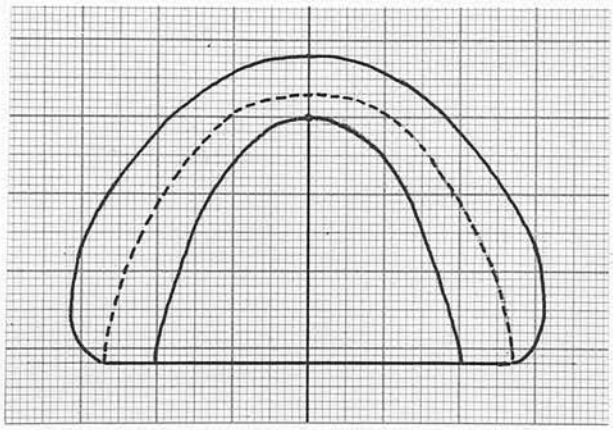
MANDIBULAR
BUCCAL & LINGUAL
OUTLINES.

Length Group : SHORT

Fig. 89



1.EXTRA LONG



13.EXTRA SHORT

MANDIBULAR
BUCCAL & LINGUAL
OUTLINES.

Fig. 90

4. Vertical measurements of Dentulous Casts

(a) Vertical measurements were made of each of the 702 dentulous casts from the horizontal plane through the reference point to the mucogingival line. The measurements were made in coronal planes on the right and left sides of the casts, and also in the median sagittal plane.

The measurements were tabulated for casts of similar length i.e. the 5 Length Groups. This was done for the reason mentioned previously, viz. that, on casts of different length, the various coronal planes crossed at different anatomical positions and vertical measurements were more relevant if tabulated for casts of similar length.

The range and means of the measurements of the dentulous maxillary casts, known as the VERTICAL BUCCAL MEASUREMENTS, are listed, for each of the 5 Length Groups, in Table 34 and shown graphically in Fig. 91 .

The range and means of the measurements of the dentulous mandibular casts, known as the VERTICAL BUCCAL and VERTICAL LINGUAL MEASUREMENTS, are listed in Tables 35 & 36 and shown graphically in Figs. 92 & 93 .

It was seen that differences between the vertical measurements of the right and left sides of the casts were small.

(b) In the 351 dentulous maxillary casts, vertical measurements were also made from the horizontal reference plane to the palate surface in the median sagittal plane. These were known as the dentulous PALATE MEASUREMENTS and the results, for the casts in each of the 5 Length Groups, are shown in Table 37 .

TABLE 34.

351 DENTULOUS MAXILLARY CASTS : VERTICAL BUCCAL MEASUREMENTS

Vertical measurements in millimetres from the horizontal reference plane to the buccal mucogingival line.

GROUP		RIGHT CORONAL PLANES					Median Sagittal Plane	LEFT CORONAL PLANES				
		40 mm.	30 mm.	20 mm.	10 mm.	RU		RU	10 mm.	20 mm.	30 mm.	40 mm.
EXTRA LONG	Mean	7.35	6.34	4.60	3.58	5.82	3.18	5.85	4.05	4.93	7.00	6.90
	Range	4.0 11.0	3.0 9.0	1.5 8.0	1.0 7.0	2.0 9.0	1.0 5.0	2.0 9.0	2.0 8.0	2.0 8.0	4.0 9.0	4.0 10.5
LONG	Mean	5.92	6.50	4.95	4.38	6.43	3.47	6.34	4.25	4.92	6.65	5.75
	Range	3.0 10.0	3.0 10.0	2.0 8.5	1.5 8.0	2.0 11.5	1.0 7.0	2.0 11.0	1.5 8.0	2.0 9.0	3.0 10.0	2.0 10.0
MEAN	Mean	5.54	6.94	5.29	4.44	6.00	3.22	6.01	4.45	5.43	7.09	5.51
	Range	3.0 10.5	4.0 10.0	3.0 8.5	2.0 7.0	2.0 10.0	1.0 6.5	2.0 11.0	2.0 7.0	3.0 9.0	4.0 10.5	2.5 10.0
SHORT	Mean	4.66	7.06	5.67	4.63	6.13	3.52	6.16	4.53	5.73	6.99	4.53
	Range	2.0 7.5	3.0 10.5	2.0 8.5	1.0 9.0	2.0 10.0	1.0 7.0	2.0 10.0	1.0 9.0	2.0 8.5	3.0 10.0	2.0 7.0
EXTRA SHORT	Mean	-	5.92	5.53	4.20	5.40	2.50	5.36	4.24	5.86	5.45	-
	Range	-	3.5 8.0	3.5 8.0	3.5 5.5	4.5 9.0	1.0 5.5	3.5 9.0	3.0 6.0	3.5 9.0	4.0 7.0	-

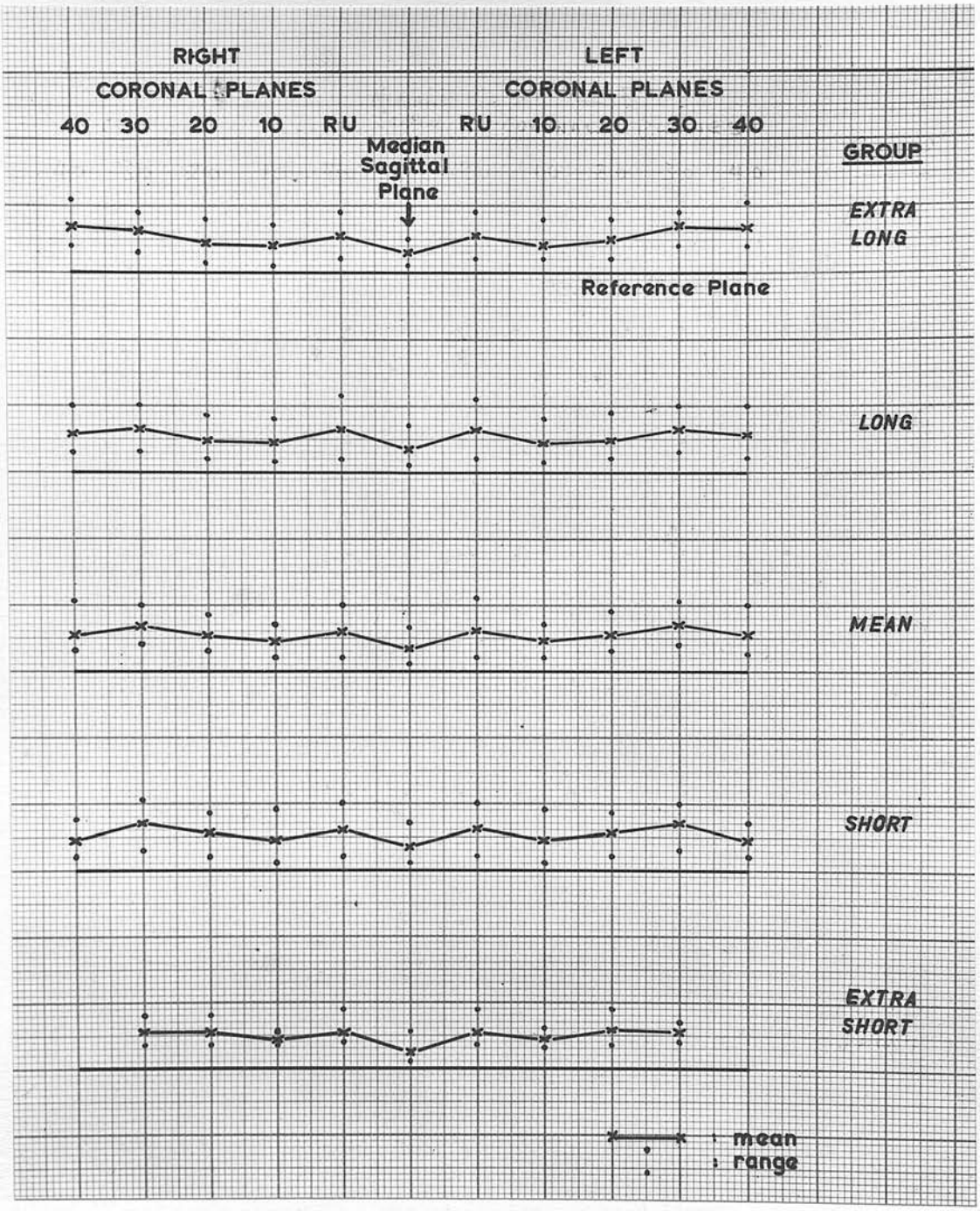


Fig. 91

DENTULOUS MAXILLARY CASTS

Vertical Buccal Measurements of each Length Group.

TABLE 35 .

351 DENTULOUS MANDIBULAR CASTS : VERTICAL BUCCAL MEASUREMENTS

Vertical measurements in millimetres from the horizontal plane through the RL point to the BUCCAL mucogingival line.

NOTE: a + sign signified the measurement was superior to the horizontal plane through the RL point.
a - sign signified the measurement was inferior to the horizontal plane through the RL point.

GROUP		RIGHT CORONAL PLANES					Median Sagittal Plane	LEFT CORONAL PLANES				
		40 mm.	30 mm.	20 mm.	10 mm.	RL		RL	10 mm.	20 mm.	30 mm.	40 mm.
EXTRA LONG	Mean	+11.43	+ 5.10	+1.55	0	-0.74	+0.10	-0.80	0	+1.49	+5.19	+11.42
	Range	$9^{+}_{\cdot}5$ $12^{+}_{\cdot}5$	$0^{-}_{\cdot}5$ $9^{+}_{\cdot}0$	$2^{-}_{\cdot}0$ $4^{+}_{\cdot}5$	$3^{-}_{\cdot}0$ $3^{+}_{\cdot}0$	$3^{-}_{\cdot}0$ $2^{+}_{\cdot}0$	$2^{-}_{\cdot}0$ $1^{+}_{\cdot}5$	$3^{-}_{\cdot}5$ $2^{+}_{\cdot}0$	$3^{-}_{\cdot}0$ $3^{+}_{\cdot}0$	$2^{-}_{\cdot}5$ $4^{+}_{\cdot}5$	$1^{-}_{\cdot}5$ $9^{+}_{\cdot}0$	$9^{+}_{\cdot}0$ $12^{+}_{\cdot}5$
LONG	Mean	-	+6.00	+2.06	+0.30	-0.81	+0.46	-0.80	+0.31	+2.00	+6.02	-
	Range	-	$1^{+}_{\cdot}0$ $10^{+}_{\cdot}0$	$1^{-}_{\cdot}0$ $7^{+}_{\cdot}0$	$3^{-}_{\cdot}5$ $3^{+}_{\cdot}5$	$4^{-}_{\cdot}5$ $4^{+}_{\cdot}0$	$3^{-}_{\cdot}0$ $4^{+}_{\cdot}0$	$4^{-}_{\cdot}5$ $4^{+}_{\cdot}0$	$3^{-}_{\cdot}5$ $3^{+}_{\cdot}5$	$1^{-}_{\cdot}5$ $7^{+}_{\cdot}0$	$1^{+}_{\cdot}5$ $10^{+}_{\cdot}0$	-
MEAN	Mean	-	+6.85	+1.90	-0.10	-1.12	+0.13	-1.10	-0.08	+2.00	+6.82	-
	Range	-	$3^{+}_{\cdot}0$ $11^{+}_{\cdot}0$	$1^{-}_{\cdot}0$ $6^{+}_{\cdot}0$	$4^{-}_{\cdot}0$ $4^{+}_{\cdot}0$	$4^{-}_{\cdot}0$ $3^{+}_{\cdot}0$	$3^{-}_{\cdot}0$ $4^{+}_{\cdot}0$	$4^{-}_{\cdot}0$ $3^{+}_{\cdot}0$	$4^{-}_{\cdot}0$ $4^{+}_{\cdot}0$	$1^{-}_{\cdot}0$ $6^{+}_{\cdot}5$	$3^{+}_{\cdot}0$ $11^{+}_{\cdot}0$	-
SHORT	Mean	-	+8.27	+2.74	+0.43	-0.83	+0.10	-0.90	+0.45	+2.75	+8.40	-
	Range	-	$3^{+}_{\cdot}0$ $12^{+}_{\cdot}0$	$2^{-}_{\cdot}0$ $7^{+}_{\cdot}0$	$4^{-}_{\cdot}0$ $4^{+}_{\cdot}0$	$4^{-}_{\cdot}5$ $4^{+}_{\cdot}0$	$4^{-}_{\cdot}0$ $3^{+}_{\cdot}0$	$4^{-}_{\cdot}5$ $4^{+}_{\cdot}0$	$4^{-}_{\cdot}0$ $4^{+}_{\cdot}0$	$2^{-}_{\cdot}0$ $7^{+}_{\cdot}0$	$3^{+}_{\cdot}0$ $12^{+}_{\cdot}0$	-
EXTRA SHORT	Mean	-	+9.90	+3.45	-0.30	-1.14	-0.50	-1.20	-0.30	+3.50	+9.81	-
	Range	-	$6^{+}_{\cdot}0$ $14^{+}_{\cdot}0$	$0^{+}_{\cdot}5$ $8^{+}_{\cdot}0$	$3^{-}_{\cdot}0$ $2^{+}_{\cdot}0$	$3^{-}_{\cdot}5$ $1^{+}_{\cdot}0$	$3^{-}_{\cdot}0$ $3^{+}_{\cdot}0$	$3^{-}_{\cdot}5$ $1^{+}_{\cdot}0$	$3^{-}_{\cdot}0$ $2^{+}_{\cdot}0$	0 $8^{+}_{\cdot}0$	$6^{+}_{\cdot}0$ $14^{+}_{\cdot}0$	-

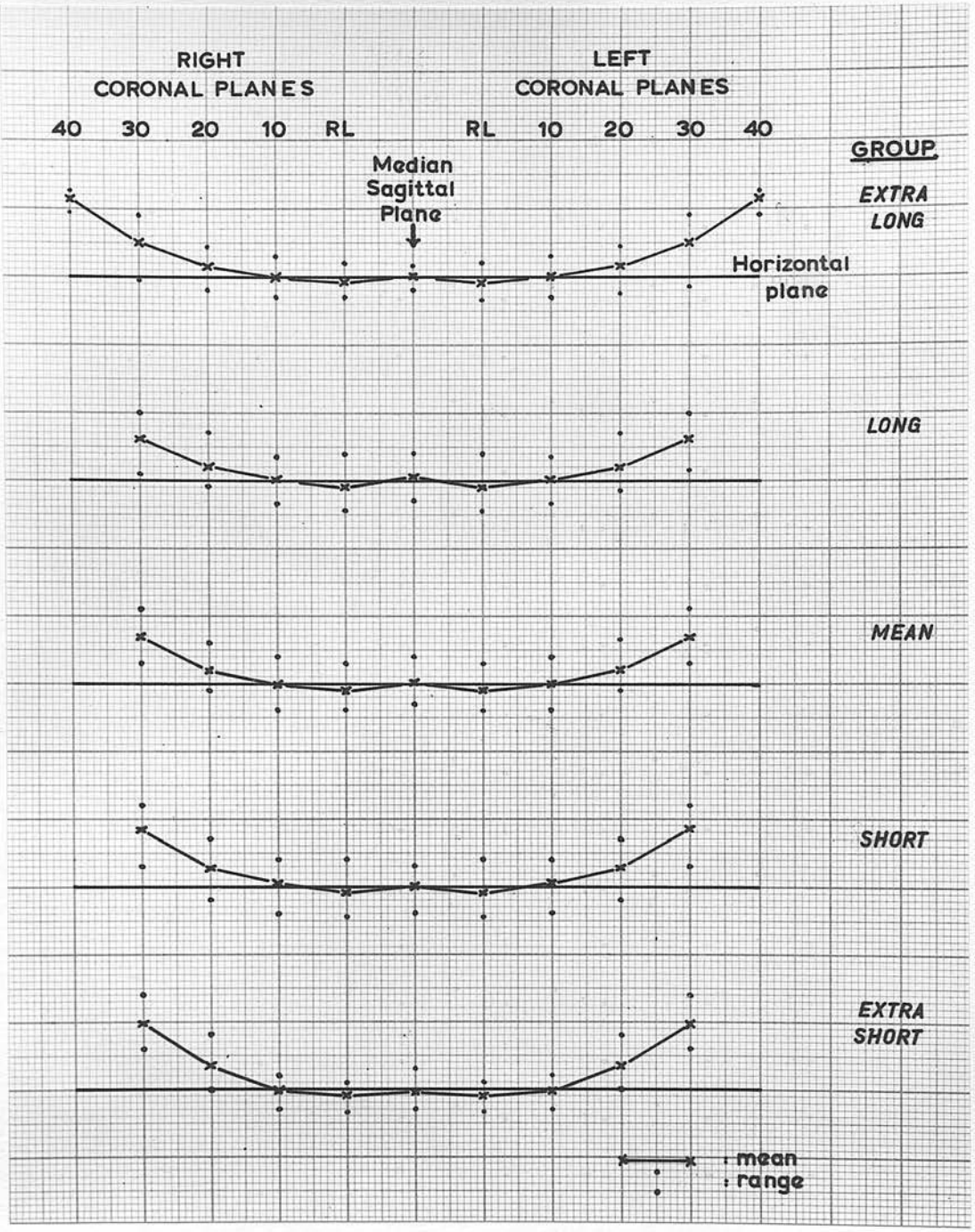


Fig. 92

DENTULOUS MANDIBULAR CASTS

Vertical Buccal Measurements of each Length Group.

TABLE 36 .

351 DENTULOUS MANDIBULAR CASTS : VERTICAL LINGUAL MEASUREMENTS

Vertical measurements in millimetres from the horizontal plane through the RL point to the LINGUAL mucogingival line.

NOTE: a + sign signified the measurement was superior to the horizontal plane through the RL point.
a - signified the measurement was inferior to the horizontal plane through the RL point.

GROUP		RIGHT CORONAL PLANES				LEFT CORONAL PLANES			
		40 mm.	30 mm.	20 mm.	10 mm.	10 mm.	20 mm.	30 mm.	40 mm.
EXTRA LONG	Mean	+ 1.75	- 1.30	- 2.10	- 0.91	- 0.90	- 2.18	- 1.32	+ 1.75
	Range	$1.^{-}_{0}$ $4.^{+}_{0}$	$4.^{-}_{0}$ $2.^{+}_{0}$	$5.^{-}_{0}$ $1.^{+}_{0}$	$4.^{-}_{0}$ $1.^{+}_{0}$	$4.^{-}_{0}$ $1.^{+}_{0}$	$5.^{-}_{5}$ $1.^{+}_{0}$	$4.^{-}_{0}$ $2.^{+}_{0}$	$1.^{-}_{0}$ $4.^{+}_{0}$
LONG	Mean	+ 2.65	- 0.46	- 1.46	- 0.65	- 0.70	- 1.50	- 0.40	+ 2.59
	Range	0 $5.^{+}_{0}$	$4.^{-}_{0}$ $3.^{+}_{0}$	$4.^{-}_{0}$ $2.^{+}_{0}$	$4.^{-}_{0}$ $4.^{+}_{0}$	$4.^{-}_{5}$ $4.^{+}_{0}$	$4.^{-}_{0}$ $2.^{+}_{0}$	$4.^{-}_{0}$ $3.^{+}_{0}$	0 $5.^{+}_{0}$
MEAN	Mean	+ 2.80	- 0.63	- 1.92	- 1.07	- 1.00	- 2.00	- 0.60	+ 2.76
	Range	0 $6.^{+}_{0}$	$3.^{-}_{5}$ $4.^{+}_{0}$	$4.^{-}_{5}$ $2.^{+}_{0}$	$4.^{-}_{0}$ $3.^{+}_{0}$	$4.^{-}_{0}$ $3.^{+}_{0}$	$4.^{-}_{5}$ $2.^{+}_{0}$	$3.^{-}_{0}$ $4.^{+}_{0}$	0 $6.^{+}_{0}$
SHORT	Mean	-	+ 0.78	- 1.33	- 0.80	- 0.90	- 1.30	+ 0.80	-
	Range	-	$3.^{-}_{0}$ $4.^{+}_{0}$	$4.^{-}_{0}$ $1.^{+}_{0}$	$4.^{-}_{0}$ $1.^{+}_{0}$	$4.^{-}_{0}$ $1.^{+}_{0}$	$4.^{-}_{0}$ $1.^{+}_{0}$	$3.^{-}_{0}$ $4.^{+}_{0}$	-
EXTRA SHORT	Mean	-	+ 1.90	- 1.32	- 1.11	- 1.20	- 1.31	+ 1.90	-
	Range	-	$0.^{-}_{5}$ $5.^{+}_{0}$	$3.^{-}_{5}$ $1.^{+}_{0}$	$4.^{-}_{0}$ $1.^{+}_{0}$	$4.^{-}_{0}$ $1.^{+}_{0}$	$3.^{-}_{5}$ $1.^{+}_{0}$	0 $5.^{+}_{0}$	-

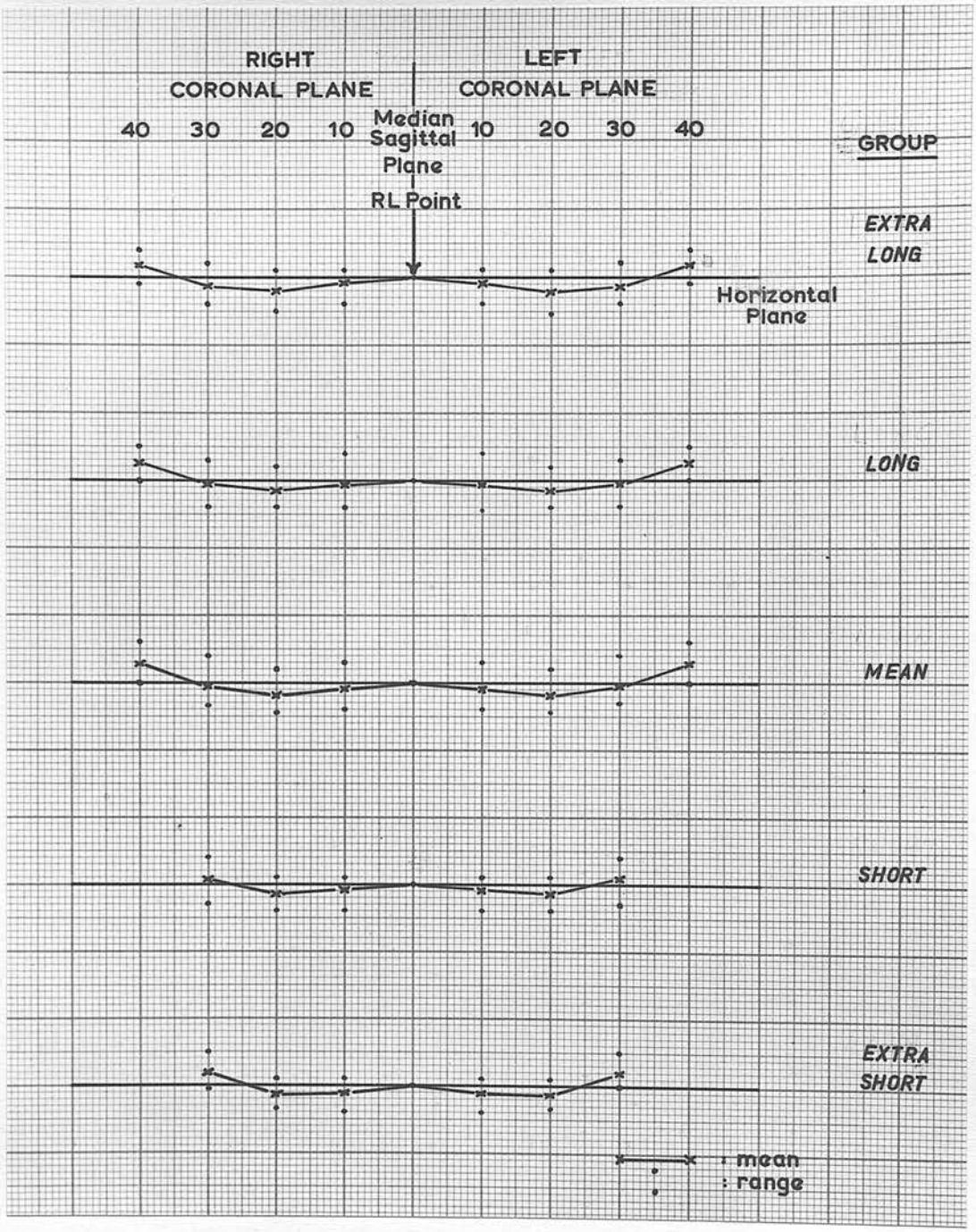


Fig. 93

DENTULOUS MANDIBULAR CASTS

Vertical lingual measurements of each Length Group.

TABLE 37.

351 DENTULOUS MAXILLARY CASTS : PALATE MEASUREMENTS

Vertical measurements in millimetres from the horizontal reference plane to the palate surface in the median sagittal plane.

GROUP		CORONAL PLANES				
		10 mm.	20 mm.	30 mm.	40 mm.	50 mm.
EXTRA LONG	Mean	10.65	14.45	14.40	12.85	9.80
	Range	8.0 14.0	11.5 18.0	11.0 18.0	11.0 16.0	8.0 12.5
LONG	Mean	10.56	14.25	13.76	11.51	-
	Range	8.0 16.0	11.0 18.0	10.0 18.0	8.0 15.0	-
MEAN	Mean	10.79	13.70	12.91	9.94	-
	Range	7.0 15.0	9.0 17.0	9.0 17.0	6.0 14.0	-
SHORT	Mean	10.43	12.71	11.64	8.98	-
	Range	8.0 16.0	9.0 18.0	8.0 16.5	6.0 14.0	-
EXTRA SHORT	Mean	11.23	13.10	11.27	-	-
	Range	9.5 14.0	9.0 15.0	8.0 14.0	-	-

The Edentulous Casts

The basic forms and sizes of the impression trays were designed from measurements of dentulous casts but, as the trays were intended for taking impressions of the mouths of edentulous patients, measurements of edentulous casts were also made for incorporation into the tray designs. These measurements were :

(a) horizontal measurements of length and width.

(b) vertical measurements from the horizontal plane through the reference point to the Crest Line and, in maxillary casts, to the palate surface.

(c) in mandibular casts, projection traces of the Crest Lines on a sagittal plane.

A measurement of length of each edentulous cast was made in the median sagittal plane from the Crest Line to a coronal plane through the more posterior of the Notch Points (or, in the case of the mandibular casts, the Retromolar Points). This measurement was defined as the maximum length of the cast.

Measurements of width were made in coronal planes at 10 mm. horizontal intervals between the Crest Lines of the right and left sides of each cast. The maximum width was defined as the maximum measurement, made in the coronal plane, between sagittal planes which cut the Crest Line on the right and left sides of the cast.

Study of these measurements showed great diversity among the casts. The measurements in a number of casts were similar, but no two casts were found in the edentulous sample in which all the length and width measurements were identical. This presented problems, as found in the dentulous sample, in devising a method of grouping the casts.

The method finally adopted was to place casts of similar maximum length and maximum width into groups. In each group a mean outline, termed the Ridge Outline, was found by averaging the widths at each 10 mm. coronal plane of each cast in the group.

This method of grouping the edentulous casts was more simple than the method used for grouping dentulous casts, and the method gave little information on the variation of outline form of the crest lines of the casts within each group because the Ridge Outline was derived from mean measurements of length and width. However, as the buccal and lingual outlines of the impression trays were designed entirely from the traces of the dentulous casts, the outline form of the edentulous casts was considered to be less important than the form of the dentulous casts.

It will be shown however, that the method of grouping the edentulous casts, according to their maximum length, was useful when tabulating the vertical measurements made on each cast from the horizontal plane through the reference point to the Crest Line. These measurements were important in the design of the impression trays as they were used to determine the antero-posterior curves of the trays. This matter of handling vertical measurements of casts in cross-section studies has already been discussed with regard to the dentulous casts.

1. Method of grouping the Edentulous Maxillary Casts

The measurements of Maximum Length of the casts were arranged as a frequency distribution (Table 38). The range was 36 to 57 mm. (mean 47.09 mm.; S.D. 3.67). This standard deviation was used to divide the casts into 5 groups designated as follows :

Group		Length	Group borders
Extra Long	: mean + 2 S.D. =	54.43 mm.	53 mm.
Long	: mean + 1 S.D. =	50.76 mm.	49 to 52 mm.
Mean	:	47.09 mm.	45 to 48 mm.
Short	: mean - 1 S.D. =	43.42 mm.	41 to 44 mm.
Extra Short	: mean - 2 S.D. =	39.75 mm.	40 mm.

Each cast was allocated into one of the 5 Length Groups according to the maximum length of that cast (Table 39).

TABLE 39 .

300 EDENTULOUS MAXILLARY CASTS : MAXIMUM LENGTH

Mean 47.09 mm.

S.D. 3.67

Division of casts into 5 groups

39.75 mm.	43.42 mm.	47.09 mm.	50.76 mm.	54.43 mm.
EXTRA SHORT	SHORT	MEAN	LONG	EXTRA LONG
40 mm. or below	41-44 mm.	45-48 mm.	49-52 mm.	53 mm. or above
13 casts (4.3 %)	60 casts (20.0 %)	119 casts (39.7 %)	89 casts (29.7 %)	19 casts (6.3 %)

The measurements of Maximum Width of the casts were also arranged as a frequency distribution (Table 4o). The range was 37 to 55 mm. (mean 45.00 mm.; S.D. 3.41) and 5 groups were designated as follows :

Group		Width	Group borders
Extra Wide	: mean + 2 S.D.	= 51.82 mm.	51 mm.
Wide	: mean + 1 S.D.	= 48.41 mm.	47 to 50 mm.
Mean	:	= 45.00 mm.	43 to 46 mm.
Narrow	: mean - 1 S.D.	= 41.59 mm.	39 to 42 mm.
Extra Narrow	: mean - 2 S.D.	= 38.18 mm.	38 mm.

and each cast was allocated into one of 5 Width Groups (Table 41).

TABLE 41 .

300 EDENTULOUS MAXILLARY CASTS : MAXIMUM WIDTH

Mean 45.00 mm.

S.D. 3.41

Division of casts into 5 groups

38.18 mm.	41.59 mm.	45.00 mm.	48.41 mm.	51.82 mm.
EXTRA NARROW	NARROW	MEAN	WIDE	EXTRA WIDE
38 mm. or below	39-42 mm.	43-46 mm.	47-50 mm.	51 mm. or above
9 casts (3.0 %)	58 casts (19.3 %)	141 casts (47.0 %)	74 casts (24.7 %)	18 casts (6.0 %)

The total sample of edentulous maxillary casts was then grouped according to the length and width of each cast. The frequency distribution is shown in Table 42 . Because of the method of grouping which was used, this distribution obviously followed a similar pattern as the dentulous casts.

From this distribution, groups were selected for the purpose of forming edentulous RIDGE OUTLINES for location within the 13 dentulous BUCCAL OUTLINES as aids to the construction of the impression trays.

The groups were as follows :

	Length	Width
1.	EXTRA LONG *	-
2.	LONG	Extra Wide
3.	"	Wide
4.	"	Mean
5.	"	Narrow
6.	MEAN	Wide
7.	"	Mean
8.	"	Narrow
9.	SHORT	Wide
10.	"	Mean
11.	"	Narrow
12.	"	Extra Narrow
13.	EXTRA SHORT *	-

* Division into separate widths was not made because of the small number of casts in these two extreme groups. The Extra Long group contained 19 casts (6.3% of total). The Extra Short group contained 13 casts (4.3% of total).

In this grouping method, measurements of length and width were used to designate the size of an edentulous cast. These measurements were dependent on two main factors :

i. the size of the jaw before the loss of the teeth.

ii. the amount of change which had taken place after the loss of the teeth.

It was found that a number of casts, in which it appeared that the teeth had been lost recently, were placed in the same group as casts in which the teeth appeared to have been lost for some time. This, of course, occurred more frequently in the Short and Extra Short groups. Thus the method of grouping the casts did not imply that the casts in one group were all of a similar pre-extraction size.

The edentulous maxillary Ridge Outlines were formed in the following way :

(a) In each of the 13 groups, the measurements of width of each cast at each coronal plane were listed. The range and means of these widths in the groups are given in Tables 43 to 46.

(b) In each of the 5 Length Groups, the measurements of anterior length of each cast were listed (the anterior length was the measurement in the median sagittal plane from the Crest Line to the coronal plane through the reference point). The range and mean of this measurement of the casts in each Length Group were as follows :

Length Group	Anterior Length (mm.)	
	Mean	Range
EXTRA LONG	3.80	2 - 5
LONG	3.63	2 - 5
MEAN	3.42	0 - 6
SHORT	3.20	2 - 5
EXTRA SHORT	2.80	2 - 4

(c) Thus in each of the 13 edentulous groups the following measurements were known :

i. the mean width at each coronal plane

ii. the mean anterior length

and these means were plotted on squared paper in relation to a reference point and median sagittal plane to form 13 different edentulous Ridge Outlines.

These RIDGE OUTLINES were then plotted in location within the dentulous Buccal Outlines, as shown in Figs. 82 to 85, by matching similarly named groups e.g. the Ridge Outline of the edentulous Long/Wide group was plotted within the Buccal Outline of the dentulous Long/Wide group.

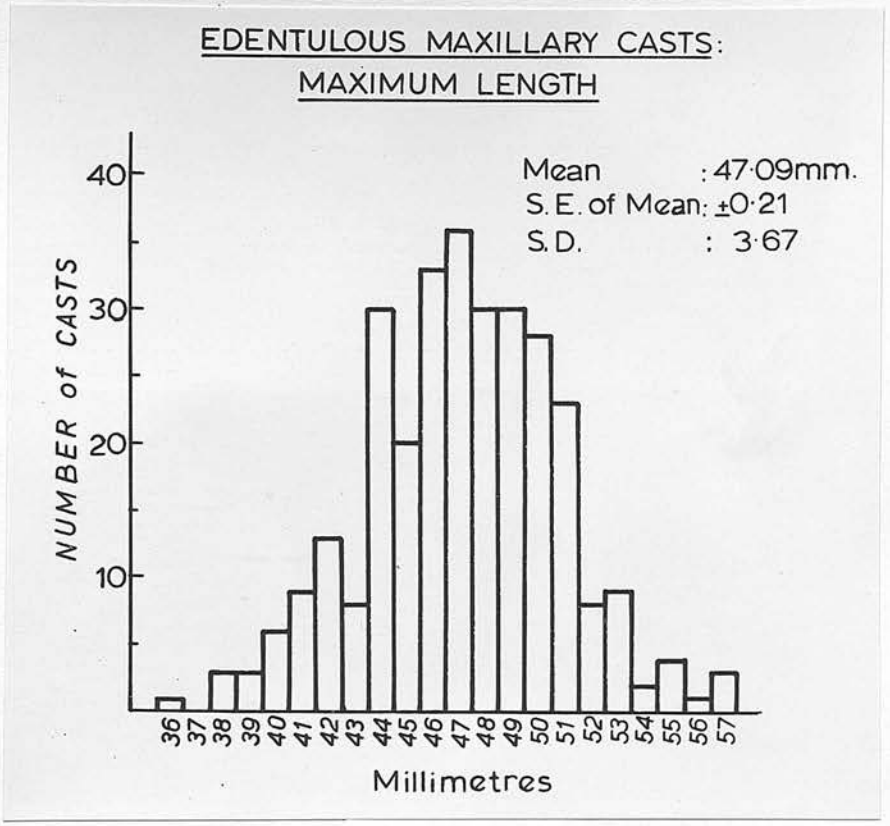


Table 38

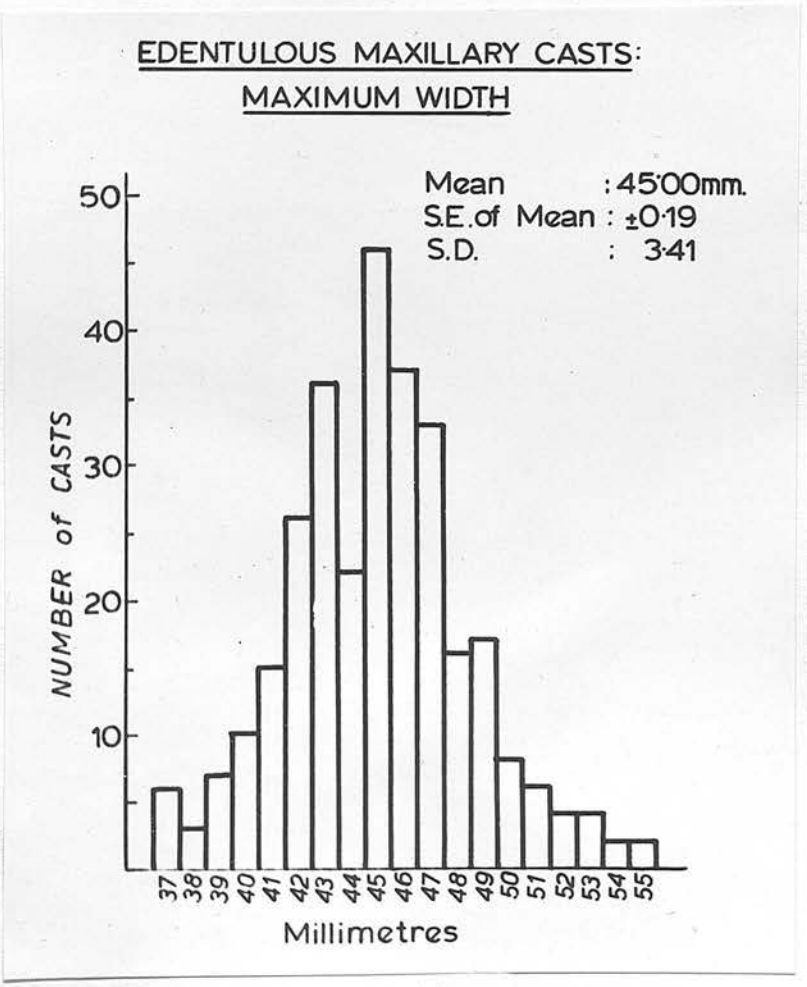


Table 40

GROUPING OF 300 EDENTULOUS MAXILLARY CASTS
BY MAXIMUM LENGTH and MAXIMUM WIDTH

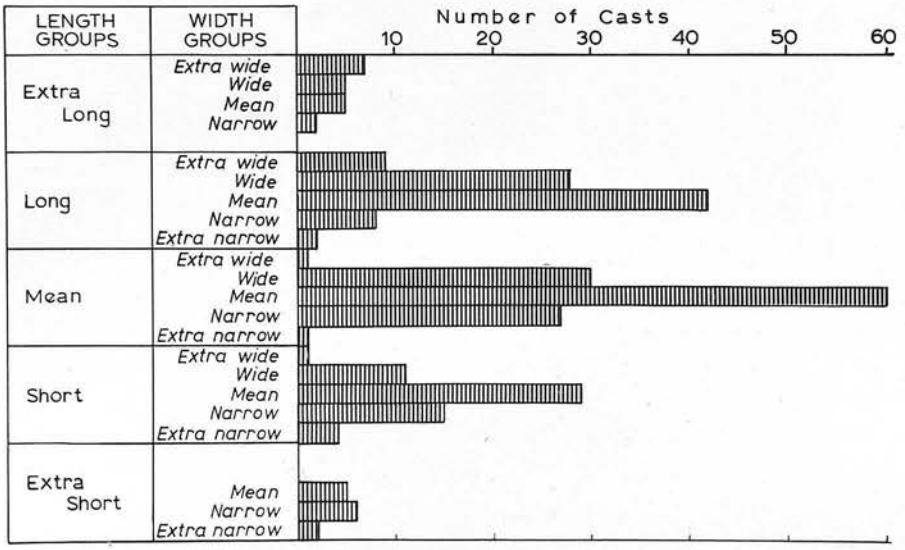


Table 42

TABLE 43.

EDENTULOUS MAXILLARY CASTS

Width measurements in millimetres between points of intersection of Crest Line with coronal planes.

LENGTH GROUPS : EXTRA LONG and EXTRA SHORT

		CORONAL PLANES				
		RU	10 mm.	20 mm.	30 mm.	40 mm.
EXTRA* LONG	Mean	20.2	35.6	42.0	46.4	48.2
	Range	14-28	29-40	36-47	41-52	40-55
EXTRA* SHORT	Mean	15.9	30.9	37.8	41.2	-
	Range	10-23	27-34	34-43	37-46	-

* These incorporated all the casts in the Group; division into separate width groups was not made because of the small number of casts.

TABLE 44 .

EDENTULOUS MAXILLARY CASTS

Width measurements in millimetres between points of intersection of Crest Line with coronal planes.

LENGTH GROUP : LONG

WIDTH GROUP		CORONAL PLANES				
		RU	10 mm.	20 mm.	30 mm.	40 mm.
EXTRA WIDE	Mean	20.1	37.0	44.8	49.9	51.8
	Range	15-24	35-41	41-49	45-53	50-55
WIDE	Mean	21.1	35.5	42.1	46.5	47.3
	Range	16-27	32-39	38-46	42-50	44-50
MEAN	Mean	19.2	34.4	40.4	43.7	44.4
	Range	12-25	28-39	35-43	40-46	39-46
NARROW	Mean	19.0	32.2	37.4	41.0	40.6
	Range	16-21	30-38	34-40	38-42	39-42

TABLE 45 .

EDENTULOUS MAXILLARY CASTS

Width measurements in millimetres between points of intersection of Crest Line with coronal planes.

LENGTH GROUP : MEAN

WIDTH GROUP		CORONAL PLANES				
		RU	10 mm.	20 mm.	30 mm.	40 mm.
WIDE	Mean	19.9	34.5	40.9	46.4	46.5
	Range	13-26	28-39	37-45	40-50	44-50
MEAN	Mean	18.7	33.3	39.3	43.7	44.0
	Range	12-25	29-38	35-42	41-46	41-46
NARROW	Mean	16.8	31.6	37.2	40.9	39.9
	Range	9-23	27-35	33-41	36-42	36-42

TABLE 46.

EDENTULOUS MAXILLARY CASTS

Width measurements in millimetres between points of intersection of Crest Line with coronal planes.

LENGTH GROUP : SHORT

WIDTH GROUP		CORONAL PLANES			
		RU	10 mm.	20 mm.	30 mm.
WIDE	Mean	19.1	35.4	42.0	47.4
	Range	15-26	31-39	39-44	46-49
MEAN	Mean	19.3	33.1	39.5	43.8
	Range	12-24	29-39	36-43	41-46
NARROW	Mean	15.1	30.0	36.0	40.5
	Range	8-21	27-34	33-38	39-42
EXTRA NARROW	Mean	13.7	25.5	33.0	37.2
	Range	10-18	23-28	29-38	36-38

2. Method of grouping the Edentulous Mandibular Casts

The method of grouping the edentulous mandibular casts was similar to that described for the maxillary casts and only the essential points of difference between the results are listed.

The measurements of Maximum Length of the casts were arranged as a frequency distribution (Table 47). The range was 32 to 54 mm. (mean 42.60 mm.; S.D. 3.74) and 5 groups were designated as follows :

Group	Length	Group borders
Extra Long :	mean + 2 S.D. = 50.08 mm.	49 mm.
Long :	mean + 1 S.D. = 46.34 mm.	45 to 48 mm.
Mean :	= 42.60 mm.	41 to 44 mm.
Short :	mean - 1 S.D. = 38.86 mm.	37 to 40 mm.
Extra Short :	mean - 2 S.D. = 35.12 mm.	36 mm.

Each cast was allocated into one of the 5 Length Groups (Table 48).

TABLE 48 .

300 EDENTULOUS MANDIBULAR CASTS : MAXIMUM LENGTH

Mean 42.60 mm.

S.D. 3.74

Division of casts into 5 groups

35.12 mm.	38.86 mm.	42.60 mm.	46.34 mm.	50.08 mm.
EXTRA SHORT	SHORT	MEAN	LONG	EXTRA LONG
36 mm. or below	37-40 mm.	41-44 mm.	45-48 mm.	49 mm. or above
15 casts (5.0 %)	58 casts (19.3 %)	141 casts (47.0 %)	66 casts (22.0 %)	20 casts (6.7 %)

The measurements of Maximum Width of the casts were also arranged as a frequency distribution (Table 49). The range was 49 to 67 mm. (mean 57.94 mm.; S.D. 2.99) and 5 Groups were designated as follows :

Group		Width	Group borders
Extra Wide	: mean + 2 S.D.	= 63.92 mm.	63 mm.
Wide	: mean + 1 S.D.	= 60.93 mm.	60 to 62 mm.
Mean	:	= 57.94 mm.	57 to 59 mm.
Narrow	: mean - 1 S.D.	= 54.95 mm.	54 to 56 mm.
Extra Narrow	: mean - 2 S.D.	= 51.96 mm.	53 mm.

and each cast was allocated into one of 5 Width Groups (Table 5o).

TABLE 5o .

300 EDENTULOUS MANDIBULAR CASTS : MAXIMUM WIDTH

Mean 57.94 mm.

S.D. 2.99

Division of casts into 5 groups

51.96 mm.	54.95 mm.	57.94 mm.	60.93 mm.	63.92 mm.
EXTRA NARROW	NARROW	MEAN	WIDE	EXTRA WIDE
53 mm. or below	54-56 mm.	57-59 mm.	60-62 mm.	63 mm. or above
15 casts (5.0 %)	84 casts (28.0 %)	115 casts (38.3 %)	66 casts (22.0 %)	20 casts (6.7 %)

The total sample of edentulous mandibular casts was then grouped according to the length and width of each cast. The frequency distribution is shown in Table 51 .

From this distribution, groups were selected for the purpose of forming edentulous RIDGE OUTLINES for location within the 13 dentulous BUCCAL & LINGUAL OUTLINES.

The groups were as follows :

	Length	Width
1.	EXTRA LONG *	-
2.	LONG	Extra Wide
3.	"	Wide
4.	"	Mean
5.	"	Narrow
6.	MEAN	Wide
7.	"	Mean
8.	"	Narrow
9.	SHORT	Wide
10.	"	Mean
11.	"	Narrow
12.	"	Extra Narrow
13.	EXTRA SHORT *	-

* Division into separate widths was not made because of the small number of casts in these two extreme groups. The Extra Long group contained 20 casts (6.7 % of total). The Extra Short group contained 15 casts (5.0 % of total).

In each of the 13 groups, the measurements of width of each cast at each coronal plane were listed. The range and means of these widths in the groups are given in Tables 52 to 55.

In each of the 5 Length Groups the measurements of anterior length of each cast were listed. The range and means were as follows :

Length Group	Anterior Length (mm.)	
	Mean	Range
EXTRA LONG	3.30	1 - 5
LONG	3.27	1 - 6
MEAN	3.19	1 - 6
SHORT	3.01	1 - 6
EXTRA SHORT	2.93	1 - 5

Thus in each of the 13 edentulous mandibular groups the following measurements were known :

i. the mean width at each coronal plane.

ii. the mean anterior length.

and these means were plotted to form 13 Ridge Outlines which are shown in location within the dentulous Buccal & Lingual Outlines in Figs. 87 to 90 .

EDENTULOUS MANDIBULAR CASTS:
MAXIMUM LENGTH

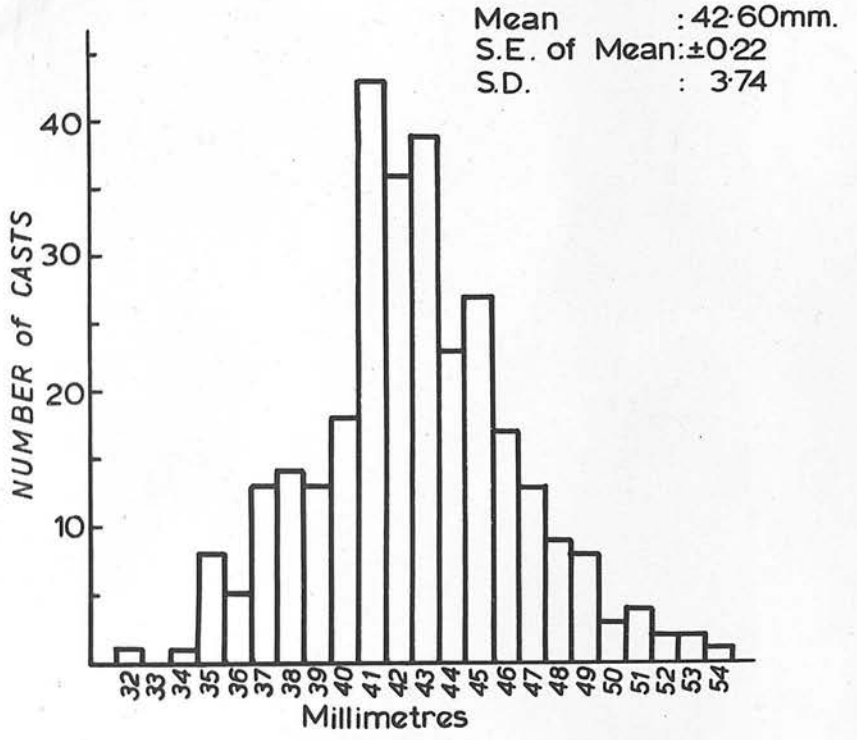


Table 47

EDENTULOUS MANDIBULAR CASTS:
MAXIMUM WIDTH

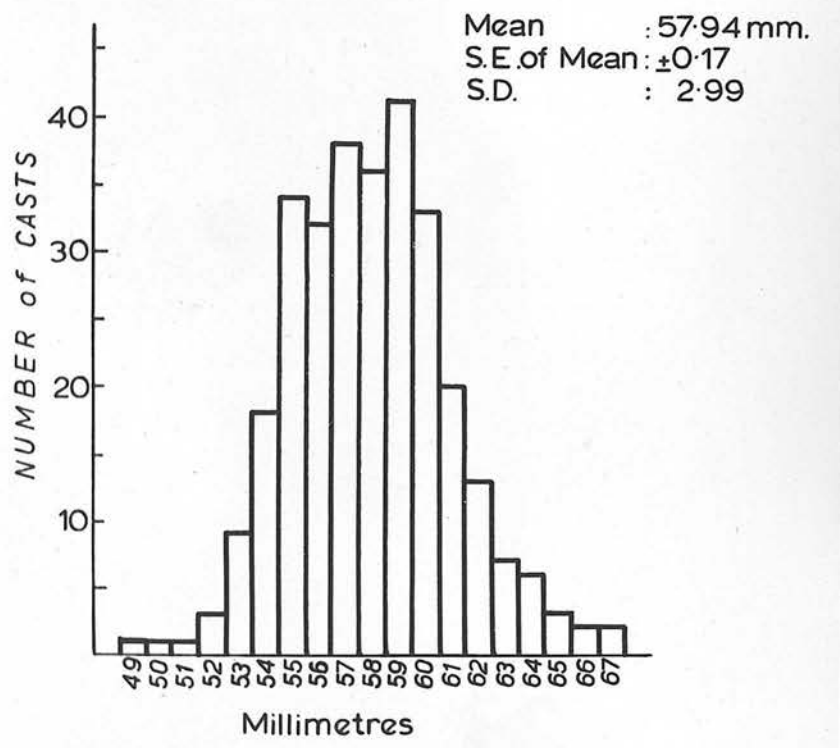


Table 49

GROUPING OF 300 EDENTULOUS MANDIBULAR CASTS
BY MAXIMUM LENGTH and MAXIMUM WIDTH

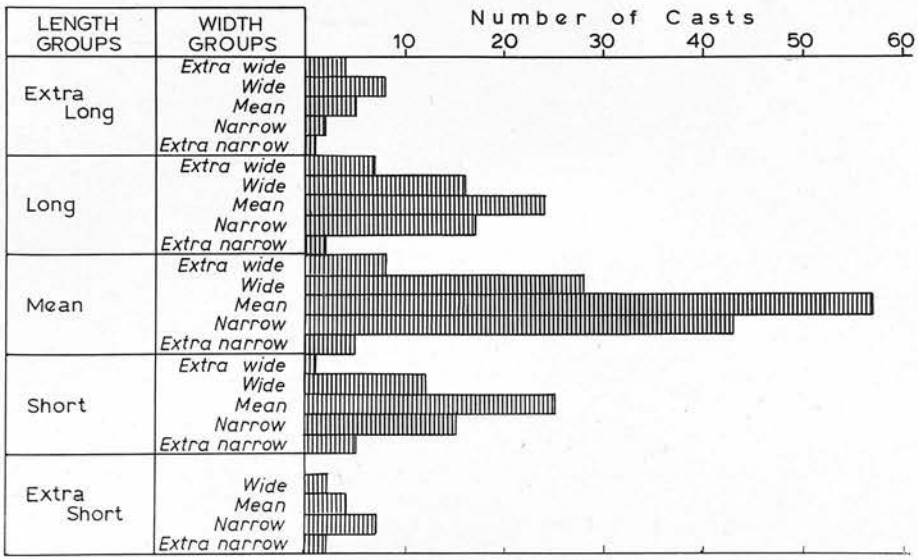


Table 51

TABLE 52.

EDENTULOUS MANDIBULAR CASTS

Width measurements in millimetres between points of intersection of Crest Line with coronal planes.

LENGTH GROUPS : EXTRA LONG and EXTRA SHORT

		CORONAL PLANES				
		RL	10 mm.	20 mm	30 mm	40 mm
EXTRA LONG *	Mean	20.4	38.0	47.7	54.0	57.6
	Range	12-29	33-41	41-50	48-58	52-63
EXTRA SHORT *	Mean	21.4	38.5	48.9	54.7	-
	Range	15-28	35-43	44-53	51-59	-

* These incorporated all the casts in the Group; division into separate width groups was not made because of the small number of casts.

TABLE 53 .

EDENTULOUS MANDIBULAR CASTS

Width measurements in millimetres between points of intersection of Crest Line with coronal planes.

LENGTH GROUP : LONG

WIDTH GROUP		CORONAL PLANES				
		RL	10 mm.	20 mm.	30 mm.	40 mm.
EXTRA WIDE	Mean	18.9	37.6	49.1	56.0	61.7
	Range	15-20	34-44	48-52	55-58	60-63
WIDE	Mean	19.7	38.3	48.0	54.9	59.1
	Range	13-28	35-44	44-51	51-58	58-60
MEAN	Mean	20.0	37.1	47.1	53.5	57.4
	Range	12-26	34-41	44-51	50-57	56-58
NARROW	Mean	20.5	36.6	45.5	51.1	53.8
	Range	14-29	34-42	42-48	48-53	53-54

TABLE 54.

EDENTULOUS MANDIBULAR CASTS

Width measurements in millimetres between points of intersection of Crest Line with coronal planes.

LENGTH GROUP : MEAN

WIDTH GROUP		CORONAL PLANES				
		RL	10 mm.	20 mm.	30 mm.	40 mm.
WIDE	Mean	21.8	39.5	49.3	56.4	60.6
	Range	16-29	35-46	44-53	51-61	60-62
MEAN	Mean	20.2	37.8	47.9	54.1	58.0
	Range	14-26	33-42	44-52	48-58	57-59
NARROW	Mean	20.1	36.2	45.5	52.2	55.3
	Range	15-26	30-41	41-50	48-55	54-56

TABLE 55 .

EDENTULOUS MANDIBULAR CASTS

Width measurements in millimetres between points of intersection of Crest Line with coronal planes.

LENGTH GROUP : SHORT

WIDTH GROUP		CORONAL PLANES			
		RL	10 mm.	20 mm.	30 mm.
WIDE	Mean	19.7	39.1	50.3	57.3
	Range	17-22	36-42	47-53	54-60
MEAN	Mean	21.2	38.3	48.4	54.9
	Range	17-29	35-43	45-52	51-57
NARROW	Mean	20.8	37.4	47.1	52.7
	Range	17-25	35-40	45-50	51-55
EXTRA NARROW	Mean	21.6	36.0	44.2	49.4
	Range	19-23	34-38	41-47	48-51

3. Vertical measurements of Edentulous Maxillary Casts

(a) Vertical measurements were made of each of the 300 edentulous maxillary casts from the horizontal reference plane to the Crest Line. These measurements, made in coronal planes on the right and left sides of the casts and in the median sagittal plane, were used to determine the antero-posterior curves of the maxillary impression trays.

The measurements were tabulated for casts of similar length i.e. the 5 Length Groups.

The range and means of the measurements of the casts, known as the VERTICAL RIDGE MEASUREMENTS, are listed, for each of the 5 Length Groups, in Table 56 and shown graphically in Fig. 94 .

It was seen that differences between the vertical measurements of the right and left sides of the casts were small.

(b) Measurements were also made from the horizontal reference plane to the palate surface in the median sagittal plane. These were known as the edentulous PALATE MEASUREMENTS, and the range and means, for the casts in each of the 5 Length Groups, are shown in Table 57 . Comment has already been made, in the Investigation of Errors, on the difference between these results and similar palate measurements of dentulous casts.

TABLE 56.

300 EDENTULOUS MAXILLARY CASTS : VERTICAL RIDGE MEASUREMENTS

Vertical measurements in millimetres from the horizontal reference plane to the Crest Line.

NOTE: a + sign signified the measurement was superior to the horizontal reference plane.
a - sign signified the measurement was inferior to the horizontal reference plane.

GROUP		RIGHT CORONAL PLANES					Median Sagittal Plane	LEFT CORONAL PLANES				
		40 mm.	30 mm.	20 mm.	10 mm.	RU		RU	10 mm.	20 mm.	30 mm.	40 mm.
EXTRA LONG	Mean	- 1.81	- 0.35	+ 0.33	0	- 0.02	- 1.0	0	0	+ 0.31	- 0.37	- 1.80
	Range	$3^{+}_{-}0$ $4^{-}_{-}0$	$4^{+}_{-}5$ $4^{-}_{-}0$	$3^{+}_{-}0$ $3^{-}_{-}0$	$3^{+}_{-}0$ $3^{-}_{-}0$	$2^{+}_{-}0$ $1^{-}_{-}5$	0 $2^{-}_{-}0$	$2^{+}_{-}0$ $1^{-}_{-}5$	$3^{+}_{-}0$ $2^{-}_{-}5$	$3^{+}_{-}0$ $3^{-}_{-}0$	$4^{+}_{-}0$ $4^{-}_{-}0$	$3^{+}_{-}0$ $4^{-}_{-}5$
LONG	Mean	- 1.40	- 0.51	+ 0.06	- 0.23	- 0.04	- 0.93	- 0.02	- 0.20	+ 0.04	- 0.40	- 1.42
	Range	$1^{+}_{-}0$ $4^{-}_{-}0$	$3^{+}_{-}5$ $4^{-}_{-}0$	$3^{+}_{-}5$ $3^{-}_{-}0$	$3^{+}_{-}5$ $3^{-}_{-}5$	$2^{+}_{-}0$ $2^{-}_{-}0$	0 $3^{-}_{-}0$	$2^{+}_{-}0$ $2^{-}_{-}0$	$3^{+}_{-}0$ $3^{-}_{-}5$	$4^{+}_{-}0$ $3^{-}_{-}0$	$3^{+}_{-}5$ $4^{-}_{-}0$	$1^{+}_{-}0$ $4^{-}_{-}0$
MEAN	Mean	- 0.67	- 0.60	+ 0.20	- 0.23	- 0.35	- 1.08	- 0.32	- 0.24	+ 0.16	- 0.59	- 0.66
	Range	$2^{+}_{-}0$ $3^{-}_{-}5$	$3^{+}_{-}0$ $4^{-}_{-}5$	$3^{+}_{-}5$ $3^{-}_{-}0$	$3^{+}_{-}5$ $3^{-}_{-}5$	$2^{+}_{-}0$ $3^{-}_{-}0$	0 $3^{-}_{-}0$	$2^{+}_{-}0$ $3^{-}_{-}0$	$3^{+}_{-}0$ $3^{-}_{-}5$	$3^{+}_{-}5$ $3^{-}_{-}0$	$3^{+}_{-}0$ $4^{-}_{-}5$	$1^{+}_{-}5$ $3^{-}_{-}5$
SHORT	Mean	-	- 0.35	+ 0.64	- 0.15	- 0.40	- 1.22	- 0.42	- 0.15	+ 0.62	- 0.34	-
	Range	-	$3^{+}_{-}5$ $4^{-}_{-}5$	$3^{+}_{-}5$ $3^{-}_{-}0$	$3^{+}_{-}5$ $3^{-}_{-}0$	$1^{+}_{-}0$ $3^{-}_{-}5$	0 $3^{-}_{-}5$	$1^{+}_{-}0$ $3^{-}_{-}5$	$3^{+}_{-}5$ $2^{-}_{-}5$	$3^{+}_{-}5$ $3^{-}_{-}0$	$3^{+}_{-}5$ $4^{-}_{-}5$	-
EXTRA SHORT	Mean	-	- 0.50	+ 0.45	- 0.22	- 0.70	- 1.40	- 0.75	- 0.20	+ 0.46	- 0.50	-
	Range	-	$1^{+}_{-}5$ $3^{-}_{-}0$	$2^{+}_{-}0$ $2^{-}_{-}5$	$1^{+}_{-}0$ $2^{-}_{-}0$	$0^{+}_{-}5$ $2^{-}_{-}5$	0 $3^{-}_{-}0$	$1^{+}_{-}0$ $2^{-}_{-}5$	$1^{+}_{-}0$ $2^{-}_{-}5$	$2^{+}_{-}0$ $2^{-}_{-}5$	$1^{+}_{-}5$ $2^{-}_{-}5$	-

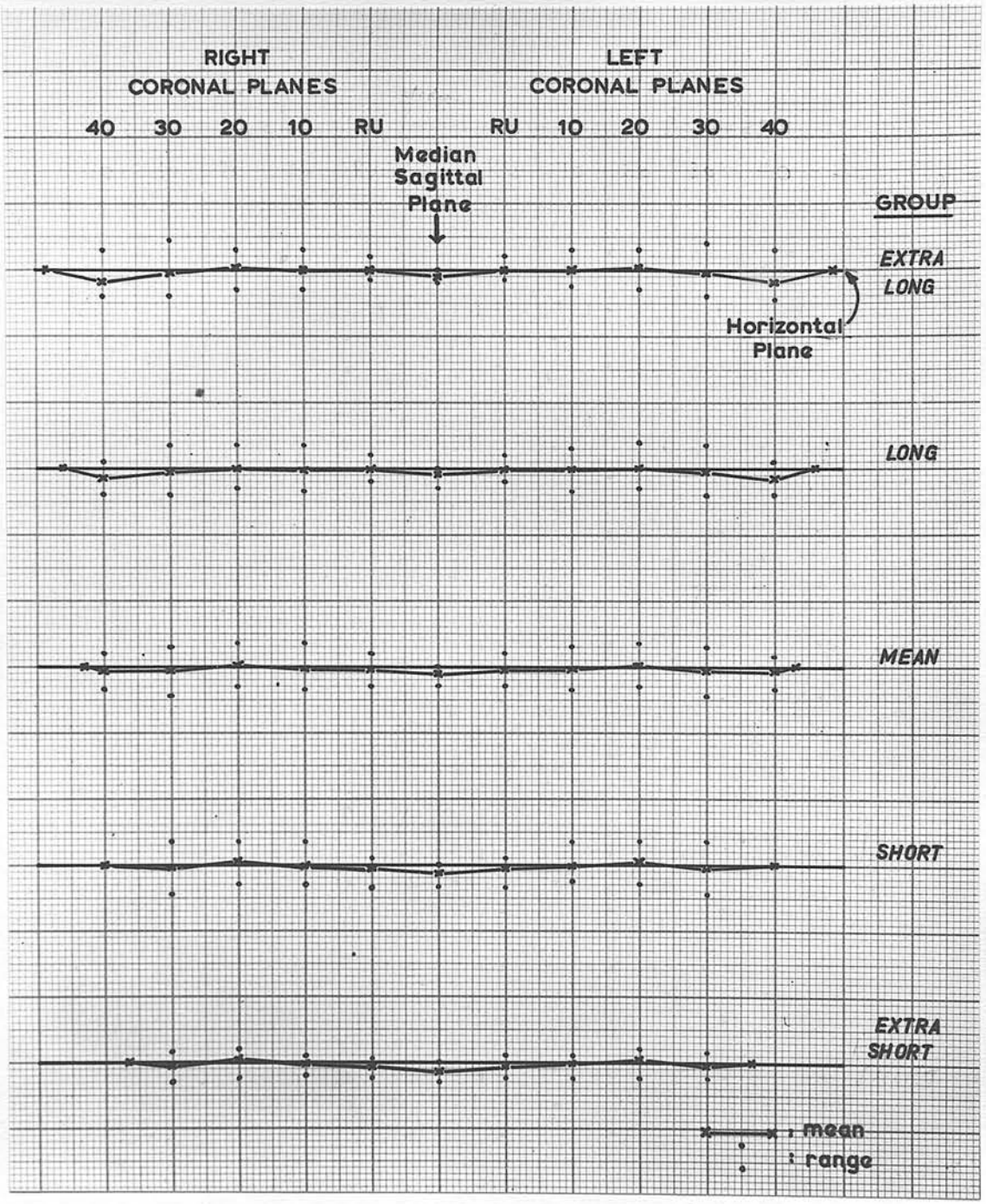


Fig. 94

EDENTULOUS MAXILLARY CASTS

Vertical Ridge Measurements of each Length Group.

TABLE 57.

300 EDENTULOUS MAXILLARY CASTS : PALATE MEASUREMENTS

Vertical measurements in millimetres from the horizontal reference plane to the palate surface in the median sagittal plane.

GROUP		CORONAL PLANES				
		10 mm.	20 mm.	30 mm.	40 mm.	45 mm.*
EXTRA LONG	Mean	8.62	12.35	12.30	11.00	9.50
	Range	5.0 13.0	9.0 15.5	8.0 15.0	8.0 14.0	6.0 13.0
LONG	Mean	8.46	12.17	11.96	9.95	7.78
	Range	6.0 12.0	8.0 18.0	7.0 17.0	7.0 15.0	5.0 10.0
MEAN	Mean	8.50	11.55	11.00	8.85	-
	Range	3.0 13.0	6.0 15.0	7.0 15.0	5.0 14.0	-
SHORT	Mean	8.79	11.23	10.23	7.90	-
	Range	5.0 12.0	8.0 16.0	7.0 15.0	5.0 12.0	-
EXTRA SHORT	Mean	8.70	10.23	8.70	-	-
	Range	6.0 14.0	7.0 16.0	6.0 12.0	-	-

* Measurements were made in this extra plane in the longest casts to give additional data on the palatal curve in the region of the junction of the hard and soft palates.

4. Vertical measurements and traces of Edentulous Mandibular Casts

Vertical measurements were made of each of the 300 edentulous mandibular casts from the horizontal plane through the reference point to the Crest Line. These were made in coronal planes on the right and left sides of the casts, and also in the median sagittal plane.

The measurements were tabulated for casts of similar length i.e. the 5 Length Groups.

The range and means of the measurements of the casts are listed, for each of the 5 Length Groups, in Table 58 and shown graphically in Fig. 95 .

It was seen that differences between the vertical measurements of the right and left sides of the casts were small. The measurements also showed, however, a wide range at each coronal plane. This was due to the great variation in form of the residual alveolar ridges of these casts and, to a certain extent, was influenced by the method used to orient the casts prior to measurement. Consequently the mean curves derived from these measurements were not representative of a large number of the casts in the sample. For this reason, traces of the Crest Lines were made in order to define and group the curves of the casts.

A trace of the projection of the Crest Line on a sagittal plane was made of each of the 300 edentulous mandibular casts (see page 89). These traces, which represented the true curves of the Crest Lines, were used, together with the direct vertical measurements, for the purpose of determining the antero-posterior curves of the mandibular impression trays.

TABLE 58 .

300 EDENTULOUS MANDIBULAR CASTS

Vertical measurements in millimetres from the horizontal plane through the RL point to the Crest Line.

NOTE: a + sign signified the measurement was superior to the horizontal plane through the RL point.
a - sign signified the measurement was inferior to the horizontal plane through the RL point.

GROUP		RIGHT CORONAL PLANES					Median Sagittal Plane	LEFT CORONAL PLANES				
		40 mm.	30 mm.	20 mm.	10 mm.	RL		RL	10 mm.	20 mm.	30 mm.	40 mm.
EXTRA LONG	Mean	+ 9.92	+ 2.80	+ 0.57	+ 1.40	+ 3.20	+ 3.70	+ 3.14	+ 1.43	+ 0.50	+ 2.80	+ 9.95
	Range	$5^{+}_{\cdot}5$ $14^{+}_{\cdot}5$	$4^{-}_{\cdot}5$ $9^{+}_{\cdot}5$	$6^{-}_{\cdot}5$ $7^{+}_{\cdot}0$	$4^{-}_{\cdot}5$ $6^{+}_{\cdot}5$	$1^{-}_{\cdot}0$ $7^{+}_{\cdot}0$	$0^{+}_{\cdot}5$ $6^{+}_{\cdot}5$	$0^{-}_{\cdot}5$ $7^{+}_{\cdot}0$	$4^{-}_{\cdot}5$ $6^{+}_{\cdot}5$	$6^{-}_{\cdot}5$ $6^{+}_{\cdot}5$	$4^{-}_{\cdot}5$ $10^{+}_{\cdot}0$	$5^{+}_{\cdot}5$ $14^{+}_{\cdot}5$
LONG	Mean	+ 13.10	+ 5.83	+ 2.47	+ 2.45	+ 3.30	+ 3.32	+ 3.30	+ 2.50	+ 2.49	+ 5.80	+ 13.0
	Range	$9^{+}_{\cdot}0$ $15^{+}_{\cdot}0$	$1^{-}_{\cdot}0$ $11^{+}_{\cdot}5$	$3^{-}_{\cdot}5$ $9^{+}_{\cdot}0$	$3^{-}_{\cdot}0$ $7^{+}_{\cdot}0$	$0^{-}_{\cdot}5$ $7^{+}_{\cdot}0$	0 $7^{+}_{\cdot}0$	0 $7^{+}_{\cdot}0$	$3^{-}_{\cdot}0$ $7^{+}_{\cdot}0$	$3^{-}_{\cdot}5$ $9^{+}_{\cdot}0$	$1^{-}_{\cdot}0$ $12^{+}_{\cdot}0$	$9^{+}_{\cdot}0$ $15^{+}_{\cdot}0$
MEAN	Mean	+ 14.01	+ 6.88	+ 2.58	+ 2.20	+ 3.47	+ 3.57	+ 3.45	+ 2.20	+ 2.55	+ 6.95	+ 14.0
	Range	$11^{+}_{\cdot}0$ $14^{+}_{\cdot}5$	$1^{-}_{\cdot}5$ $12^{+}_{\cdot}5$	$4^{-}_{\cdot}0$ $8^{+}_{\cdot}5$	$4^{-}_{\cdot}0$ $8^{+}_{\cdot}0$	$1^{-}_{\cdot}0$ $8^{+}_{\cdot}5$	0 $8^{+}_{\cdot}0$	$1^{-}_{\cdot}0$ $8^{+}_{\cdot}0$	$4^{-}_{\cdot}0$ $8^{+}_{\cdot}0$	$4^{-}_{\cdot}0$ $8^{+}_{\cdot}5$	$1^{-}_{\cdot}0$ $12^{+}_{\cdot}5$	$11^{+}_{\cdot}0$ $14^{+}_{\cdot}5$
SHORT	Mean	-	+ 7.13	+ 3.01	+ 2.66	+ 3.56	+ 3.48	+ 3.50	+ 2.61	+ 3.0	+ 7.22	-
	Range	-	$2^{+}_{\cdot}0$ $11^{+}_{\cdot}0$	$1^{-}_{\cdot}5$ $8^{+}_{\cdot}5$	$2^{-}_{\cdot}0$ $8^{+}_{\cdot}0$	0 $8^{+}_{\cdot}0$	0 $8^{+}_{\cdot}0$	0 $8^{+}_{\cdot}0$	$2^{-}_{\cdot}0$ $8^{+}_{\cdot}0$	$1^{-}_{\cdot}5$ $8^{+}_{\cdot}5$	$1^{+}_{\cdot}5$ $11^{+}_{\cdot}0$	-
EXTRA SHORT	Mean	-	+ 8.20	+ 3.70	+ 3.0	+ 3.48	+ 3.50	+ 3.50	+ 2.91	+ 3.70	+ 8.10	-
	Range	-	$3^{+}_{\cdot}5$ $10^{+}_{\cdot}5$	$4^{-}_{\cdot}0$ $6^{+}_{\cdot}0$	$3^{-}_{\cdot}0$ $5^{+}_{\cdot}5$	0 $6^{+}_{\cdot}0$	$0^{+}_{\cdot}5$ $5^{+}_{\cdot}5$	0 $6^{+}_{\cdot}0$	$3^{-}_{\cdot}0$ $5^{+}_{\cdot}0$	$4^{-}_{\cdot}0$ $6^{+}_{\cdot}0$	$3^{+}_{\cdot}5$ $10^{+}_{\cdot}5$	-

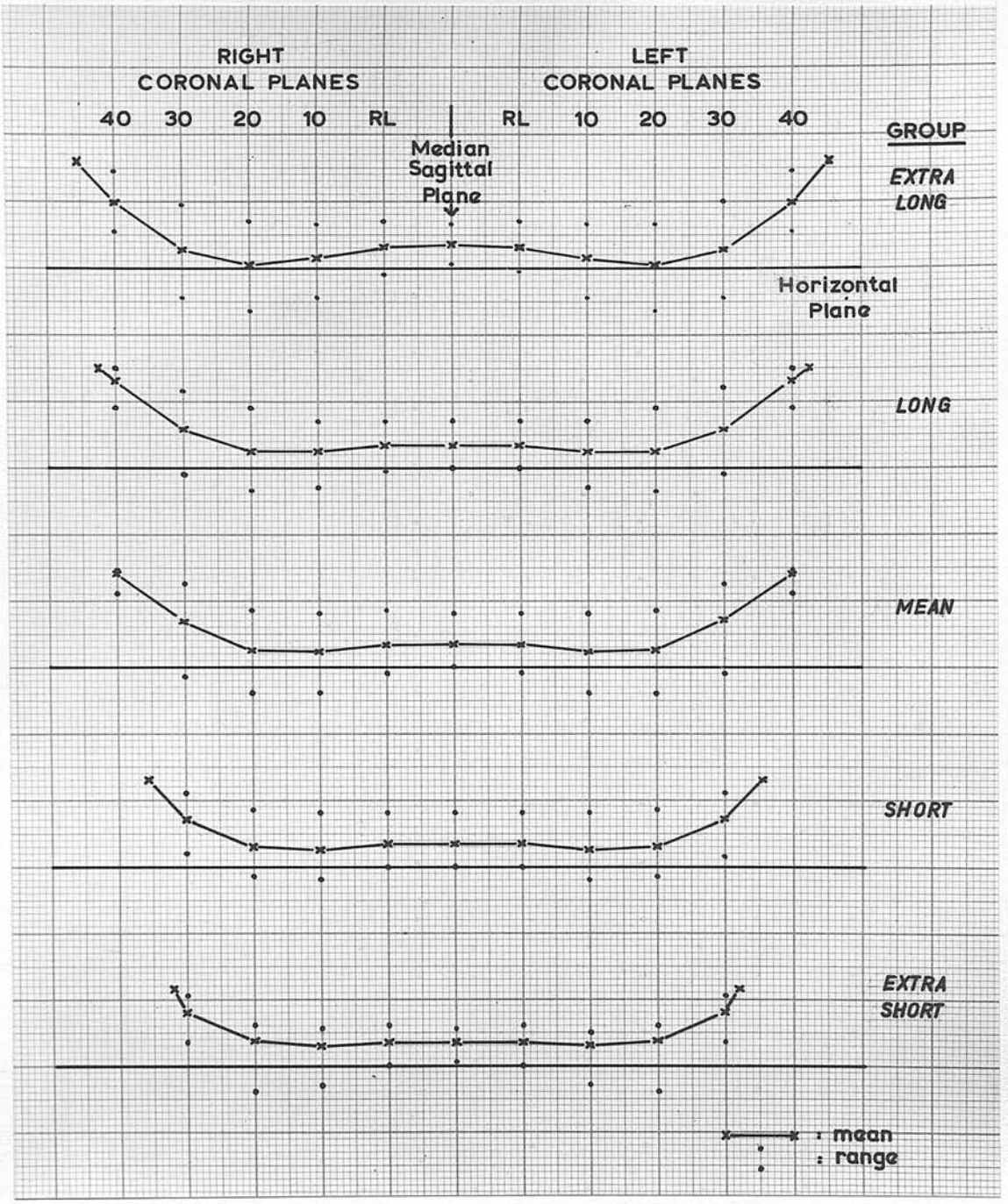


Fig. 95

EDENTULOUS MANDIBULAR CASTS

Vertical measurements from the horizontal plane through the RL point to the Crest Line of each Length Group.

Study of these 300 traces showed considerable variation in the curves, and a number of methods of handling them were investigated.

The method finally adopted was to divide the traces into five groups according to the 5 Length Groups of the edentulous mandibular casts. In each group the following procedure was used :

An angle of 19.6° was drawn on tracing paper to represent the horizontal plane and the reference plane. The position of the Retromolar Point on the latter plane was known from the mean length of the casts as measured along the horizontal plane. The mean curve derived from the direct vertical measurements (results of right and left sides combined) was then plotted in relation to the two planes (Fig. 96A).

Each trace was now compared with this plotted mean curve by superimposing the RL point and the Retromolar Point of the trace on the reference plane. The purpose of this was to group the traces according to whether the individual traces lay superior or inferior to the mean plotted curve (the term superior implied a greater vertical distance from the horizontal plane). It was found that in most cases, this grouping system was straightforward but the following method was used to decide in which group to place a trace which crossed the mean curve. The total antero-posterior length of the trace was measured and, if a greater length of the trace lay superior to the mean curve, then the trace was grouped as "superior", and vice versa. In addition, 21 traces out of the total number of

300 were found to superimpose on the mean curves and these traces were placed in neither group. (In this context, superimposition implied a separation measurement of less than 0.5 mm. throughout the total antero-posterior length of the trace.)

Thus the traces were arranged into 2 groups, "superior" and "inferior", as related to the mean plotted curve.

Another angle of 19.6° was then drawn on tracing paper to represent the horizontal plane and the reference plane, and on this tracing paper each individual trace in the "superior" group was copied. The RL point and Retromolar Point of each trace was superimposed on the reference plane. This produced a composite trace of the individual traces (Fig. 96B).

A composite trace of the individual traces in the "inferior" group was also made (Fig. 96C).

On each of these two composite traces, a common curve was drawn on tracing paper through the main mass of the composite trace. These two curves (Fig. 96 D) represented the traces of the Crest Lines in that particular length group of casts.

This method of drawing a common curve on a composite trace may seem inaccurate but it must be pointed out that, as the composite trace was gradually built up by repeated superimposition of the traces, the form and position of the individual traces was clearly seen. This was a considerable aid in selecting the form and position of a common curve on the completed composite trace. This, of course, cannot be seen in Fig. 96 B & C which only show the traces en masse.

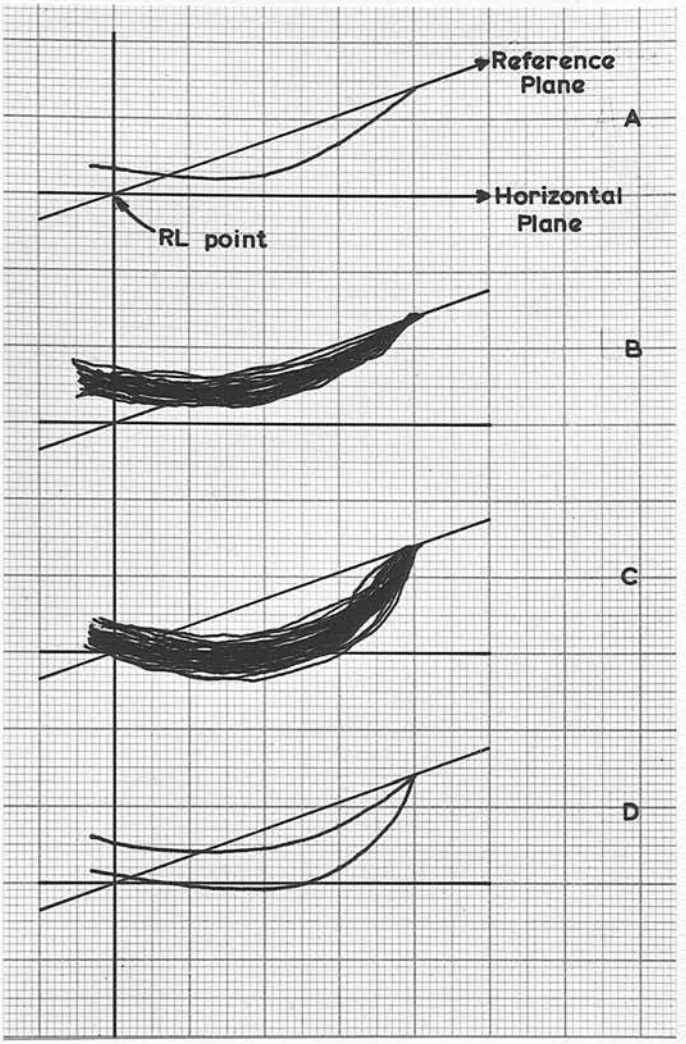


Fig. 96

EDENTULOUS MANDIBULAR CASTS

Length group : MEAN

The method of producing "superior" & "inferior" curves from the Crest Line traces.

(Another method of producing a common curve from a composite trace was investigated. The vertical distance from the horizontal plane to each individual curve was measured at each 10 mm. coronal plane. The mean measurements at each coronal plane were then plotted and joined with a smooth curve. It was found, however, that the shape of the curve made in this way corresponded very closely to the mean plotted curve produced from the direct vertical measurements. As it was felt that this curve did not represent the curves of the composite trace, the method was not used.)

The vertical position of the "superior" and "inferior" curves, in relation to the horizontal plane through the RL point, was then measured under a transparent millimetre grid and measurements were read off, to the nearest 0.5 mm., in each coronal plane. These measurements of the two curves, known as the VERTICAL RIDGE MEASUREMENTS, are listed, for each of the 5 Length Groups of mandibular casts, in Table 59 and shown graphically in Fig. 97 .

TABLE 59.

300 EDENTULOUS MANDIBULAR CASTS : VERTICAL RIDGE MEASUREMENTS

Vertical measurements in millimetres from the horizontal plane through the RL point to the SUPERIOR and INFERIOR crest line curves. The mean curve obtained from the direct measurements (right and left sides combined) is also given for comparison. N.B. a - sign signified the measurement was inferior to the horizontal plane through the RL point.

GROUP	CURVE	Median Sagittal Plane	CORONAL PLANES					Retro-molar Point *
			RL	10 mm.	20 mm.	30 mm.	40 mm.	
EXTRA LONG	Superior	6.0	5.5	4.0	4.0	7.0	12.5	16.5
	Mean	3.7	3.2	1.4	0.5	2.8	9.9	16.5
	Inferior	2.0	1.0	-1.5	-2.0	0.5	8.0	16.5
LONG	Superior	5.5	5.0	4.5	5.0	8.0	13.5	15.0
	Mean	3.3	3.3	2.5	2.5	5.8	13.0	15.0
	Inferior	2.0	1.5	0	-0.5	1.5	10.0	15.0
MEAN	Superior	6.0	5.0	4.0	4.5	7.5	-	14.0
	Mean	3.6	3.5	2.2	2.6	6.9	-	14.0
	Inferior	1.5	1.0	-0.5	-1.0	2.0	-	14.0
SHORT	Superior	5.5	5.0	4.5	5.0	9.0	-	13.0
	Mean	3.5	3.5	2.6	3.0	7.2	-	13.0
	Inferior	2.5	2.0	-0.5	0	4.0	-	13.0
EXTRA SHORT	Superior	5.5	5.0	4.0	4.5	9.0	-	11.5
	Mean	3.5	3.5	3.0	3.7	8.2	-	11.5
	Inferior	2.0	1.5	0	0.5	5.0	-	11.5

* The similarity of the measurements at the Retromolar Point in each group was due to all 3 curves terminating at one common point on the reference plane (see Fig. 97).

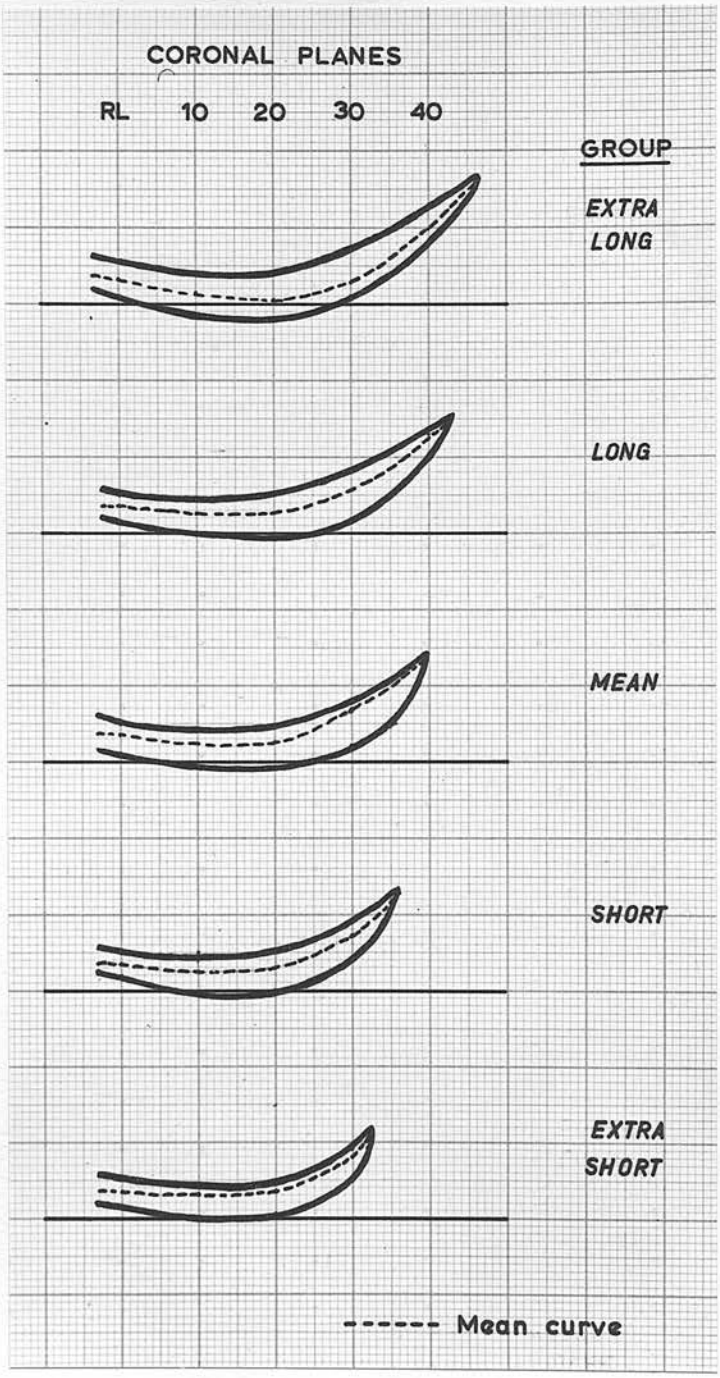


Fig. 97

EDENTULOUS MANDIBULAR CASTS

Vertical Ridge Measurements : the "superior" and "inferior" curves of each Length Group.

THE APPLICATION OF THE FINDINGS TO THE DESIGN OF IMPRESSION TRAYS

1. The measurements and traces of the DENTULOUS CASTS were applied to the design of the impression trays in the following way :

The Buccal and Lingual Outlines were derived from traces of the dentulous casts, the traces being projections of the mucogingival lines on the horizontal plane; the Vertical Buccal and Vertical Lingual measurements were made from the horizontal plane through the reference point to the mucogingival lines of the dentulous casts.

The mucogingival line was used for the following reasons :

(a) it was a definite anatomical landmark.

(b) it was located and marked on the buccal and lingual surfaces of the casts.

(c) projections of the lines on the horizontal plane resulted in contour lines which represented the buccal and lingual surfaces of the alveolar processes of the jaws.

(d) it was a line situated in a region of the mouth which was less liable to distortion by impression techniques and materials than the loose areolar tissue of the vestibule. Because of this distortion, measurements and traces in the region of the vestibule of dentulous and edentulous casts were found to be unreliable as a method of describing the size and form of the jaws.

(e) it could be located in both dentulous and edentulous mouths.

(f) it was the line of junction between the attached gingivae and the reflected alveolar mucosa. This is an important zone with regard to dental impressions and the subsequent design of full dentures.

The measurements and traces of the dentulous casts, made in relation to the mucogingival lines, indicated the range of size and outline contour of the alveolar processes of the dentulous jaws.

After the loss of teeth, resorption of the alveolar process occurs and the original contours of the dentulous jaws change. Moreover, the pre-extraction contours of the jaws of edentulous persons are seldom known. In order that the impression trays might contribute to the restoration of edentulous mouths, it was important that the outlines of the trays were designed as precisely as possible to the measurements and traces of the dentulous casts.

The outlines of the impression trays were, therefore, designed according to the various Buccal and Lingual Outlines derived from the traces of the dentulous casts, and the vertical heights of the tray flanges were determined from the vertical measurements of these casts.

(a) Buccal & Lingual Outlines of Mandibular Casts

The 351 dentulous mandibular casts were grouped according to the maximum length and maximum width of each cast and it was found that 94.6% of the total number of casts were placed in 13 groups.

Study of the measurements of these 13 groups showed a small deviation around the means of both the Maximum Width and the Width at the RL point.

Investigation of these measurements showed :

(i) Maximum Width (Tables 24 and 25).

range : 57 to 76 mm.

mean : 66.7 mm.

S.D. : 3.29

Thus the total range was 20 mm. It was seen, however, that the measurements of 93.9% of the total number of casts were between 61 and 72 mm. i.e. a range of only 12 mm.

(ii) Width at RL point (Tables 27 and 28).

range : 29 to 47 mm.

mean : 36.18 mm.

S.D. : 2.45

The total range was 19 mm. It was seen, however, that the measurements of 94.5% of casts were between 32 and 40 mm. i.e. a range of only 9 mm.

The Buccal & Lingual Outlines were derived from the 13 groups but, because of the small range of the width measurements, and particularly of the width at the RL point, it was felt that all 13 Outlines were unnecessary to represent the range of size and outline form of the dentulous mandibular casts.

In addition, study of the groups showed that the number of casts occurring in two of the groups was small :

Long/Extra Wide : 6 casts (1.7 % of total)

Short/Extra Narrow : 6 casts (1.7 % of total)

These two groups were, therefore, eliminated from the 13 groups together with two other groups, the widths of which were similar to the widths in adjacent groups. The original grouping is shown below and the four eliminated groups are marked with an asterisk.

	Maximum Length	Maximum Width	Width at RL point
1	EXTRA LONG	Mean	Mean
* 2	LONG	Extra Wide	Wide
3	"	Wide	Mean
* 4	"	Mean	Mean
5	"	Narrow	Mean
6	MEAN	Wide	Wide
7	"	Mean	Mean
8	"	Narrow	Narrow
9	SHORT	Wide	Mean
*10	"	Mean	Mean
11	"	Narrow	Mean
*12	"	Extra Narrow	Narrow
13	EXTRA SHORT	Narrow	Mean

Thus the final grouping of dentulous mandibular casts is shown in Table 60 . The outlines of the mandibular impression trays were made to the size of these 9 Buccal & Lingual Outlines. The method of construction of the trays is discussed later.

(b) Buccal Outlines of Maxillary Casts

The 351 dentulous maxillary casts were also grouped according to the maximum length and maximum width of each cast and it was found that 94.9% of the total number of casts were placed in 13 groups.

Study of the measurements of Maximum Width and the Width at the RU point, both of which were used to determine the maxillary Buccal Outlines, showed a greater deviation around the means than was found in the mandibular casts.

Investigation of the maxillary measurements showed :

(i) Maximum Width (Tables 13 and 14).

range : 52 to 75 mm.

mean : 62.33 mm.

S.D. : 3.83

Thus the total range was 24 mm. (mandibular : 20 mm.). The percentage of the total number of casts with measurements in the range 57 to 68 mm. (i.e. a range of 12 mm.) was 89.5% (mandibular : 93.9 % in a similar range of 12 mm.).

(ii) Width at RU point (Tables 16 and 17).

range : 23 to 49 mm.

mean : 38.05 mm.

S.D. : 3.92

Thus the total range was 27 mm. (mandibular : 19 mm.). The percentage of the total number of casts with measurements in the range 34 to 42 mm. (i.e. a range of 9 mm.) was 75.5 % (mandibular : 94.5 % in a similar range of 9 mm.).

It seemed, therefore, because of the large deviation around the means of the width measurements, and particularly of the width at the RU point, that all 13 Buccal Outlines were required to represent the varied size and outline form of the dentulous maxillary casts.

Thus the grouping of dentulous maxillary casts is shown in Table 61 . The outlines of the maxillary impression trays were made to the size of these 13 Buccal Outlines. The method of construction of the trays is discussed later.

TABLE 60 .

MANDIBULAR DENTULOUS CASTS

The grouping and measurements (in millimetres) of the 9 Buccal & Lingual Outlines which determined the design of the mandibular impression trays.

	Maximum Length	Anterior Length	Maximum Width	Width at RL point
1.	EXTRA LONG (53.98)	8.57	Mean (66.70)	Mean (36.18)
3.	LONG (50.49)	8.34	Wide (69.99)	Mean (36.18)
5.	LONG (50.49	"	Narrow (63.41)	Mean (36.18)
6.	MEAN (47.00)	8.10	Wide (69.99)	Wide (38.63)
7.	MEAN (47.00)	"	Mean (66.70)	Mean (36.18)
8.	MEAN (47.00)	"	Narrow (63.41)	Narrow (33.73)
9.	SHORT (43.51)	8.01	Wide (69.99)	Mean (36.18)
11.	SHORT (43.51)	"	Narrow (63.41)	Mean (36.18)
13.	EXTRA SHORT (40.02)	8.00	Narrow (63.41)	Mean (36.18)

TABLE 61.

MAXILLARY DENTULOUS CASTS

The grouping and measurements (in millimetres) of the 13 Buccal Outlines which determined the design of the maxillary impression trays.

	Maximum Length	Anterior Length	Maximum Width	Width at RU point
1	EXTRA LONG (59.83)	11.25	Wide (66.16)	Extra Wide (45.89)
2	LONG (56.28)	10.30	Extra Wide (69.99)	Wide (41.97)
3	" "	"	Wide (66.16)	Wide (41.97)
4	" "	"	Mean (62.33)	Mean (38.05)
5	" "	"	Narrow (58.50)	Narrow (34.13)
6	MEAN (52.73)	9.98	Wide (66.16)	Mean (38.05)
7	" "	"	Mean (62.33)	Mean (38.05)
8	" "	"	Narrow (58.50)	Mean (38.05)
9	SHORT (49.18)	9.32	Wide (66.16)	Mean (38.05)
10	" "	"	Mean (62.33)	Mean (38.05)
11	" "	"	Narrow (58.50)	Narrow (34.13)
12	" "	"	Extra Narrow (54.67)	Narrow (34.13)
13	EXTRA SHORT (45.63)	9.26	Narrow (58.50)	Narrow (34.13)

(c) Vertical measurements of Dentulous Casts

The Vertical Buccal and Vertical Lingual measurements were made from the horizontal plane through the reference point to the buccal and lingual mucogingival lines of the maxillary and mandibular dentulous casts.

These measurements were used to design the vertical height of the flanges of the impression trays for two reasons :

i. the flange of the tray would assist in the support of the lips and cheeks at the level of the mucogingival line.

ii. the edge of the flange would not interfere with the areolar tissue of the vestibule of the mouth.

Study of the vertical measurements (Tables 34,35,36) showed that the range in the median sagittal plane and in each coronal plane was small. Therefore, the mean measurements, in the median sagittal plane and in each coronal plane of the 5 Length Groups, were used to define the vertical heights of the flanges of the various maxillary and mandibular trays, e.g. the flange heights of the 4 Long maxillary trays were made according to the mean vertical measurements of the Long Group of dentulous maxillary casts.

2. The measurements of the EDENTULOUS CASTS were applied to the design of the impression trays in the following way :

The Vertical Ridge measurements of the edentulous casts were used to determine the vertical position of the Ridge Outlines within the Buccal Outlines, in order to ensure that the antero-posterior curvatures of the maxillary and mandibular impression trays matched the variations of residual alveolar ridge height found in edentulous jaws.

(a) Edentulous Maxillary casts

(i) Study of the Vertical Ridge measurements of these casts (Table 56) showed that the range in the median sagittal plane and in each coronal plane was small. Therefore, the mean measurements in the median sagittal plane and in each coronal plane of the 5 Length Groups of casts, were used to define the vertical positions of the Ridge Outlines in the various maxillary trays, e.g. in the 4 Short maxillary trays, the vertical positions of the Ridge Outlines were located according to the mean vertical ridge measurements of the Short Group of edentulous maxillary casts.

These measurements, however, were made from the surface of the casts. Therefore, 2 mm. were subtracted from each of the selected mean measurements, in the construction of the trays, to accommodate a thickness of impression material between the mucosal surface of the edentulous residual alveolar ridge and the impression tray. This figure of 2 mm. was arbitrary but was based on the accepted clinical procedure of using one or two sheets of

baseplate wax (approximately 1.4 to 2.8 mm.) as a "spacer" in individually prepared impression trays for edentulous patients.

(ii) Palate measurements were made, on dentulous and edentulous maxillary casts, from the horizontal reference plane to the surface of the palate in the median sagittal plane. It has already been shown that changes in the palate after the loss of teeth were small and, therefore, it was of little account whether the dentulous or the edentulous measurements were used in the design of the impression trays. However, it has been shown that changes occurred in the anterior regions of the palate and, for this reason, it was felt that the measurements made on the edentulous casts gave a more reliable indication to palatal shape, especially in respect to measurements made in the 10 mm. coronal plane. Therefore, the mean edentulous palate measurements (Table 57), in each coronal plane of each of the 5 Length Groups of casts, were used to define the vertical position of the palatal curve in the various maxillary trays. From each of the mean measurements, 2 mm. were subtracted to allow for a thickness of impression material.

The use of the mean Vertical Ridge and Palate measurements in the design of the trays might well be questioned because of the obvious difficulty of locating such trays in edentulous mouths which comprised vertical measurements less than the mean. (This phrase "less than the mean" implied that either the palate vault in the edentulous mouth was shallow, or the residual alveolar

ridge was well formed.) It has been shown, in the Investigation of Errors, that the average vertical measurement between the dentulous and edentulous reference planes was about 2 mm. This was due to the changes in the region of the RU point and the Notch Points after the loss of teeth. The figure of 2 mm. was approximate and obviously varied between different edentulous casts, depending on the amount of change which had taken place. For any one particular cast the amount of the change was not known. In the construction of the impression trays, all the vertical measurements were related to a common reference plane in order to make the measurements of maxillary casts comparable. Thus a compensation factor of 2 mm. was applied to the vertical edentulous measurements, in addition to the 2 mm. allowance for impression material, and this ensured adequate clearance of the impression trays in edentulous mouths which comprised vertical measurements less than the mean.

(b) Edentulous Mandibular casts

The Vertical Ridge measurements of the edentulous mandibular casts (Table 59) were derived from a combination of the direct measurements and sagittal traces (see page 163). The "superior" and "inferior" measurements in the median sagittal plane and in each coronal plane of the 5 Length Groups of edentulous casts were used to define the vertical positions of the Ridge Outlines in the various mandibular trays. Thus, for each mandibular Buccal & Lingual Outline two designs of impression tray were made. The two designs

differed only in their Vertical Ridge measurements, but in all other respects were identical. Thus, a total of 18 mandibular impression trays were finally made.

In the tray construction an adjustment of 2 mm. was applied to each Vertical Ridge measurement, as in the maxillary trays, to allow for a thickness of impression material.

THE METHOD OF CONSTRUCTION OF THE IMPRESSION TRAYS

Construction of Maxillary Impression Trays

The following method was used to construct each of the 13 maxillary impression trays :

(i) The Buccal Outline and Ridge Outline were drawn on millimetre-squared paper. This represented the horizontal section of the tray (Fig. 98).

(ii) Coronal sections through the RU point and at each 10 mm. coronal plane were then drawn. The number of these coronal sections obviously varied according to the length of the tray. At each section a line was drawn to represent the dentulous horizontal reference plane and the following measurements, obtained from the Length Group of the particular tray under construction, were accurately plotted in relation to this reference plane :

(a) the right and left mean Vertical Buccal measurements.

(b) the right and left mean Vertical Ridge measurements.

(c) the mean edentulous Palate measurement.

Before plotting (b) and (c), two millimetres were subtracted from the measurements to allow clearance for impression material.

A vertical line was dropped from the Vertical Buccal mark to meet the horizontal reference plane and the line was continued to meet the Vertical Ridge mark. The latter was then joined to the Palate mark. This completed the coronal section (Fig. 98).

(iii) A median sagittal section was then drawn in relation to the horizontal reference plane. In this section the following measurements were plotted :

(a) the mean Vertical Buccal measurement.

(b) the mean Vertical Ridge measurement.

(c) the mean edentulous palate measurements at each coronal plane.

Before plotting (b) and (c), two millimetres were subtracted from the measurements. A mark was also made in the RU plane at a point 2 mm. inferior to the reference plane. This ensured vertical clearance of the tray in the region of the RU point.

A vertical line was dropped from the Vertical Buccal mark to meet the reference plane and the line was continued to meet the Vertical Ridge mark. The palate marks were joined by a smooth curve. This completed the median sagittal section (Fig. 98).

It will be seen that the vertical line from the Vertical Buccal mark to the reference plane in the coronal and median sagittal sections represented the vertical flange of the impression tray. The flange was designed in this way so that the lips and cheeks of an edentulous person were offered an adequate surface for support when the impression tray was located in the mouth.

Each of the coronal sections and the sagittal section was glued to 1 mm. thick Perspex sheet which was then accurately trimmed to the perimeter of each section.

Care was taken to leave an excess of Perspex to act as a base for mounting the section. A small horizontal ledge of Perspex was also made opposite each Vertical Buccal mark.

A median line was scribed along the length of a block of $\frac{1}{2}$ in. Perspex which measured approximately 6 ins. x 3 ins. A series of grooves 1 mm. wide were cut at 10 mm. intervals at right angles to the line. The block was laid on an engineers' surface table.

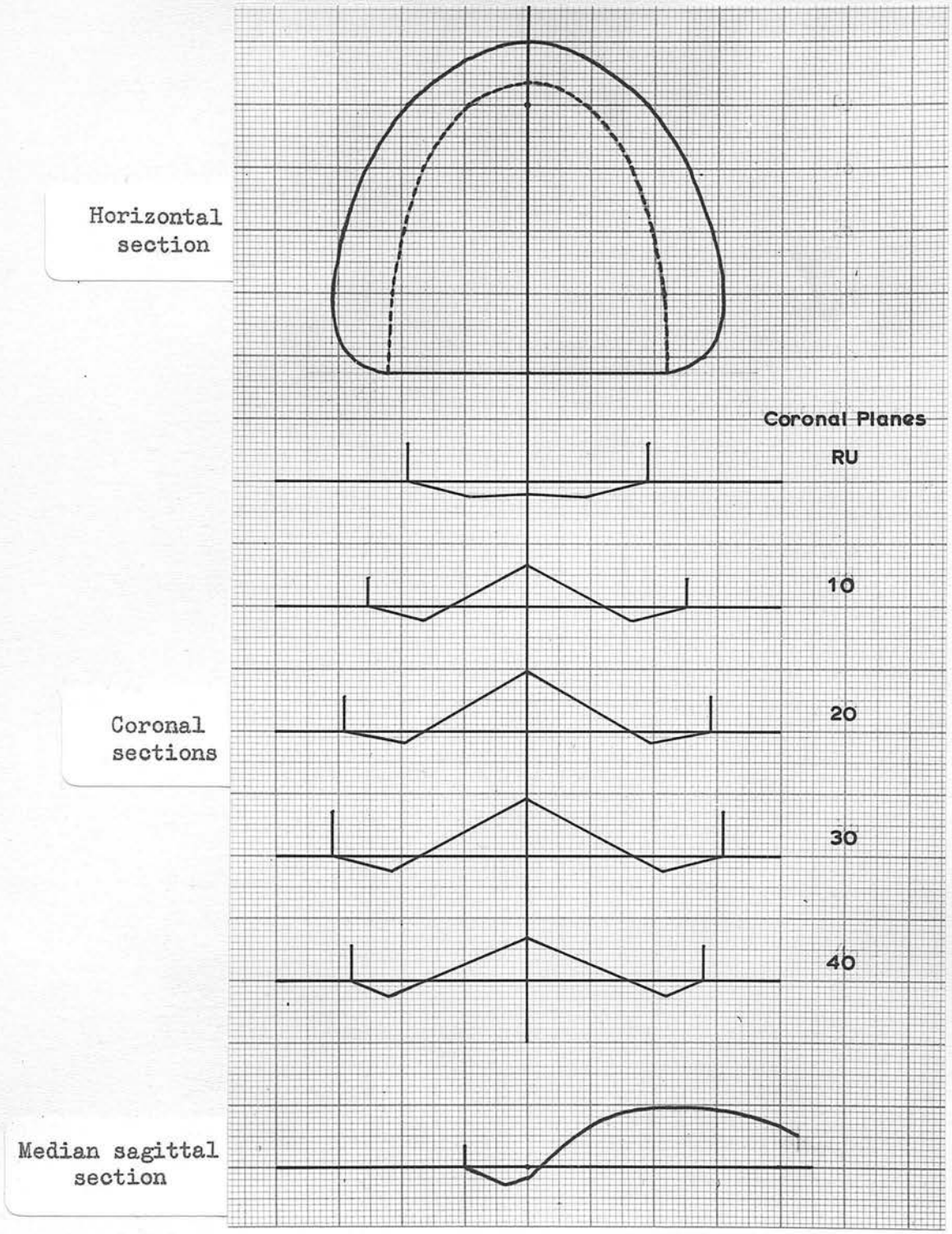
One of the coronal sections was inverted and fitted into one of the grooves. (The sections were drawn on the paper in their anatomical relationships and the reason for inverting the section was for ease of construction of the tray.) The point of a surface gauge was adjusted to an appropriate height and the horizontal reference plane of the coronal section was made to coincide with the point (Fig. 99). The median sagittal plane of the section was made to coincide with the median line of the block. The other coronal sections were then inverted and run into the appropriate grooves and the horizontal reference plane of each was set to the same vertical positions as the first as determined by the fixed position of the surface gauge (Fig. 99). The median sagittal section was then trimmed and fitted into position on the block. Each section was then firmly luted to the block by means of sticky wax.

Plasticine was then packed between the various sections and made flush with the perimeter of each section (Fig. 100). Care was taken that the Plasticine was trimmed accurately between the sections at the level of the Vertical Buccal marks (the small ledges of Perspex assisted this trimming).

The final form of the Plasticine was checked against the horizontal section of the tray (i.e. the Buccal Outline).

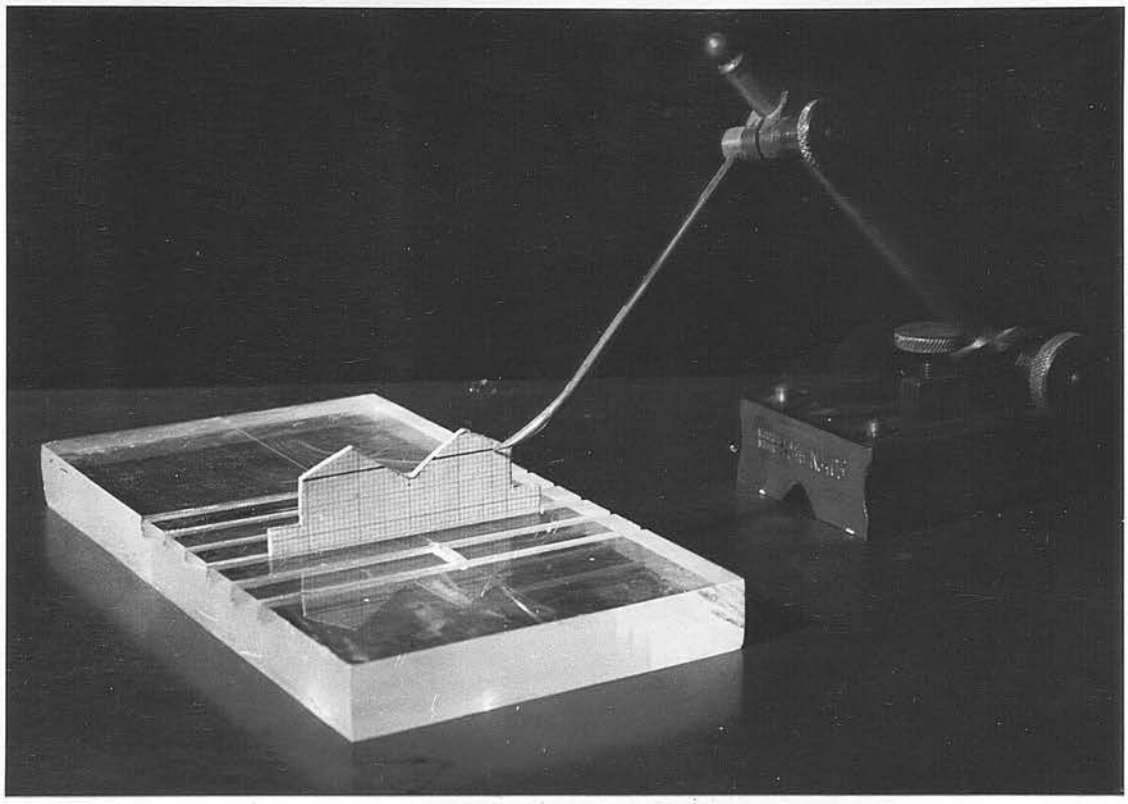
The surface of the Plasticine was smoothed and an impression of the whole was taken in an alginate material (Duplit) and poured in artificial stone (Kaffir D) (Fig. 101). A single sheet of dental baseplate wax was then adapted to this cast and a handle was added. The wax was invested in artificial stone in a dental flask and reproduced in self-polymerising acrylic resin to form a maxillary impression tray (Fig. 102).

The cast, on which the wax was adapted, was made to the exact measurements of the Buccal Outline and, therefore, the outside measurements of the acrylic tray were greater by the thickness of the baseplate wax (approximately 1.4 mm.). This excess thickness would have the effect of causing a slight buccal and labial displacement of the mucosal surface of the cheeks and lips of an edentulous person but this was accepted for the reason that a slight elastic displacement of the surrounding compressible tissue would help to maintain a valve seal in the region of the periphery and facial surface of a full denture. It should be noted, however, that the displacement in the molar region would be minimal because the Buccal Outlines, which were formed from traces of the buccal and labial surfaces of dentulous casts, did not take into account the small space which exists, in the maxillary molar region, between the alveolar process and the mucosal surface of the cheek. This space has been termed the zygomatic fossa (PENDLETON 1942b) and also the tuberosity vestibular space (LEE 1954).



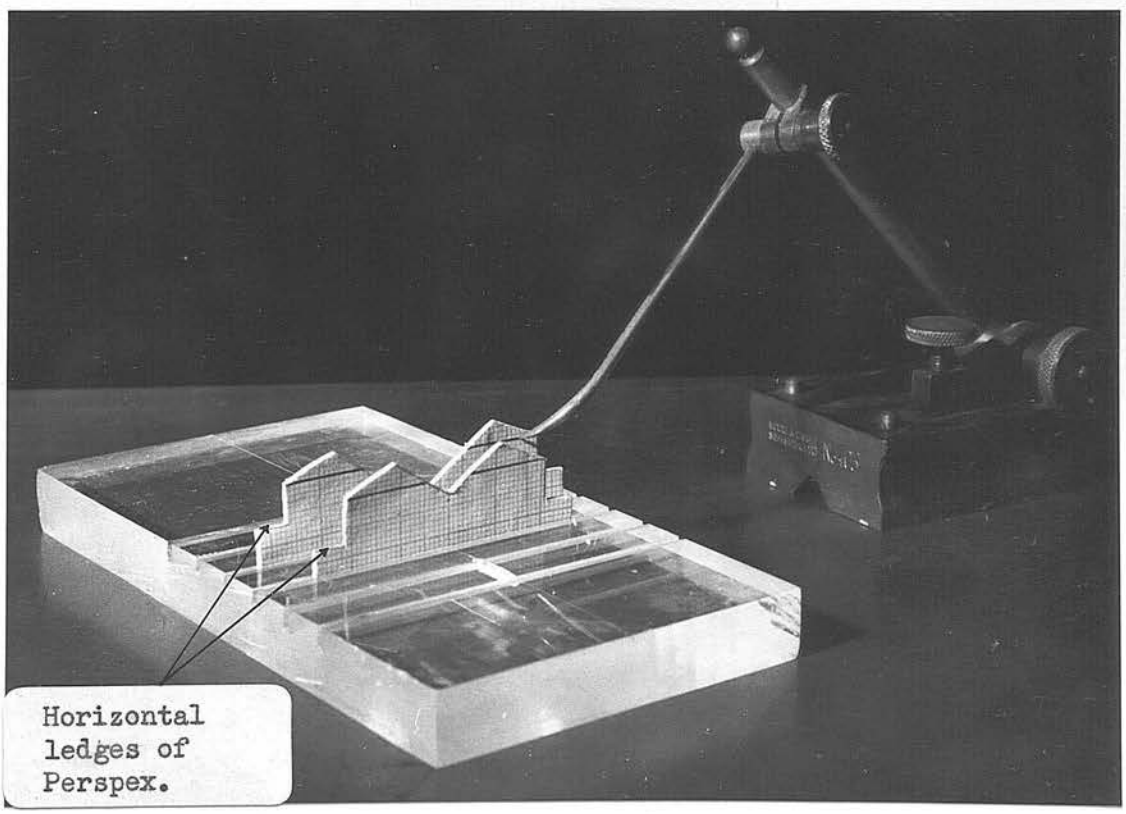
CONSTRUCTION OF MAXILLARY IMPRESSION TRAY
Length : mean
Width : mean

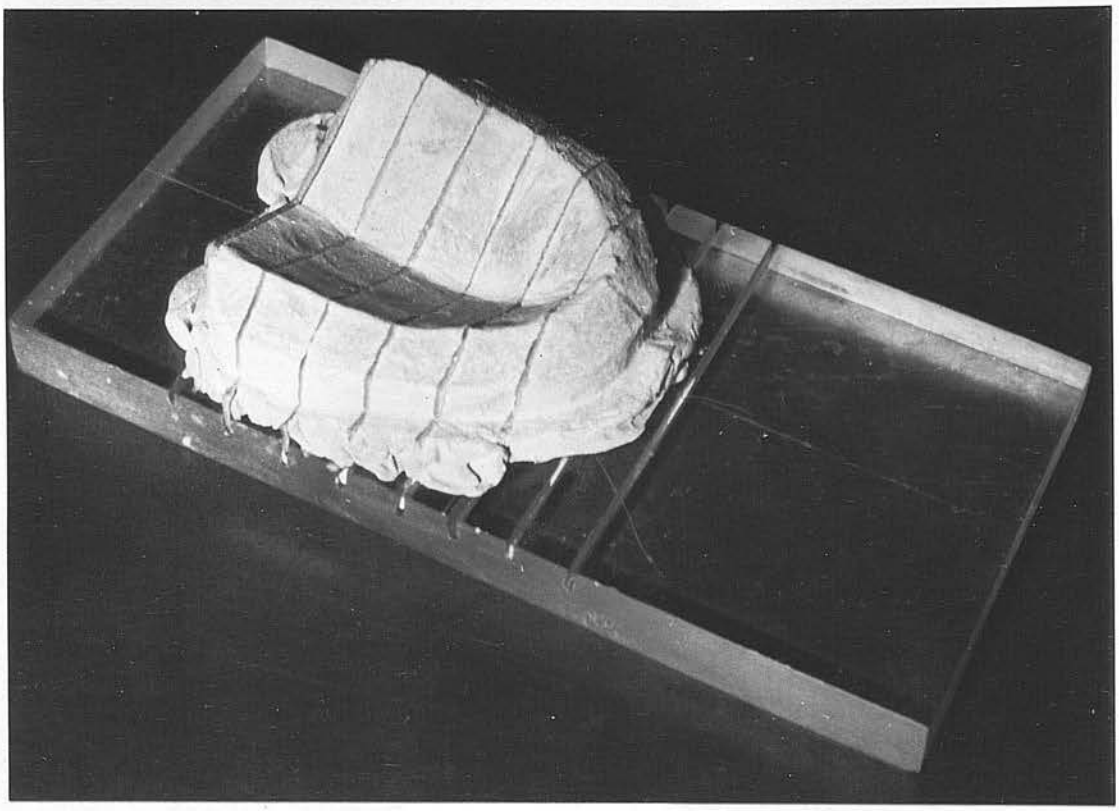
Fig. 98



Locating the Coronal sections in the Perspex block.

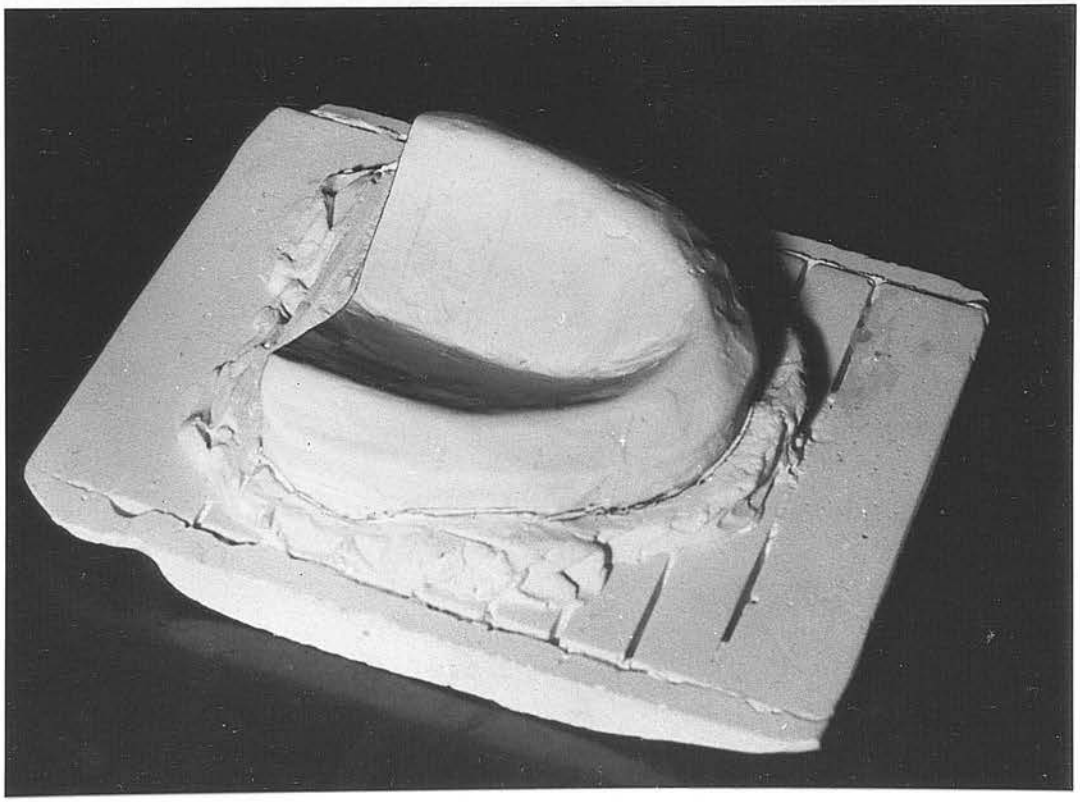
Fig. 99





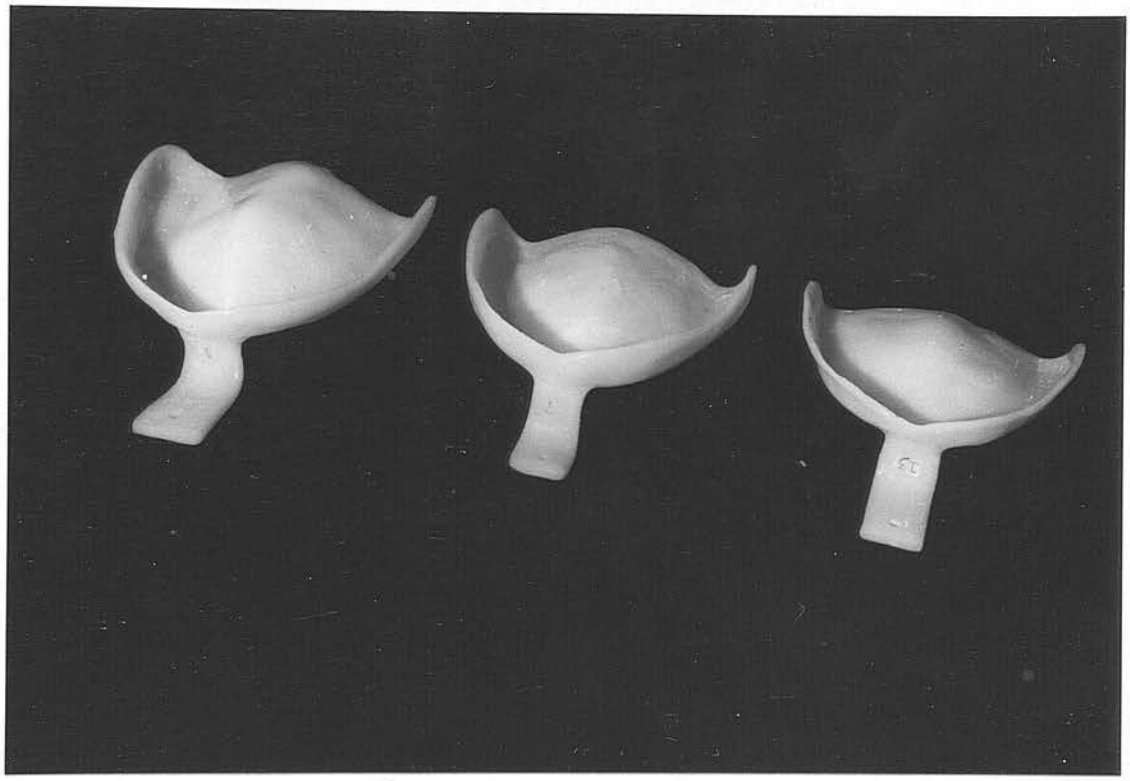
Plasticine packed between the Coronal sections.

Fig. 100



Artificial stone cast.

Fig. 101



MAXILLARY
IMPRESSION
TRAYS

Fig. 102

Construction of Mandibular Impression Trays

The method of constructing the 18 mandibular impression trays was similar to that described for the maxillary trays and only the essential points of difference are reported.

(i) The Buccal & Lingual Outline and Ridge Outline were drawn on paper to represent the horizontal section of the tray (Fig. 103).

(ii) It has already been stated that for each Buccal Outline two different designs of mandibular tray were produced, the differences being only with respect to the Vertical Ridge measurements. Therefore, two columns of Coronal sections were drawn on the paper, one column comprising the "superior" Vertical Ridge measurements, the other column comprising the "inferior" (Fig. 103). All other measurements, at comparable Coronal sections in the two columns, were identical.

A line representing the horizontal plane through the RL point was drawn at each section and the following measurements, from the Length Group of the particular tray under construction, were plotted in relation to that line :

(a) the right and left mean Vertical Buccal and Vertical Lingual measurements (the vertical lingual measurements, in the Coronal section through the RL point were, of course, coincident with the line).

(b) the "superior" and "inferior" Vertical Ridge measurements. Before these were plotted, two millimetres were added to the measurements to allow for a thickness of impression material.

(iii) A median sagittal section was then drawn in each of the two columns (Fig. 103). The following measurements were plotted :

(a) the mean Vertical Buccal measurements (the vertical lingual measurement was coincident with the RL point).

(b) the "superior" and "inferior" Vertical Ridge measurement (with a 2 mm. addition).

The median sagittal sections of mandibular trays were, of course, small but, nevertheless, were important in the tray construction.

The details of the method of constructing the mandibular trays were thereafter similar to that described for maxillary trays and need not be repeated (Figs.104 105).

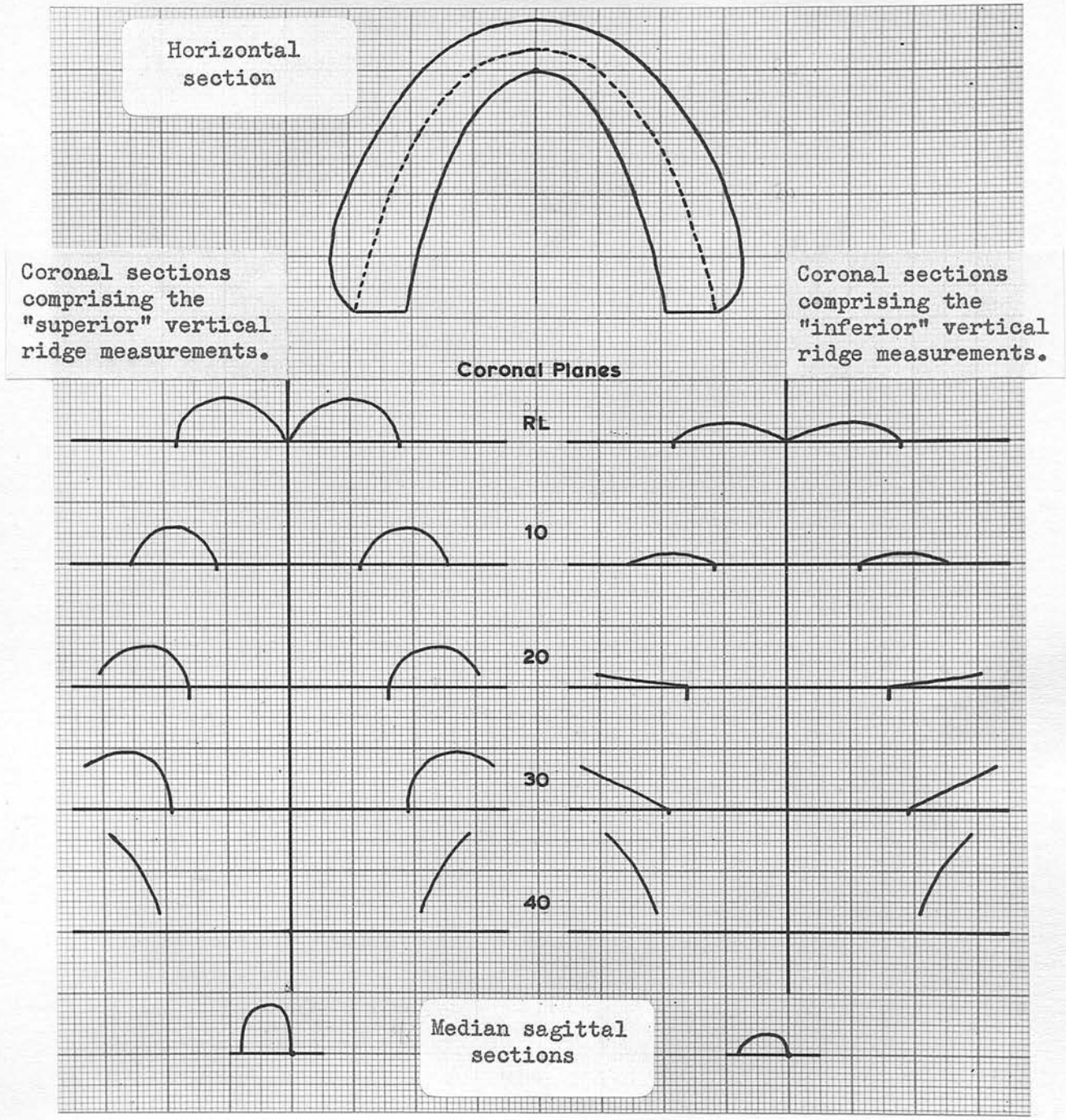
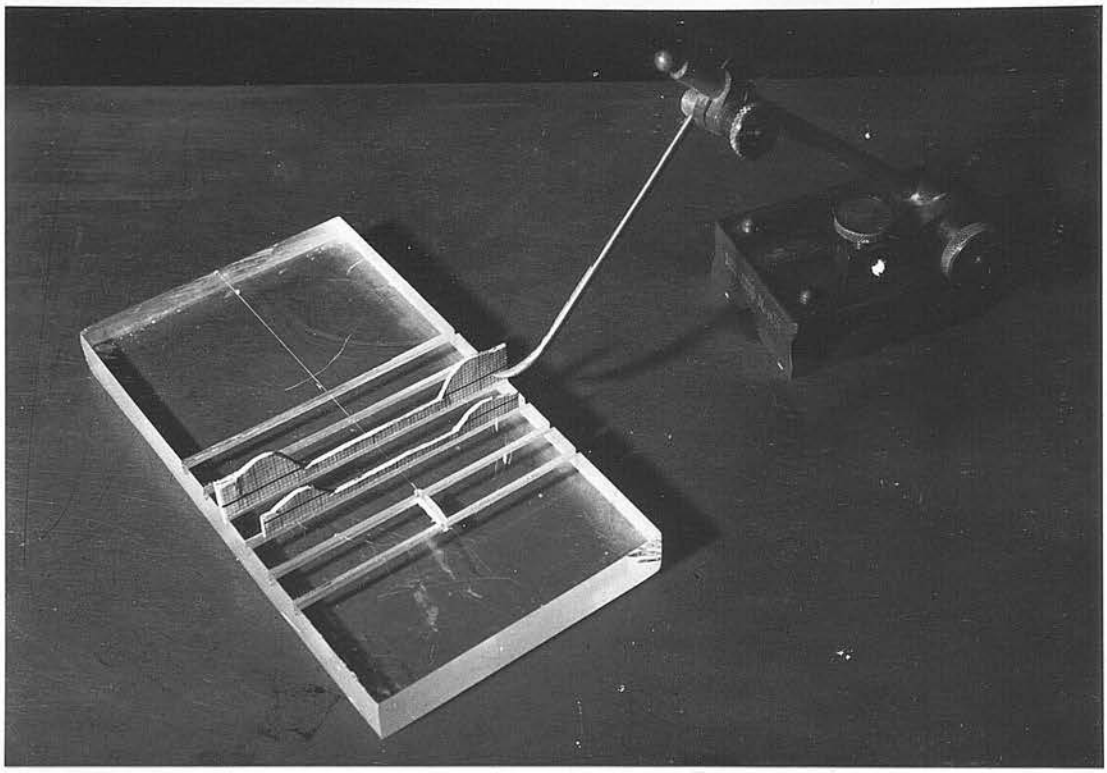


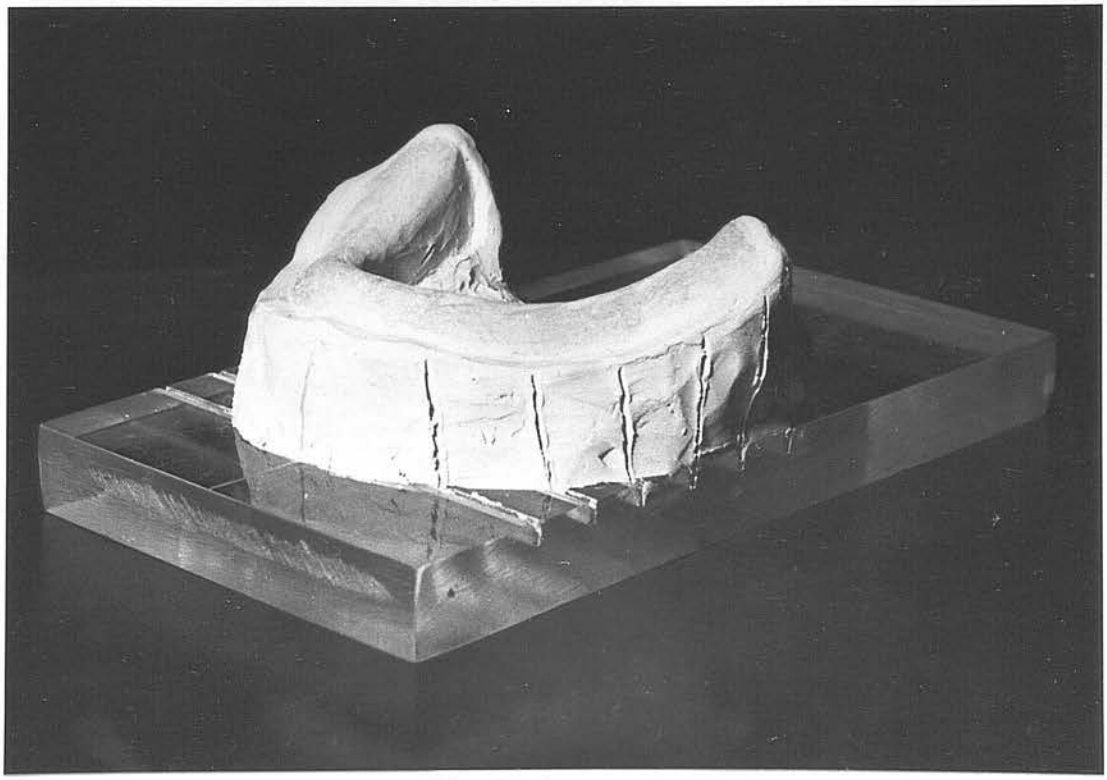
Fig. 103

CONSTRUCTION OF MANDIBULAR IMPRESSION TRAYS
Length : mean
Width : mean

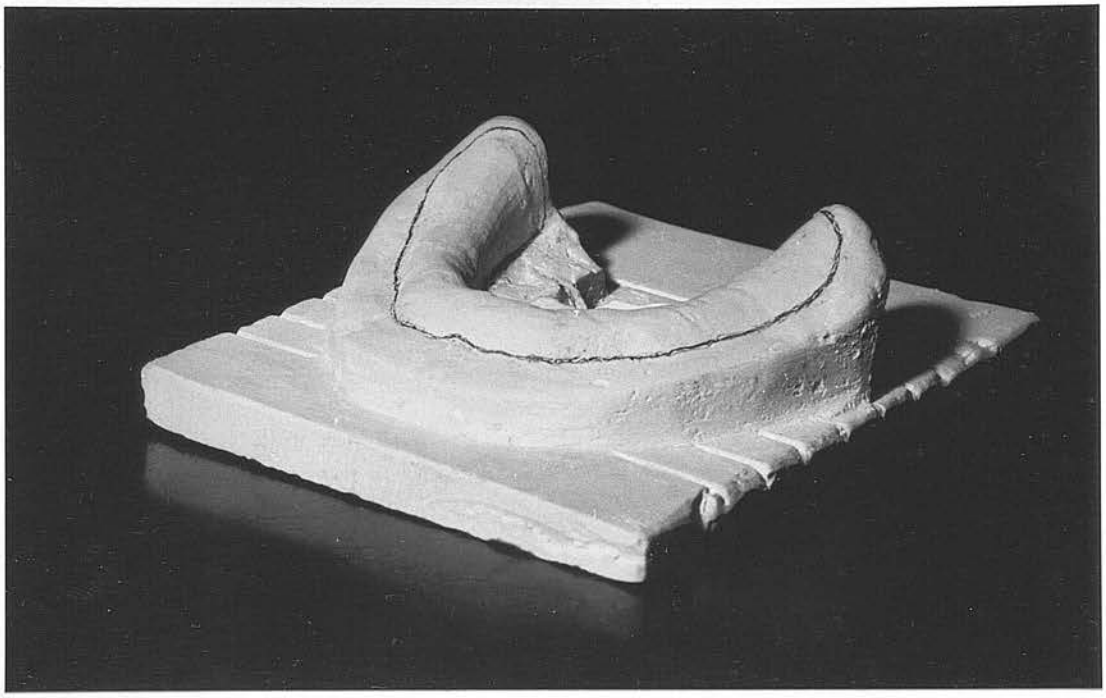


Locating the Coronal sections in the Perspex block.

Fig. 104

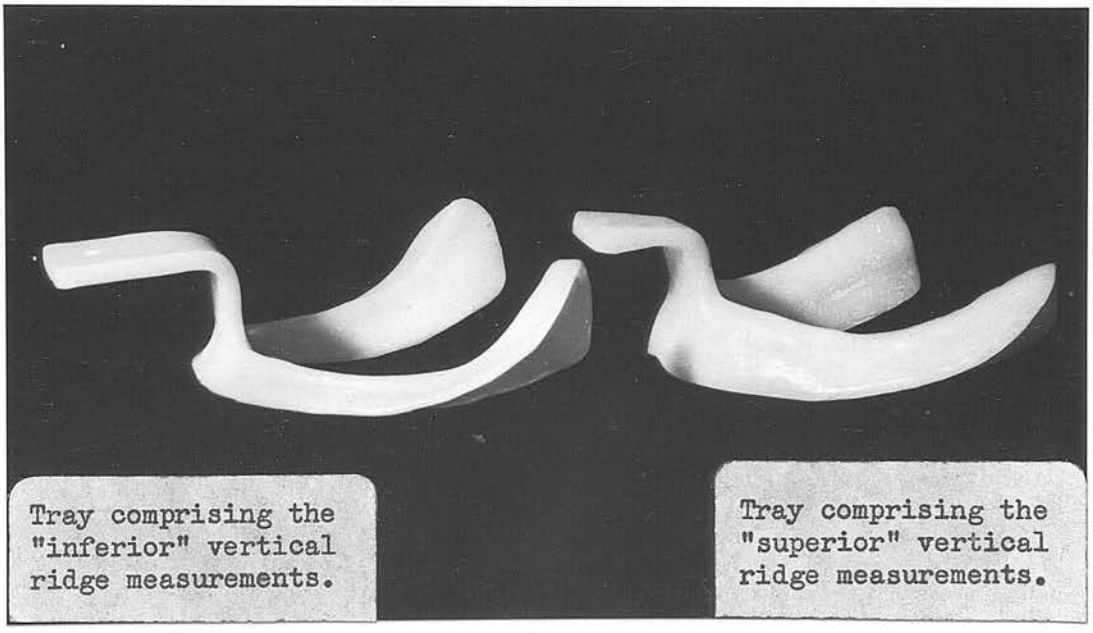


Plasticine packed between the Coronal sections.



Artificial
stone cast.

Fig. 105



Mandibular impression
trays of the same
Buccal & Lingual
Outline (Long/Wide).

CLINICAL APPLICATION OF THE IMPRESSION TRAYS

The buccal and lingual outlines of the impression trays made in the present study were designed from the dentulous casts with the intention that when an impression tray was placed in the mouth of an edentulous patient, the lips and cheeks would be supported by the tray in their approximate pre-extraction position. Thus the form and extent of the vestibular sulcus would be recorded by an impression material with the lips and cheeks in this position. In addition, it was intended that the impression tray flange would not impinge on the loose areolar tissue of the vestibular sulcus when the tray was located in the mouth.

As these intentions depended not only on the selection of the correct tray for a particular edentulous patient but also on the location of the tray in the correct horizontal and vertical position in the mouth, additional measurements and traces were made of the edentulous casts in order to assist in the selection and location of the impression trays.

Measurements and traces were made of 99 pairs of edentulous casts (see page 87).

The traces were projections of the buccal mucogingival lines of maxillary and mandibular casts on the horizontal plane.

Vertical measurements were made from the horizontal reference plane of each maxillary cast to the buccal mucogingival line in coronal planes.

1. Traces

Composite traces were made by superimposition of the individual traces of the maxillary and the mandibular

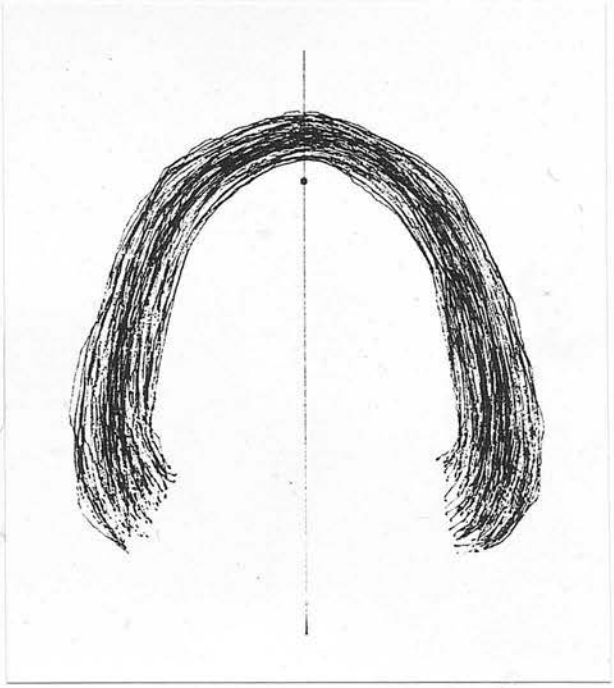
casts (Fig. 106). These were made by the method used for dentulous casts. Each composite trace showed much variation between individual traces because, in this investigation, the casts were not divided into Width Groups. In order to find the mean buccal outline of the traces, each individual trace was measured under a millimetre grid. Width measurements were made between the points of intersection of the trace of the buccal mucogingival line with the coronal plane through the Reference Point and with coronal planes at 10 mm. intervals from the Reference Point. The range and mean of these width measurements, at each coronal plane, were tabulated for the maxillary casts (Table 62) and the mandibular casts (Table 63).

The mean width measurements were plotted to show the mean position of the buccal mucogingival line of the edentulous casts in relation to (a) the mean dentulous mucogingival line and (b) the mean edentulous Crest Line (Fig. 107). These diagrams showed the mean difference in the projections on a horizontal plane of the buccal mucogingival lines between the dentulous and edentulous casts, and the horizontal relationship between the lines and the edentulous residual alveolar ridge crest lines.

2. Vertical measurements

Vertical measurements were made of each of the 99 edentulous maxillary casts from the horizontal reference plane to the buccal mucogingival line in coronal planes through the RU point and at 10 mm. intervals from the RU point. The range and means of these measurements are given in Table 64 . In presenting these results, no attempt was

Edentulous maxillary casts



Composite traces of the projections of the buccal mucogingival lines on the horizontal plane.

Fig. 106

Edentulous mandibular casts

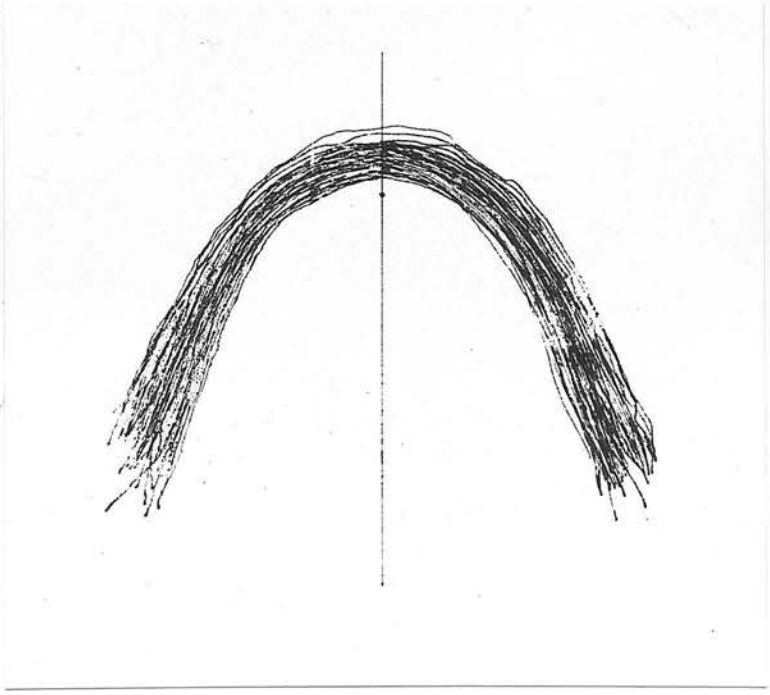


TABLE 62 .

99 EDENTULOUS MAXILLARY CASTS

Width measurements in millimetres between points of intersection of the Buccal Mucogingival Line with coronal planes. (Measurements made on traces of casts.)

	CORONAL PLANES				
	RU	10 mm.	20 mm.	30 mm.	40 mm.
Mean	25.2	39.4	46.5	52.4	53.6
Range	16-40	33-51	38-58	42-63	42-63

Length measurement from RU point to buccal mucogingival line : mean 6.4 mm. (range 3 to 9 mm.).

TABLE 63 .

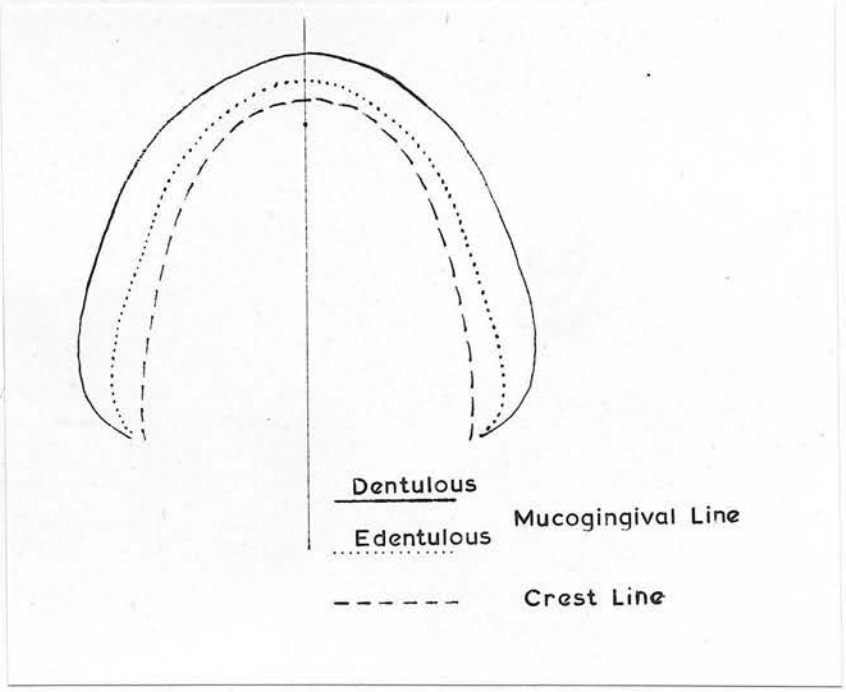
99 EDENTULOUS MANDIBULAR CASTS

Width measurements in millimetres between points of intersection of the Buccal Mucogingival Line with coronal planes. (Measurements made on traces of casts.)

	CORONAL PLANES				
	RL	10 mm.	20 mm.	30 mm.	40 mm.
Mean	25.8	40.9	51.2	59.1	64.3
Range	14-37	34-52	44-63	51-71	59-72

Length measurement from RL point to buccal mucogingival line : mean 5.6 mm. (range 2 to 9 mm.).

Maxillary casts



The relationship of the mean positions of the buccal mucogingival lines and Crest Lines.

Fig. 107

Mandibular casts

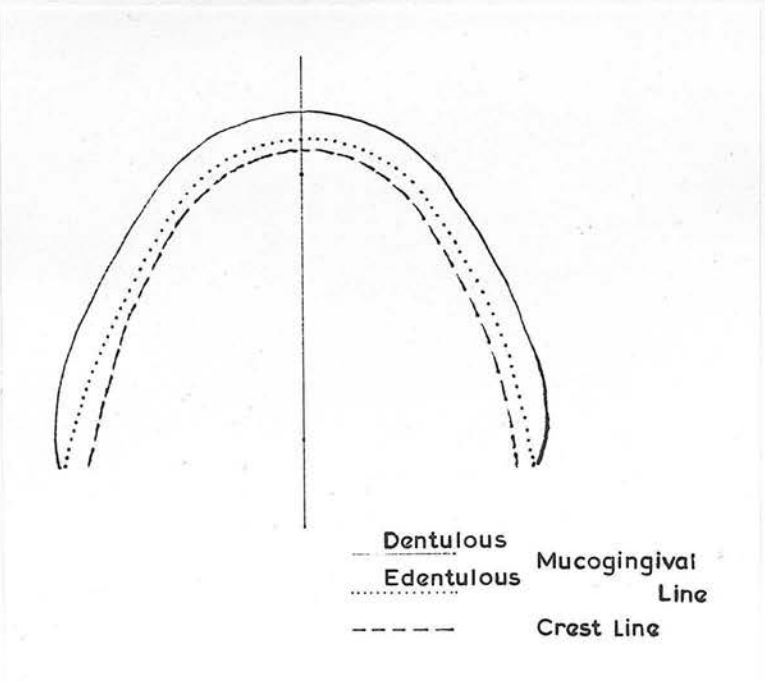


TABLE 64.

99 EDENTULOUS MAXILLARY CASTS

Vertical measurements in millimetres from the horizontal reference plane to the buccal mucogingival line.

	RIGHT CORONAL PLANES					LEFT CORONAL PLANES				
	40 mm.	30 mm.	20 mm.	10 mm.	RU	RU	10 mm.	20 mm.	30 mm.	40 mm.
Mean	4.98	5.46	4.48	4.13	5.01	5.19	4.24	4.55	5.44	5.01
Range	2.0 10.0	2.5 9.5	0 8.0	0 7.0	0 9.0	0 9.0	0.5 7.0	0 8.0	2.5 9.0	2.0 9.5

made to divide the 99 casts into various Length Groups because of the small number of the casts.

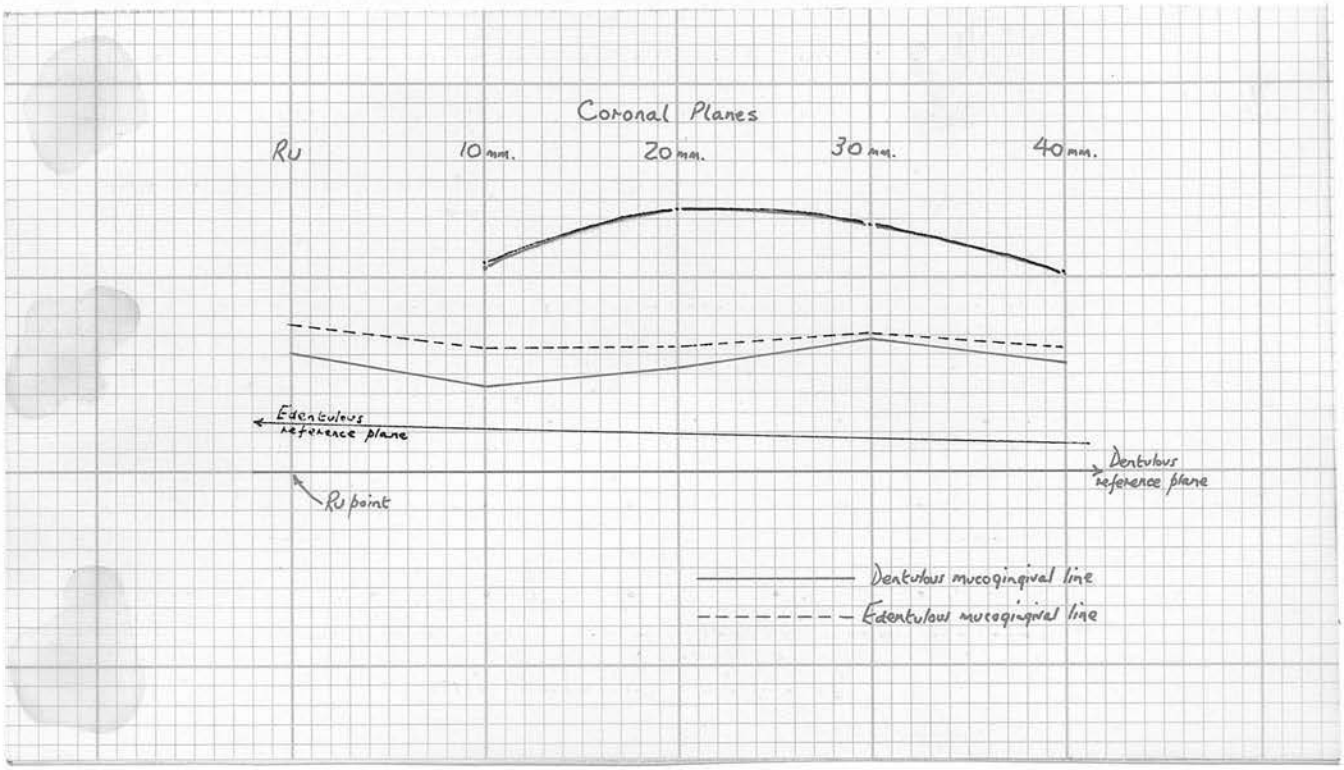
Comparison of these results were then made with similar measurements made on the total dentulous sample of 351 casts.

The mean measurements (right and left sides combined) of the dentulous and edentulous samples were tabulated as follows :

	Number of casts	Coronal Planes				
		RU	10 mm.	20 mm.	30 mm.	40 mm.
Dentulous	351	6.08	4.39	5.35	6.82	5.64
Edentulous	99	5.10	4.18	4.52	5.45	4.99

(measurements in millimetres)

In order to compare these measurements, the position of the points were plotted on squared paper and the mean palatal curves of the dentulous and edentulous samples were superimposed (Fig. 108). This showed the vertical positions of the mucogingival lines of the dentulous and edentulous casts in relation to a common palatal curve and appeared to indicate that a small shift of the mucogingival line possibly occurred in a superior direction after loss of the maxillary teeth. Owing to the nature of this cross-section study it was not possible to reach any definite conclusion as regards the amount of this shift. Further clarification on this matter could only be obtained by a longitudinal study.

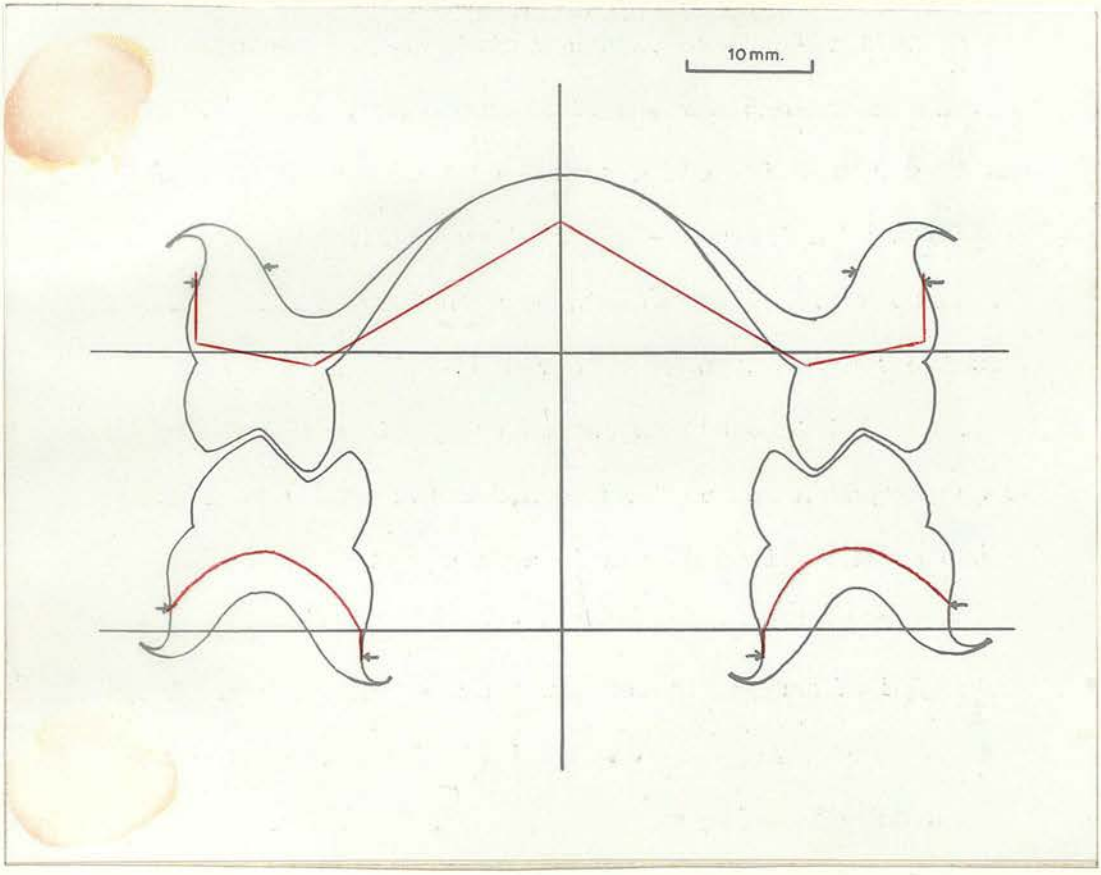


Mean palatal curves of dentulous and edentulous casts superimposed to compare the positions of the buccal muco-gingival lines.

Fig. 108

The diagrams in Fig. 107 showed the difference between the mean outline contours of the buccal alveolar processes of the dentulous and edentulous casts, at the level of the mucogingival lines, and thus indicated the amount of vestibular width required to effect restoration of a residual alveolar ridge to its approximate pre-extraction buccal contour. In any particular edentulous patient, of course, the amount of change in the alveolar process after the loss of the teeth was unlikely to be known with certainty and, therefore, the final selection of an impression tray depended on the degree of facial restoration of the lips and cheeks with the tray held in the mouth in such a way that the edge of the impression tray flange was located approximately at the level of the mucogingival line.

The diagram in Fig. 109 , which comprises the mean measurements of the casts of the total dentulous and edentulous maxillary and mandibular samples, shows coronal section outlines of maxillary and mandibular impression trays superimposed to show the horizontal and vertical position of the trays in relation to the edentulous residual alveolar ridges and palate. This diagram also shows that the space between the tray and the mucosal surface of the mouth was unlikely to be uniform. This space obviously varied according to the size of the selected tray and the size and form of the edentulous residual alveolar ridge. It was appreciated that an unequal thickness of impression material might lead to small dimensional inaccuracies in the impression, but it was felt that the effect of this on the resultant full denture would be negligible.



Composite diagram comprising the mean measurements of the casts of the total dentulous and edentulous maxillary and mandibular samples. All measurements made in the 20 mm. coronal plane (approximately the first molar region). Tooth positions based on measurements of adult dental arches given in Table 3 . Arrows show the mean positions of the mucogingival lines. Coronal section outlines of maxillary and mandibular impression trays superimposed.

Fig. 109

In addition to the restoration of the facial contour of an edentulous patient by means of an impression tray, it was also important that the tray covered the denture bearing area of the mouth. In the design of the maxillary trays, the posterior edge was made to coincide with the coronal plane through the Notch Points. This ensured that the length of the tray was sufficient to cover the posterior part of the denture bearing area. The extent of the selected tray was checked in the mouth by adding tracing stick in the postdam region, so that the tracing stick contacted both the palatal mucosa and the mucosal ridge of each pterygomaxillary notch. On mandibular trays, the lengths of which were determined by the Retromolar Points, tracing stick was added to the postero-inferior surface so that the tracing stick covered the retromolar pad on each side of the mandibular denture bearing area.

In the selection of impression trays for some edentulous patients it was considered that difficulties might arise when attempting to restore the lips and cheeks to pre-extraction positions. The reasons for these difficulties were as follows :

(a) the dentulous and edentulous casts of the sample showed a great diversity in form and size, and approximation was found to be necessary when designing the range of impression trays from the measurements and traces of the casts.

(b) the lips and cheeks of an edentulous patient cannot be restored to their exact pre-extraction position by an impression tray alone because the facial contour also

depends on support from the teeth and, to a certain extent, on the lip and cheeks in the region of the opposing jaw.

(c) in certain instances, for functional or cosmetic reasons, it may be considered unwise to attempt restoration of the lips and cheeks to a pre-extraction contour because of irrevocable senile or pathological changes.

(d) the degree of facial restoration of an edentulous patient is, to a certain extent, dependent on the subjective opinion of the observer.

CLINICAL TRIAL OF THE IMPRESSION TRAYS

4 observers, who were members of the full-time University staff of the Prosthetic Department of the Edinburgh Dental School, took part in a clinical trial to test the utility of the impression trays which were designed in the manner described in this work (these were called "the acrylic trays").

24 edentulous patients requiring full dentures were selected at random from a waiting list of patients in the Edinburgh Dental Hospital. Of these, 2 failed to attend.

The remaining 22 patients were divided into 4 groups and each observer was asked to take 4 impressions for each patient in his group : (a) maxillary and mandibular impressions in standard manufactured trays * and (b) maxillary and mandibular impressions in the acrylic trays. The only addition to the trays permitted was tracing stick in the postdam region. All impressions were taken with an alginate impression material (Identica) using water at room temperature. The clinical procedure was so arranged that each observer had at his disposal a full range of standard and acrylic impression trays from which to select the maxillary and mandibular trays which he considered suitable for each patient.

* The range of standard manufactured trays comprised trays made by Coe Laboratories Inc., Dental Manufacturing Co. Ltd., Amalgamated Dental Co. Ltd., and also a number of trays of various forms and sizes made in the Edinburgh Dental Hospital some years previously.

Assessment of Casts

The impressions were poured in artificial stone (Kaffir D) by one technician who numbered each cast after trimming. The numbering system was unknown to the 4 clinical observers, thus when each observer was presented with the total batch of 88 casts and asked to assess each cast, the assessment was made "blind".

(a) Each cast was assessed as to its suitability as a master cast i.e. whether or not a satisfactory full denture could be constructed on the cast.

(b) Each observer was also asked to make a similar "blind" assessment of the casts in pairs. The purpose of this comparison was to select which of the two similar casts in each pair the observer considered to be more suitable for the construction of a satisfactory full denture, so that at the end of the trial, when the numbering system was disclosed, the casts obtained from the standard tray impressions could be compared with the casts obtained from the acrylic tray impressions.

The numbering system used on the casts was not, of course, revealed to the observers at any time during their assessment of the casts.

Criteria of selection or rejection of casts

In these assessments of the casts, the following criteria for rejection or selection were applied :

(1) Criteria for rejection :

(a) Faults or deficiencies in any part of the denture bearing area of the cast which contraindicated the construction of a satisfactory full denture on the cast, with the exception of the following :

(i) small surface faults caused by blows in the impression or pouring of the cast in the laboratory.

(ii) errors of cast trimming in the laboratory.

(b) Underextensions or overextensions of the buccal or lingual sulcus, in either width or depth, which contraindicated the construction of a satisfactory full denture on the cast.

(2) Criteria for selection :

That a satisfactory full denture could be constructed on the cast.

Results

(a) Assessment of 88 separate casts

Results showed that 66 casts were accepted by a majority opinion of the 4 observers as being suitable as master casts. Of these, 37 casts were obtained from impressions taken in the acrylic trays while 29 were obtained from impressions taken in standard manufactured trays :

	44 casts from acrylic trays		44 casts from standard manufactured trays		Total number of casts
	Number	%	Number	%	
SELECTED	37	84.1 %	29	65.9 %	66
REJECTED	7	15.9 %	15	34.1 %	22
Total	44	100 %	44	100 %	88

(b) Assessment of 44 paired casts

The casts were assessed in pairs in order to select the cast in each pair considered more suitable as a master cast. In 5 of the 44 pairs opinion was divided equally among the 4 observers.

Of the 39 remaining casts selected, it was found that 31 were obtained from impressions taken in the acrylic trays while 8 were obtained from impressions taken in standard manufactured trays :

	44 casts from acrylic trays		44 casts from standard manufactured trays		Total number of casts
	Number	%	Number	%	
SELECTED	31	70.4 %	8	18.2 %	39
REJECTED	8	18.2 %	31	70.4 %	39
Undecided	5	11.4 %	5	11.4 %	10
Total	44	100 %	44	100 %	88

Conclusion

The results from this clinical trial indicated that a majority of the casts obtained from impressions taken in the acrylic trays were more suitable for the construction of full dentures than the casts obtained from impressions taken in the standard manufactured trays.

Satisfactory full dentures were subsequently made on the selected casts.

In addition to the clinical trial, the impression trays were used by the author to take final impressions of a further 14 edentulous patients and satisfactory full dentures were made on the casts obtained from these impressions.

These results appear to indicate that the trays may be suitable for taking final impressions and thus the preparation of individual or special trays may be unnecessary in some cases. However, the trays will have to be used on a much greater number of edentulous patients before any conclusions can be made on this matter.

APPENDIX

Investigation of the position of the mucogingival line on the surface of dentulous and edentulous maxillary and mandibular casts.

MUCOGINGIVAL LINE

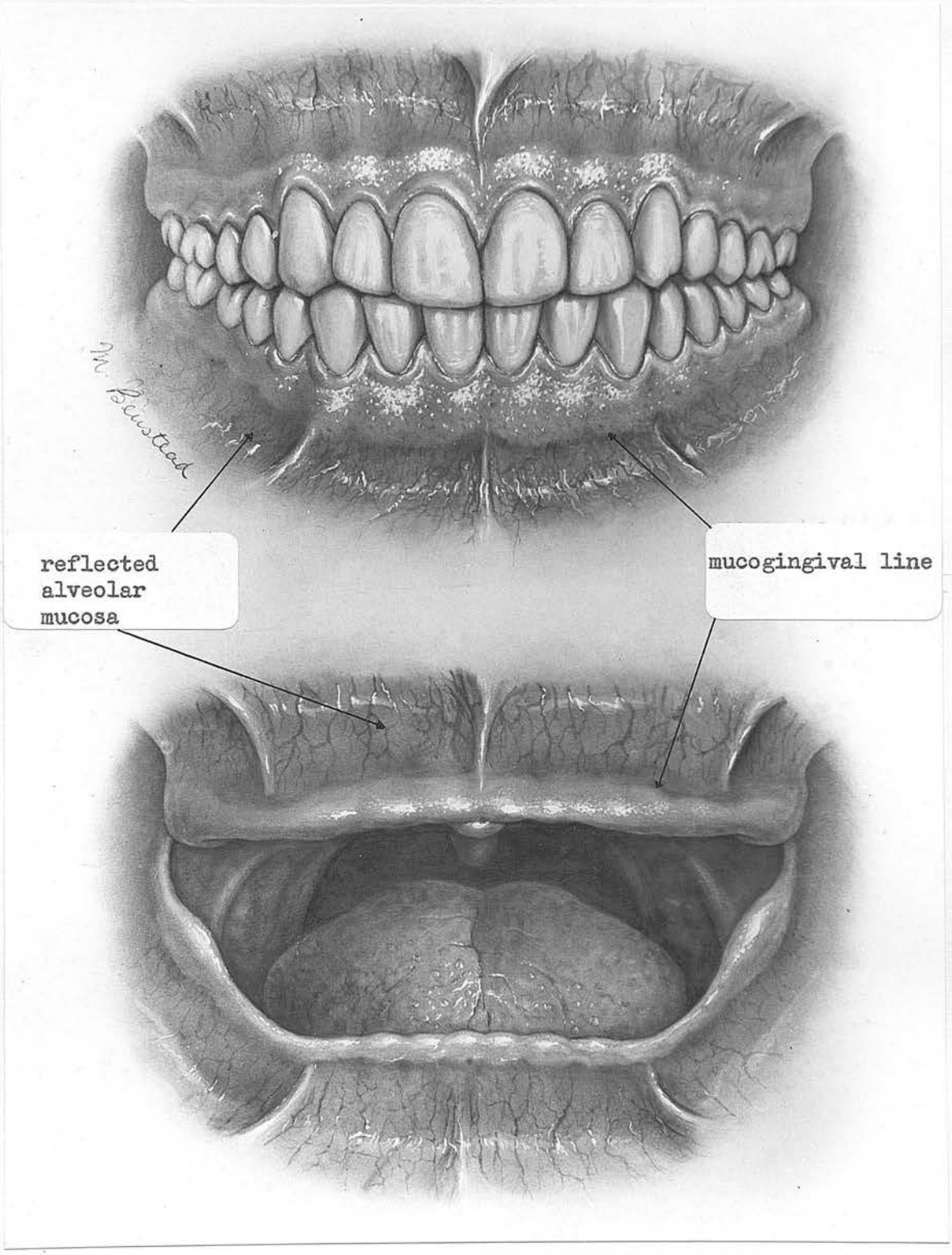
The mucogingival line is the scalloped line of junction between the attached gingiva and the reflected alveolar mucosa (Fig. 110). It is found on the buccal surface of the upper jaw and on the buccal and lingual surfaces of the lower jaw.

The reflected alveolar mucosa, termed areolar mucosa by GLICKMAN (1953) and vestibular mucosa by WADE (1960), extends from the mucogingival line to the sulcus. It is thin, smooth, vascular and loosely attached to the underlying bone.

In the dentulous mouth the attached gingiva lies between the free gingival groove and the mucogingival line. It is firmly attached to the underlying bone and has a stippled surface which KING (1945) referred to as an orange peel appearance. In the edentulous mouth the attached gingiva covers the residual alveolar ridge. The stippled surface is then much reduced and often absent.

Few reports appear to have been published on the extent of the attached gingiva in the dentulous mouth. ORBAN (1948) gave a figure of approximately 3 to 4 mm. while BOWERS (1963), who measured the buccal attached gingiva in 160 subjects by means of a periodontal gauge, concluded that the width varied from 1 to 9 mm. STRAHAN (1963) discussed the possible variations in the relationship between the alveolar bone margin and the mucogingival line.

The position of the mucogingival line can be located readily in the mouth, although in some cases the exact demarcation between the attached gingiva and the alveolar mucosa is ill-defined.



The MUCOGINGIVAL LINE in dentulous and edentulous mouths.

Fig. 110

The ability to locate and mark the position of the mucogingival line on the surface of casts, however, required further investigation.

An investigation was therefore carried out by means of two experiments devoted to dentulous casts and one experiment devoted to edentulous casts.

EXPERIMENT I

The aims were to find :

i. the variation in position of the mucogingival line pencilled by five different observers on identical dentulous casts.

ii. the variation in position of the mucogingival line pencilled by the same observer on two different occasions on identical dentulous casts.

iii. the effect that variations in position of the mucogingival lines pencilled by five observers on identical dentulous casts had on projections of these lines on the horizontal plane.

Method

Maxillary and mandibular casts of six persons were selected by random numbers from the dentulous sample. On each of these twelve master casts two reference marks were made :

On the maxillary casts a mark was made at the junction of the posterior border of the incisive papilla and the palatine raphe; a second mark was made on an easily identifiable point on the palatine raphe about one or two centimetres posterior to the ruga zone.

On the mandibular casts a mark was made on an easily identifiable point near the anterior part of the lingual frenum; a second mark was made on the floor of the cast midway between the last molar of each side of the cast.

Each of the 12 casts was then duplicated 5 times to make 60 casts in all. An alginate duplicating material (Duplit) was used and the casts were poured in artificial stone (Kaffir D). Both reference marks were located on each duplicated cast, marked with a sharp pencil and ringed for future identification. For the purpose of this experiment, a vertical plane through the two reference marks at right angles to the occlusal plane was the median sagittal plane of the cast.

The author and 4 other observers * were each given one group of the 12 casts and a sharp 3H pencil and asked to pencil the position of the mucogingival line on the buccal surface of each maxillary cast and the buccal and lingual surfaces of each mandibular cast. Each observer was advised not to make any mark unless he felt reasonably confident in the position of the line.

Measurement of casts

The horizontal level of the measuring instrument base was checked by spirit levels and each cast was secured to the adjustable platform. A flat metal plate, which carried spirit levels, was laid over the incisal edges and occlusal surfaces of all the teeth. The cast was then oriented in such a way that the occlusal plane was horizontal and that the median sagittal plane of the cast coincided with the sagittal plane of the instrument.

* 2 senior members of the Prosthetic Department and 2 senior members of the Periodontology Department of the Edinburgh Dental Hospital.

A pointed stylus was laid on the anterior reference mark and readings were made on the two horizontal scales. This located the position of the mark in coronal and sagittal planes.

The flat metal plate was again laid over the occlusal surface of the cast and a reading was made on the vertical scale with the stylus in contact with the plate. This reading was the horizontal reference plane of each cast and all other vertical measurements were made relative to this plane. In each group of five similar casts this reading on the vertical scale differed occasionally, of course, because it was affected by the height of the cast base and the position the cast was secured to the platform. Nevertheless, the reference plane, as defined by the flat plate on the occlusal surfaces of the teeth, was constant to the casts in the group and vertical measurements made from this plane of each cast in the group were, therefore, comparable.

On each cast vertical measurements were made from the horizontal reference plane to the pencilled mucogingival line on both sides of the cast at :

(a) a coronal plane through the anterior reference mark,

(b) coronal planes at 10 mm. intervals from the anterior reference mark and

(c) sagittal planes 5 mm. from the median sagittal plane.

On each mandibular cast, an additional measurement was made to the lingual mucogingival line in the median sagittal plane.

All measurements were made to the nearest 0.5 mm. (the mean width of a line made by a sharp 3H pencil on the surface of a cast was found to be 0.17 mm.).

Tracing of casts

In addition to the measurements made on the casts, a projection of the pencilled mucogingival line of each cast was traced on paper clamped to the base of the tracing instrument.

The horizontal level of the tracing instrument base was checked by spirit levels. Each cast was secured to the adjustable platform and the occlusal plane oriented to the horizontal. The stylus was tracked along the pencilled mucogingival line and the pen traced a projection of the line on the horizontal plane.

The two reference marks which were marked on the surface of each cast were transferred to the tracing paper. These points were used to superimpose the five traces of each group of five casts for comparison.

Repetition of measurements

After each cast had been measured, and a trace had been made, the experiment was repeated.

The pencil lines were washed off the casts and each observer was again given 12 casts and asked to pencil the position of the mucogingival line.

Vertical measurements were made in the same way as before. These were termed the 2nd measurements. Traces were not made a second time. All measurements and traces were made by the author.

Results of vertical measurements

A total of 1402 measurements were made.

The five observers were listed, A, B, C, D, & E (observer A was the author).

For each cast the vertical measurements from the pencilled mucogingival line to the horizontal reference plane were tabulated.

The results showed that (a) on any group of casts the position of the line varied slightly from one observer to another and (b) there was a small variation in position of the line pencilled by the same observer on two different occasions on the same cast.

In any group of casts, however, the variation of position appeared to be quite random i.e. there were variations in both the anterior and posterior regions of the casts and in no one region did the variations appear lesser or greater than in any other.

The results, therefore, were tabulated to show :

(a) the positions of the lines pencilled by the 4 observers compared with the positions of the lines pencilled by the author (Table 65).

(b) comparison of the positions of the lines pencilled by each of 5 observers on 2 different occasions (Table 66).

Measurement of the traces

The 5 separate traces of each group of casts were superimposed by means of the anterior and posterior reference marks. This superimposition allowed rough comparison of each group of traces but measurement was not possible because the lines were not sharp. This was due

TABLE 65.

The position of the lines of each observer compared with the position of the lines of Observer A (the latter used as standard).

Total number of measurements : 1402.

Measurement compared with position of line of Observer A.		OBSERVER			
		B	C	D	E
Identical		52.9%	51.4%	46.1%	64.5%
0.5 or 1 mm.	+	7.9	13.9	20.1	14.3
	-	24.4	20.0	9.6	12.7
1.5 or 2 mm.	+	3.1	4.5	14.4	3.5
	-	7.5	5.4	3.3	2.4
2.5 or 3 mm.	+	2.7	1.7	4.9	1.8
	-	1.5	3.1	1.6	0.8
		100%	100%	100%	100%
Percentage of measurements within ± 1 mm. of the position of the lines of observer A.		85.2	85.3	75.8	91.5

A + sign signified that the line was pencilled nearer the vestibular sulcus than the line of Observer A; a - sign signified the line was pencilled nearer the gingival margin.

TABLE 66.

The position of the 2nd line of each observer compared with the position of the 1st line of the same observer (the position of the 1st line used as standard).

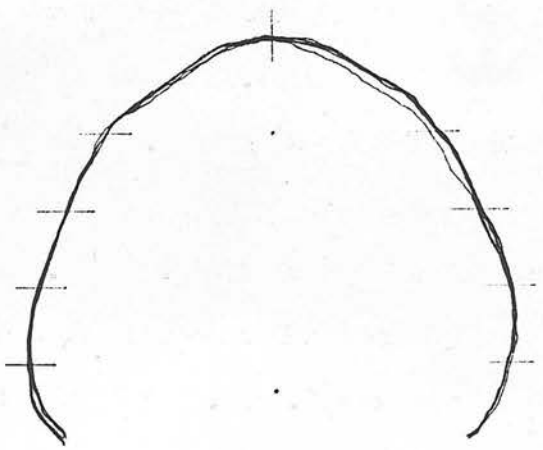
Measurement compared with position of 1st line of each observer.		OBSERVER				
		A	B	C	D	E
Identical		64.1%	46.8%	39.8%	42.8%	58.8%
0.5 or 1 mm.	+	7.7	21.2	8.5	27.7	6.6
	-	20.0	10.7	23.8	12.8	24.6
1.5 or 2 mm.	+	0.6	10.7	1.3	8.6	0.0
	-	3.8	5.8	13.0	4.7	8.0
2.5 or 3 mm.	+	0.0	3.8	0.6	1.7	0.0
	-	3.8	1.0	13.0	1.7	2.0
		100%	100%	100%	100%	100%
Percentage of measurements of the 2nd line within $\pm$ 1 mm. of the position of the 1st line.		91.8	78.7	72.1	83.3	90.0

A + sign signified that the 2nd line was pencilled nearer the vestibular sulcus than the 1st line; a - sign signified that the 2nd line was pencilled nearer the gingival margin.

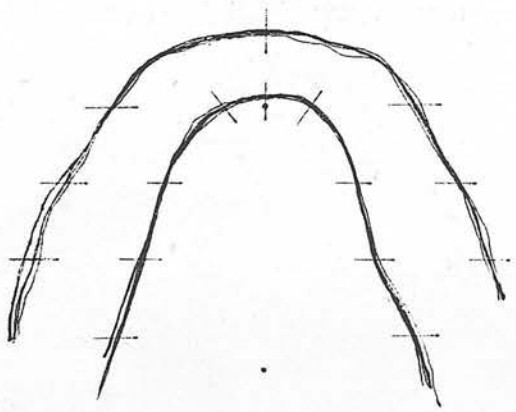
to diffusion of light through the layers of tracing paper. For this reason, a "combined" trace of each group of casts was made by copying the 5 traces on to one single tracing paper by means of a pen which produced a line width of 0.2 mm. The "combined" trace showed clearly the variation in line position among the 5 observers.

This variation was measured. The total width of the "combined" trace was measured by an eyepiece micrometer at the positions shown in Fig. 111 . The variation in the 5 lines at the positions of measurement was found by subtracting the width of one line (0.2 mm.) from the measurement. From these measurements a mean variation in position of the lines in each "combined" trace was calculated (Table 67).

"Combined" dentulous maxillary trace.



"Combined" dentulous mandibular trace



5 traces of mucogingival lines of identical casts superimposed to show positions at which the "combined" trace was measured.

Fig. 111

TABLE 67.

The mean variation in position of the mucogingival line pencilled by 5 observers on 12 groups of identical casts. Measurements (in mms.) made on traces of the projections of the mucogingival lines on the horizontal plane.

	Cast I	Cast II	Cast III	Cast IV	Cast V	Cast VI	Total mean variation
Dentulous Maxillary	0.91	0.83	0.91	0.51	1.27	0.71	0.86 mm.
Dentulous Mandibular	1.08	0.94	0.88	0.92	0.70	1.13	0.94 mm.

Errors

The errors of this experiment were investigated.

1. The errors connected with the instruments and the measuring and tracing of casts were discussed on page 95 .
2. Possible error in the duplication of the master casts was investigated :

The method of duplicating that was used was to take an impression of each cast with an alginate material ("Duplit") contained in a "Duplit" flask. The impression was poured in artificial stone (Kaffir D) with a W/P ratio of approximately 0.35.

This method of duplicating casts is a normal laboratory procedure. Its accuracy was investigated by duplicating a standard metal die of known dimensions and measuring the resultant artificial stone cast by means of a travelling microscope.

The die was duplicated two times and the measurements were done by two observers. The results showed a linear expansion of the cast of between 0.16 and 0.22 per cent over a period of 7 days.

3. A third source of error was the width of the line made by the point of a sharp 3 H pencil on the surface of an artificial stone cast.

A total of 12 lines were scribed on 4 separate casts with 3 pencils.

The width of the lines were measured by two observers by means of an eyepiece micrometer. The range of widths was 0.10 mm. to 0.23 mm. and the mean 0.17 mm.

Conclusions

1. It was concluded from this experiment that the position of the mucogingival line pencilled by each of 4 observers on dentulous maxillary and mandibular casts did not vary more than about 1 mm. from the position of the mucogingival line pencilled by the author on the same casts.

2. It was also concluded that the position of the mucogingival line pencilled by an observer on two different occasions on the same dentulous maxillary and mandibular casts did not vary more than about 1 mm.

3. It was further concluded that the variation of the position of the mucogingival line pencilled by 5 observers on identical casts affected the outline of the mucogingival line projected as a trace on the horizontal plane. The mean variation of the traces, however, was less than 1 mm.

EXPERIMENT II

The aim was to find how accurately the position of the mucogingival line, pencilled on the maxillary and mandibular casts of 20 dentulous persons by the author, compared with the position of the mucogingival line in the mouths of the same 20 persons.

Method

10 male and 10 female dental students were selected at random from the dentulous sample. Some weeks before the experiment the assessed position of the mucogingival line was marked on the surface of each maxillary and mandibular cast with a sharp 3 H pencil.

(a) In the mouth of each person the mucosa around certain teeth was dried by gauze and a mark was made by a sharp indelible pencil on the mucogingival line.

The teeth used were :

$$\frac{6\ 2\ /\ 1\ 3\ 5}{6\ 3\ /\ 2\ 5}$$

In cases where a tooth was missing the tooth mesial to the missing one was used.

A measurement was made with sliding calipers from the indelible pencil mark to the apex of the arc formed by the margin of the gingiva of each tooth. The points of the caliper legs were placed in line with the long axis of the tooth.

Each measurement was made twice and the mean recorded to the nearest 0.5 mm. It was felt impossible to read to any greater accuracy.

Measuring with calipers on the mandibular lingual surface was extremely difficult and a pair of dividers was used in that region. The pointed arms of the dividers were bent to a right angle and the measurements were read off on a millimetre rule. It was found impossible, however, to measure in the mandibular lingual region in 7 of the 20 persons because of the difficulty in using the dividers in the mouth.

A total of 223 measurements were made in the mouths of the 20 persons.

(b) On the casts, measurements were made with calipers from the pencilled mucogingival line to the apex of the arc formed by the margin of the gingiva of the same teeth that were used in the mouth. The points of the caliper legs were placed in line with the long axis of the tooth. Measurements were made to the nearest 0.5 mm.

Results

Study of the measurements showed that the position of the mucogingival line pencilled on the cast surfaces was slightly different from the position in the mouth. However, the difference of position appeared to be quite random i.e. differences occurred in both anterior and posterior regions of the casts and in no one region were they greater or lesser than in any other. The difference between the measurement from the mouth and the measurement on the cast was listed for each tooth of each person.

The results were tabulated as follows :

Total number of measurements : 223

Measurement compared with position of line in the mouth	Measurement on casts	% of total
Identical	171	76.68 %
0.5 or 1 mm. +	18	13.45 %
0.5 or 1 mm. -	12	
1.5 or 2 mm. +	12	9.87 %
1.5 or 2 mm. -	10	

Percentage of measurements on casts within ± 1 mm. of the measurements in mouth : 90.13 %.

Conclusions

It was concluded from this experiment that it was possible to pencil the position of the mucogingival line on the majority of a sample of maxillary and mandibular dentulous casts within an accuracy of 1 mm.

As regards the mandibular lingual surface this conclusion was only tentative because of the smaller numbers of cases measured and because of the difficulties encountered in measuring in this region of the mouth.

EXPERIMENT III

The aims were to find :

i. the variation in position of the mucogingival line pencilled by 3 different observers on identical edentulous casts.

ii. the effect that variations in position of the mucogingival lines pencilled by 3 observers on identical edentulous casts had on projections of these lines on the horizontal plane.

Method

Maxillary and mandibular casts of 3 persons were selected by random numbers from the edentulous sample. On each of these master casts two reference marks were made :

On the maxillary casts a mark was made at the junction of the posterior border of the incisive papilla and the palatine raphe; a second mark was made on an easily identifiable point on the palatine raphe about one or two centimetres posterior to the ruga zone.

On the mandibular casts a mark was made on an easily identifiable point near the anterior part of the lingual frenum; a second mark was made on the floor of the cast approximately midway between the retromolar regions of each side of the cast.

Each of the 6 casts was then duplicated 3 times to make 18 casts in all. An alginate duplicating material (Duplit) was used and the casts were poured in artificial stone (Kaffir D). Both reference marks were located on each duplicated cast, marked with a sharp pencil and ringed for future identification. For the purpose of this experiment,

a vertical plane through the two reference marks at right angles to the residual alveolar ridge was the median sagittal plane of the cast.

The author and 2 other observers were each given one group of the 6 casts and asked to pencil the position of the mucogingival line on the surface of each cast.

Measurement of casts

Each cast was secured to the adjustable platform of the measuring instrument and a flat metal plate, which carried spirit levels, was laid in contact with the residual alveolar ridge. The cast was then oriented in such a way that the flat plate was horizontal and that the median sagittal plane of the cast coincided with the sagittal plane of the instrument.

A pointed stylus was laid on the anterior reference mark and readings were made on the two horizontal scales. This located the position of the mark in coronal and sagittal planes.

The flat metal plate was again laid over the residual alveolar ridge of the cast and a reading was made on the vertical scale with the stylus in contact with the plate. This reading was the horizontal reference plane of each cast and all other vertical measurements were made relative to this plane.

On each cast vertical measurements were made from the horizontal reference plane to the pencilled mucogingival line on both sides of the cast at :

(a) a coronal plane through the anterior reference mark,

(b) coronal planes at 10 mm. intervals from the anterior reference mark and

(c) sagittal planes 5 mm. from the median sagittal plane.

On each mandibular cast, an additional measurement was made to the lingual mucogingival line in the median sagittal plane.

All measurements were made by the author to the nearest 0.5 mm.

Tracing of casts

In addition to the measurements made on the casts, a projection of the pencilled mucogingival line of each oriented cast was traced on paper clamped to the horizontal base of the tracing instrument.

Results of measurements

The 3 observers were listed A, B and C (observer A was the author).

For each cast the vertical measurements, from the pencilled mucogingival line to the horizontal reference plane of the cast, were tabulated.

The results showed that on any one cast the position of the line varied from one observer to another but the variation of position appeared to be quite random.

The measurements, therefore, were grouped as the difference between the vertical measurements of Observer A (taken as standard) and 2 other observers (Table 68).

Conclusions

It was concluded from this experiment that the position of the mucogingival line pencilled by each of 2 observers on edentulous maxillary and mandibular casts did not vary more than about 1 mm. from the position of the mucogingival line pencilled by the author on the same casts.

The greatest variation was found on the maxillary casts and this variation effected the outlines of the mucogingival lines of the maxillary casts projected as traces on the horizontal plane (Fig. 112).

TABLE 68.

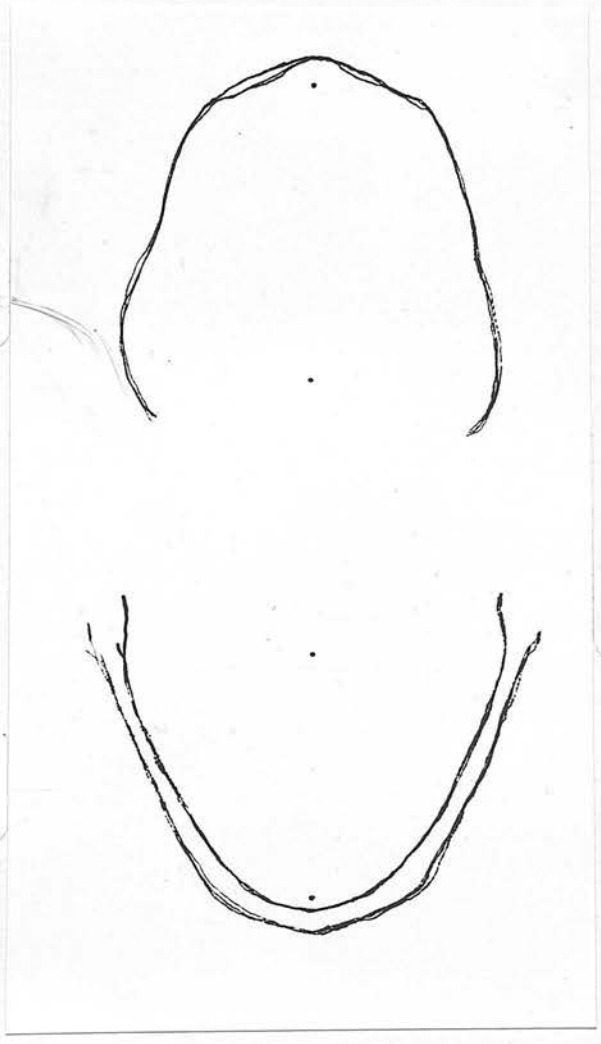
The position of the lines of each observer compared with the position of the lines of Observer A (the latter used as standard).

Total number of measurements made on the casts of each observer : 85.

Measurement compared with position of line of Observer A.		Observer	
		B	C
Identical		57.6%	62.3%
0.5 or 1 mm.	+	12.1%	17.6%
	-	24.4%	10.6%
1.5 or 2 mm.	+	2.3%	5.9%
	-	3.6%	-
over 2 mm.		-	3.6%
		100%	100%
Percentage of measurements within ± 1 mm. of the position of the lines of Observer A.		94.1%	90.5%

A + sign signified that the line was pencilled nearer the vestibular sulcus than the line of Observer A; a - sign signified the line was pencilled nearer the crest of the alveolar ridge.

"Combined" edentulous maxillary trace



"Combined" edentulous mandibular trace

3 traces of mucogingival lines of identical casts superimposed.

Fig. 112

SUMMARY and CONCLUSIONS

1. The aims of this cross-section study were to devise a method for measuring the size and form of the denture bearing areas of the jaws of a sample of dentulous and edentulous adults and to apply these measurements to the design of impression trays for edentulous adults.

2. The relevant literature was reviewed and discussed. A number of investigations were revealed of dental arch length and width and changes in the jaws following the loss of teeth, but none was found in which measurements of dentulous casts were made in a manner similar to the present study.

   Only one paper was found which contained measurements of edentulous casts related to impression tray design (Nyquist 1959). The measurements of maxillary casts given in this paper, which were summarised in Table I, may be compared with the findings in the present study as follows :

	Length	Width
Nyquist	range : 40-69 mm.	range : 35-59 mm.
(192 casts)	mean : not stated	mean : not stated
Present study	range : 36-57 mm.	range : 37-55 mm.
(300 casts)	mean : 47.09 $\pm$ 0.21mm.	mean : 45.0 $\pm$ 0.19 mm.

The explanation for the difference between the range of length measurements was that the posterior measuring point of maxillary casts was not defined by Nyquist and measurements were listed only in centimetre intervals. It was not possible to compare his measurements of mandibular casts because the number of casts listed in his results did not correspond to the number in the sample and, therefore, were unreliable.

The methods used in the present study for measuring edentulous casts made it impossible to comment on Nyquist's observation that an asymmetry existed in edentulous casts. It was found, however, that an asymmetry existed in a number of dentulous casts, but it was noted that the direction of this asymmetry appeared to be quite random and neither side was affected more than the other.

3. The material of the study comprised the maxillary and mandibular casts of a selected sample of dentulous and edentulous male and female adults.

The sample consisted of 651 persons, 351 of whom were dentulous and 300 were edentulous. The age and sex distributions were tabulated.

Thus 1302 casts comprised the total cast material for this study.

4. Reference planes were defined by points on the casts in regions of dentulous and edentulous mouths in which changes following the loss of teeth appeared to be minimal.

The pre-extraction and post-extraction casts of a longitudinal sample of 17 patients were studied and the following conclusions on the changes following the loss of teeth were reached within the limits of this sample :

(a) the most superior point in the crescentic ridge of mucosa on the oral surface of the pterygomaxillary notch moved upwards and forwards about 1 mm.;

(b) the changes in the mandibular retromolar regions were small;

(c) a point on the mandibular lingual mucogingival line in the midline moved forward about 1 mm.

5. The variation in the position of the mucogingival line, as marked by different observers on the surface of maxillary and mandibular dentulous and edentulous casts, was investigated.

It was concluded that the position of the mucogingival lines marked by the author on the casts did not differ more than about 1 mm. from the position of the lines marked by the observers on the same casts. The effect of this difference on the outlines of the mucogingival lines, projected as traces on the horizontal plane, was found to produce a mean variation of the traces of less than 1 mm.

6. Measurements and traces of 1302 casts were made by means of two instruments which were designed and constructed for this study.

The casts were oriented in such a way that all measurements and traces were made parallel to one of

three reference planes which intersected at a specified reference point on the surface of each cast. The total number of traces made was in the region of 1200 and the number of separate measurements made directly on the casts was approximately 21000.

7. It was concluded from an investigation of errors that the methods employed were sufficiently accurate for the purpose of the study.

8. The measurements and traces of the sample of 1302 casts provided the data from which a range of 13 maxillary and 18 mandibular impression trays were designed and constructed.

9. The measurements and traces of the dentulous casts were used to define the buccal and lingual outlines of the impression trays in order that the trays might assist in the restoration of the lips and cheeks of edentulous patients to pre-extraction facial contours.

10. The measurements and traces of the edentulous casts were used to define the antero-posterior curves of the impression trays in order that the trays matched the variation in form of the edentulous casts.

11. A method of construction of the impression trays was devised and described.

12. The clinical application of the impression trays was described and discussed.

13. It was concluded from the results of a "blind" clinical trial, in which four observers took part, that 70% of the total number of casts obtained from the impression trays made in this study were more suitable for the construction of full dentures than the casts obtained from a range of different types of manufactured standard impression trays.

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REFERENCES

ALEXANDER, M., ZEIGEN, R.S. & EMANUEL, I. (1961) Anthropometric data presented in three-dimensional forms. Amer. J. phys. Anthrop., 19 , 147.

ANTHONY, D.H. & PEYTON, F.A. (1959) Evaluating dimensional accuracy of denture bases with a modified comparator. J. prosth. Dent., 9 , 683.

ATKINSON, H.F. & JOHNSON, K. (1962a) An instrument for model measurement in immediate denture research. Aust. dent. J., 7 , 310.

ATKINSON, H.F. & JOHNSON, K. (1962b) A cephalostat for investigating alveolar resorption. Aust. dent. J., 7 , 381.

ATWOOD, D.A. (1957) A cephalometric study of the clinical rest position of the mandible. J. prosth. Dent., 7 , 544.

BALKWILL, F.H. (1880) Mechanical Dentistry in Gold and Vulcanite, 127. London : Churchill.

BALLARD, C.F. (1963) Variations of posture and behaviour of the lips and tongue which determine the position of the labial segments; the implications in orthodontics, prosthetics and speech. Trans. europ. orthod. Soc., 67.

BANGER, E. (1957) Clinical experience with the impression trays "Jescoform" and "Jescoplast". Dent. Abstr., 2 , 687.

BARR, J.H. & GRØN, P. (1960) Configuration of the adult palate. J. Canad. dent. Ass., 26 , 62.

BASU, P.K. (1962) A technique for contour study of the edentulous maxillary ridge. M.S.D. Thesis, Indiana University.

BENINGTON, R.C. (1911) Cranial type contours. Biometrika, 8 , 123.

BJÖRK, A. (1954) Cephalometric X-ray investigations in dentistry. Int. dent. J., 4 , 718.

BLOCH, V. (1922) Atrophic changes in the shape of the human jaw bones. Nordiskt odont. Archiv., 55-74.

BOWERS, G.M. (1963) A study of the width of attached gingiva. J. Periodont., 24 , 201.

BRAUN, M.L. (1938) Likeness of dental arches of twins and of persons without blood relationship. J. Amer. dent. Ass., 25 , 1093.

BROADBENT, B.H. (1927) Investigations on the orbital plane. Dent. Cosmos, 69 , 797.

CAMPBELL, J. (1950) The mylohyoid line in the assessment of facial asymmetry. Dent. Rec., 70 , 204.

CAMPBELL, R.L. (1960) A comparative study of the resorption of the alveolar ridges in denture-wearers and non-denture-wearers. J. Amer. dent. Ass., 60 , 143.

CAMPION, G.G. (1927) Facial measurements in diagnosis. Int. J. Orthod., 13 , 739.

CARLSSON, G.E. & PERSSON, G. (1963) Personal communication.

COLES, O. (1880) Deformities of the upper jaw: an attempted classification of them. Odontolog. Soc. Trans., new series, 12 , 103.

COMAS, J. (1960) Manual of Physical Anthropology. Springfield: Thomas.

CRADDOCK, F.W. (1953) Retromolar region of the mandible. J. Amer. dent. Ass., 47 , 453.

CRADDOCK, F.W. (1956) Prosthetic Dentistry, 3rd ed., 31. London: Kimpton.

FISH, E.W. (1947) Tongue space in full denture construction. Brit. dent. J., 83 , 137.

FISH, E.W. (1948) Principles of Full Denture Prosthesis, 4th ed., 104. London: Staples.

GLICKMAN, I. (1953) Clinical Periodontology, 9. Philadelphia & London : Saunders.

GOLDSTEIN, M.S. & STANTON, F.L. (1935) Changes in dimensions and form of the dental arches with age. Amer. J. Orthodont., 21 , 357.

GOOSE, D.H. (1962) Reduction of palate size in modern populations. Arch. oral Biol., 7 , 343.

GRAHNEN, H. & INGERVALL, B. (1963) Tooth width and morphology of the dentition in a group of caries resistant men. Odont. Revy, 14 , 70.

GRIEVE, G.W. (1926) Some points on diagnosis of malocclusion. Int. J. Orthod., 12 , 577.

HEDEGARD, B. (1962) Some observations on tissue changes with immediate maxillary dentures. Dent. Practit., 13 , 70.

HEDEGARD, B. (1963) Personal communication.

HENRIQUES, A.C. (1953) The growth of the palate and the growth of the face during the period of the changing dentition. Amer. J. Orthodont., 39 , 836.

HOOPER, B.L. (1934) Functional factors in the selection and arrangement of artificial teeth. J. Amer. dent. Ass., 21 , 603.

HOWES, A.E. (1947) Case analysis and treatment planning based upon the relationship of the tooth material to its supporting bone. Amer. J. Orthodont., 33 , 499.

IZARD, G. (1950a) La Pratique Stomatologique : Orthodontie, 3rd ed., 143-145. Paris: Masson.

IZARD, G. (1950b) La Pratique Stomatologique : Orthodontie, 3rd ed., 305. Paris: Masson.

JAEGGI, S. (1960) Die Entwicklung der zahnarztlichen Abdruckverfahren von den Anfangen bis zur Gegenwart. Inaugural Dissertation, University of Basel.

JOHNSON, K. (1963) Study of the dimensional changes occurring in the maxilla after tooth extraction. Aust. dent. J., 8 , 428.

KEITH, A. (1924) Concerning certain structural changes which are taking place in our jaws and teeth. London: Dental Board Lectures.

KING, J.D. (1945) Gingival disease in Dundee. Dent. Rec., 65 , 9.

KORKHAUS, G. (1928) A new pair of calipers for orthodontia. Int. J. Orthod., 14 , 146.

KORKHAUS, G. (1930) A new orthodontic symmetrograph. Int. J. Orthod., 16 , 665.

KORKHAUS, G. (1934) Diagnostic examination of anomalies on cases of unilateral disto-occlusion or of crossed bite. Dent. Rec., 54 , 401.

KORKHAUS, G. (1957) Diagnosis in dento-maxillo-facial orthopedics. Int. dent. J., 7 , 155.

KROGH-POULSEN, W.G., PAFFENBARGER, G.C. & SCHOONOVER, I.C. (1948) Two methods of graphing the contour of the "mucosal" surface of plaster models. J. Amer. dent. Ass., 36 , 379.

LAMMIE, G.A. (1956) Aging changes and the complete lower denture. J. prosth. Dent., 6 , 450.

LANDA, J.S. (1954) The troublesome transition from a partial lower to a complete lower denture. J. prosth. Dent., 4 , 42.

LEE, J.H. (1954) The form of the denture surfaces. Dent. Rec., 74 , 318.

LEE, J.H. (1962) Dental Aesthetics, 103. Bristol: Wright.

LINDER-ARONSON, S. (1960) The effect of premature loss of deciduous teeth. Acta odont. scand., 18 , 101.

LONBERG, P. (1951) Changes in the size of the lower jaw on account of age and loss of teeth. Stockholm.

LUNDSTROM, A.F. (1925) Malocclusion of the teeth regarded as a problem in connection with the apical base. Int. J. Orthod., 11 , 591.

LUNDSTROM, A. (1948) Tooth size and occlusion in twins. New York & Basel: Karger.

LUNDSTROM, A. (1961) Some asymmetries of the dental arches, jaws, and skull, and their etiological significance. Amer. J. Orthodont., 47 , 81.

LYSELL, L. (1955) Plicae palatinae transversae and papilla incisiva in man. Acta odont. scand., 13 , Supp. 18.

LYSELL, L. (1958) A biometric study of occlusion and dental arches in a series of medieval skulls from Northern Sweden. Acta odont. scand., 16 , 177.

MacCONAILL, M.A. & SCHER,E.A. (1949) The ideal form of the human dental arcade, with some prosthetic application. Dent. Rec., 69 , 285.

MARTIN, R. (1928) Lehrbuch der Anthropologie, 661. Jena.

MARTONE, A.L. (1963) Clinical applications of concepts of functional anatomy and speech science to complete denture prosthodontics. J. prosth. Dent., 13 , 204.

MODICA, R. (1961) Cast orientation by cephalometrics. J. prosth. Dent., 11 , 422.

MONTAGU, A.M.F. (1960) An Introduction to Physical Anthropology, 3rd ed., 603. Springfield : Thomas.

MOORREES, C.F.A. (1959) The Dentition of the Growing Child. Cambridge, Massachusetts : Harvard University Press.

MORANT, G.M. (1936) A biometric study of the human mandible. Biometrika, 28 , 84.

MOYERS, R.E., HARVOLD, E., JENKINS, H. SHULTIS, K. & CROUCH, J.T. (1954) Intraoral factors affecting case assessment. Amer. J. Orthodont., 40 , 341.

MURPHY, T. (1957) Changes in mandibular form during postnatal growth. Aust. dent. J., 2 , 267.

NEUFELD, J.O. (1958) Changes in the trabecular pattern of the mandible following the loss of teeth. J. prosth. Dent., 8 , 685.

NEVIN, J.J. (1962) Introducing the McGowan-Winkler full denture trays. Cal, 24 , 1.

NYQUIST, G. & THAM, P. (1951) Method of measuring volume movements of impression, model and prosthetic base materials in a photo-grammetric way. Acta odont. scand., 9 , 111.

NYQUIST, G. (1959) Den tandlosa kakens form och storlek jamte synpunkter pa standardskedar for avtryckstagning av tandlosa fall. Svensk tandlak. Tidskr., 52 , 381.

NYQUIST, G. (1961) Personal communication.

OLOW, M. (1954) A metric study of transversal size of the dental arches in children at 7, 12 and 18 years of age. Odont. Tidskr., 62, 266.

ORBAN, B. (1948) Clinical and histologic study of the surface characteristics of the gingiva. Oral Surg., 1 , 827.

OSBORNE, J. (1963) Application of basic sciences to prosthetic dentistry. Aust. dent. J., 8 , 292.

PENDLETON, E.C. (1942a) The minute anatomy of the lower jaw in relation to the denture problem. J. Amer. dent. Ass., 29 , 719.

PENDLETON, E.C. (1942b) in The American Textbook of Prosthetic Dentistry edited by Anthony, L.P., 7th ed., 159. London : Kimpton.

POUND, E. (1960) Modern American concepts in esthetics. Int. dent. J., 10 , 154.

REES, D.J. (1953) A method for assessing the proportional relation of apical bases and contact diameters of the teeth. Amer. J. Orthodont., 39 , 695.

RUPP, N.W., DICKSON, G., LAWSON, M.E. & SWEENEY, W.T. (1957) A method for measuring the mucosal surface contours of impressions, casts and dentures. J. Amer. dent. Ass., 54 , 24.

RYGE, G. & FAIRHURST, C.W. (1959) The contour meter : an apparatus for comparison of mucosal surface contour of impressions, models and dentures. J. prosth. Dent., 9 , 676.

SCHREINEMAKERS, J. (1959a) De essentiele beginselen van de zuigende prothese. Tijd. Tandheelk., 66 , 361.

SCHREINEMAKERS, J. (1959b) De praktische verwezenlijking van het zuigeffect in de prothese. Tijd. Tandheelk., 66 , 453.

SCHREINEMAKERS, J. (1962) Die Vollsaugende Clan-Tray-Prothese. Utrecht : Tholen.

SCHWARZ, R. (1925) New cephalometric method and apparatus and its application to orthodontia. Int. J. Orthod., 11 , 910.

SCOTT, J.H. (1957) The shape of the dental arches. J. dent. Res., 36 , 996.

SEDWICK, H.J. & BRAWLEY, R.E. (1938) Palatometer. Amer. J. Orthodont., 24 , 673.

SEIPEL, C.M. (1946) Variation of tooth position: a metric study of variation and adaptation in the deciduous and permanent dentitions. Svensk tandlak. Tidskr., 39. Supplement. Lund.

SICHER, H. (1960a) Oral Anatomy, 3rd ed., 95. St. Louis : Mosby.

SICHER, H. (1960b) Oral Anatomy, 3rd ed., 501. St. Louis : Mosby.

SICHER, H. (1960c) Oral Anatomy, 3rd ed., 195. St. Louis : Mosby.

SIMON, P.W. (1924) On gnathostatic diagnosis in orthodontics. Int. J. Orthod., 10 , 755.

SKINNER, E.W. & PHILLIPS, R.W. (1960) The Science of Dental Materials, 5th ed., 64. Philadelphia & London : Saunders.

SLOANE, R.B. & COOK, J.A. (1953) A guide to the orientation of the plane of occlusion. J. prosth. Dent., 3 , 53.

STANTON, F.L. (1916) Orthodontic engineering. Int. J. Orthod., 2 , 235.

STANTON, F.L. (1922) Arch predetermination and a method of relating the predetermined arch to the malocclusion, to show the minimum tooth movement. Int. J. Orthod., 8 , 757.

STANTON, F.L. (1933) A technique for measuring the relative movements of teeth due to the growth of the jaws or the premature loss of deciduous teeth. Int. J. Orthod., 19 , 1229.

STANTON, F.L., FISH, G.D. & ASHLEY-MONTAGU, M.F. (1931) Description of three instruments for use in orthodontic and cephalometric investigations, with some remarks on map construction. J. dent. Res., 11 , 885.

STRAHAN, J.D. (1963) The relation of the mucogingival junction to the alveolar bone margin. Dent. Practit., 14 , 72.

STRENGER, F. (1946) Praktisk tillampning av stereometrisk matning. Svensk tandlak. Tidskr., 39 , 68.

SVED, A. (1925) A new method of diagnosis for orthodontic cases. Int. J. Orthod., 11 , 295.

SWENSON, M.G. (1959) Complete Dentures, 4th ed., 51 & 174. St. Louis : Mosby.

SZMYD, L., McCALL, C.M. & ALLEN, L.R. (1958) A method for measuring topographic changes of the maxillary residual ridge mucosa. J. Amer. dent. Ass., 57 , 193.

TALBOT, E.S. (1892) A study of the degeneracy of the jaws of the human race. Dent. Cosmos, 34 , 337.

TALLGREN, A. (1957) Changes in adult face height due to ageing, wear and loss of teeth and prosthetic treatment. Acta odont. scand., 15 , Supp. 24.

TAYLOR, R.M.S. (1962) The human palate. Acta Anat., 49 , Supp. 43, 1.

THAM, P. (1946) Fotogrammetriska matmetoders tillampning inom odontologien. Svensk tandlak. Tidskr., 39 , 57.

TOMES, J. (1859) A System of Dental Surgery, 1st ed., 114. London : Churchill.

TUCKFIELD, W.J. (1950) Review of impression techniques in full denture prosthesis. Int. dent. J., 1 , 1, 112.

Van LOON, J.A.W. (1915) A new method for indicating normal and abnormal relations of the teeth to the facial lines. Dent. Cosmos, 57 , 973.

WADE, A.B. (1960) Basic Periodontology, 29. Bristol : Wright.

WATT, D.M. (1960) Morphological changes in the denture bearing area following the extraction of maxillary teeth. Ph.D. Thesis, University of Edinburgh.

WEINBERGER, B.W. (1926) Orthodontics : an historical review of its origin and evolution, 350. St. Louis : Mosby.

WOELFEL, J.B. (1962) Contour variations in impressions of one edentulous patient. J. prosth. Dent., 12 , 229.

WOELFEL, J.B., KREIDER, J.A. & BERG, T. (1962) Deformed lower ridge caused by the relining of a denture by a patient. J. Amer. dent. Ass., 64 , 763.

WOODS, G.A. (1950) Changes in width dimensions between certain teeth and facial points during human growth. Amer. J. Orthodont., 36 , 676.

WRIGHT, W.H. (1929) The importance of tissue changes under artificial dentures. J. Amer. dent. Ass., 16 , 1027.

YOUNG, H.A. (1955) Diagnostic survey of edentulous patients. J. prosth. Dent., 5 , 5.

YOUNG, R.W. (1956) The measurement of cranial shape. Amer. J. phys. Anthrop., 14 , 59.