

PROCESSING ACRYLIC DENTURES

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dimensional accuracy of acrylic resin dentures:
variation in contour changes occurring during
processing of resin denture bases according
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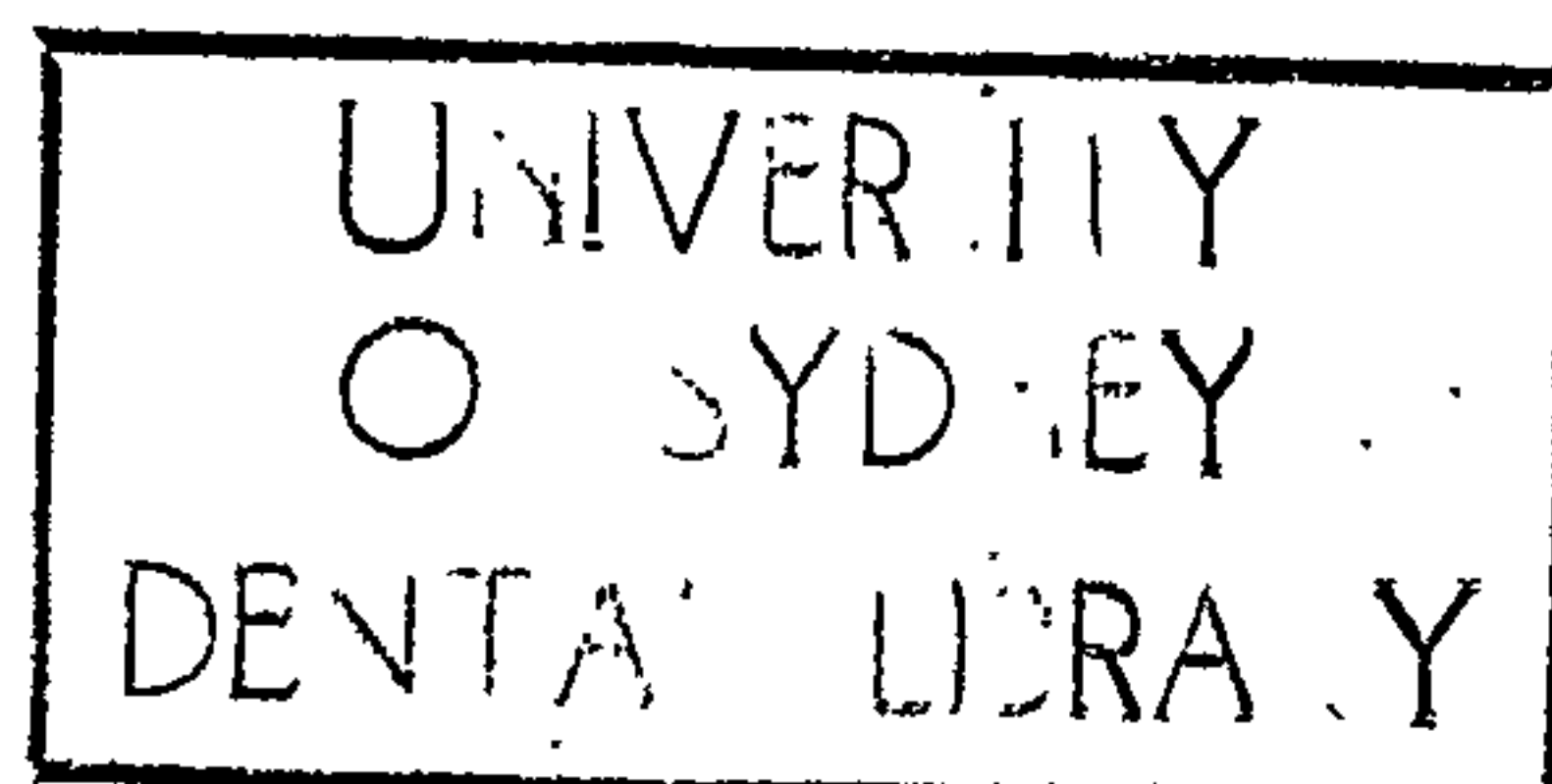
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The effect of processing techniques on the dimensional accuracy of acrylic resin dentures: variation in contour changes during processing of resin denture bases according to curing techniques.

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1.1 An ideal denture base material might have qualities grouped in the following way¹:

1. Biological properties - compatibility with the oral environment - hard tissues, supportive tissues, secretory and sensory elements.
2. Manipulative properties - ease of construction, low cost of material and associated equipment required for its application.
3. Physical properties - dimensional stability and consequently adaptation or fit, resistance to wear and dissolution, resistance to corrosion and abrasion and simplicity of hygiene.

The most widely used denture base materials at present are the acrylic resins. Their combination of desirable properties led Woelfel to describe them as "a tough act to beat" and their use has supplanted vulcanite and porcelain.

Nevertheless, alternative denture base resins and other materials^{2,3} continue to be presented, and various other methods of using the resins have been used. Cold-curing resins of the dough type⁴ and pour-type have shown satisfactory clinical performance, although the simplicity of manipulation, low cost and predictable behaviour of heat-cured resins seem to have aided their continued wide acceptance.

Most resins have demonstrated the following disadvantages:

1. Manipulative difficulties in processing.
2. Dimensional changes in processing.
3. Dimensional change in service.
4. Mechanical failure in service.

1.2 It is intended to present a review of studies of the behaviour of acrylic resins during processing, and to include methods of observing their behaviour. Different methods of polymerization and their influence on the properties of the denture base have been compared by a variety of methods, enabling some conclusions to be drawn regarding selection and use of resins and their handling techniques (Figs. 1.1, 1.2, 1.3, 1.4).

In particular, the use of silicone as an investing medium will be discussed. The value of this material is in simplification of investment technique, reduction of the finishing procedures, maintenance of occlusal relationship and fit, and in reduction of porosity. Silicone mould linings aid wax elimination, eliminate the necessity for application of mould sealers, and greatly facilitate investment and processing of partial dentures and of relines (Fig. 1.4).

A survey of methods for the study and comparison of denture base materials will demonstrate some of the difficulties experienced in the field. Derivation of data which will have clinical significance will be discussed in the light of the tolerance of oral tissues.

The laboratory study on which the report will be written will demonstrate:

1. Simplification of the investment procedure and processing.
2. Dimensional stability and occlusal accuracy of bases and dentures produced by this technique.
3. Inaccuracy of occlusal relationships and distortion of bases produced by reinvestment in gypsum in the second-cure technique.

TWO - POUR GYPSUM INVESTMENT

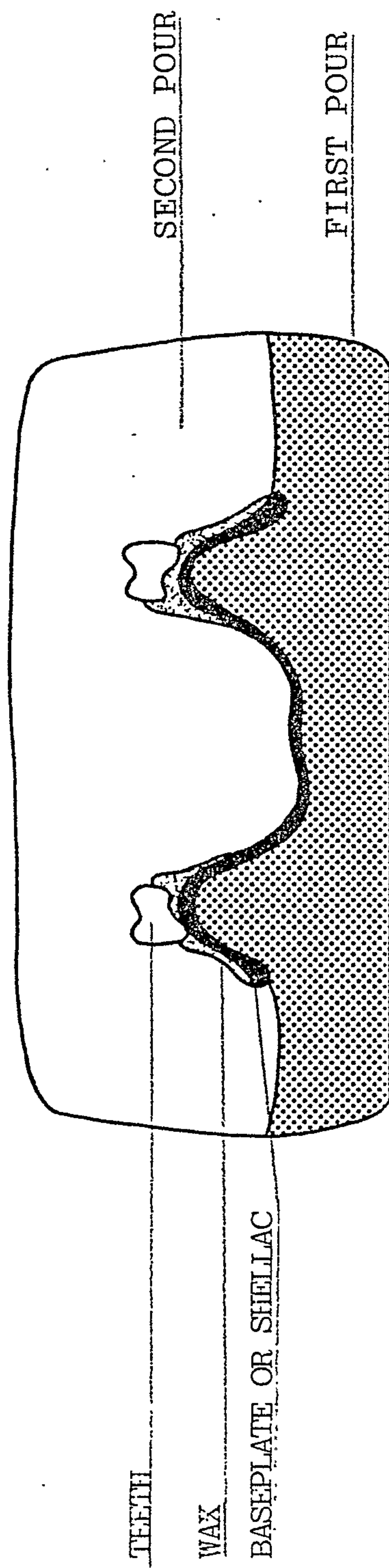


FIG. 1.1.

THREE POUR GYPSUM INVESTMENT

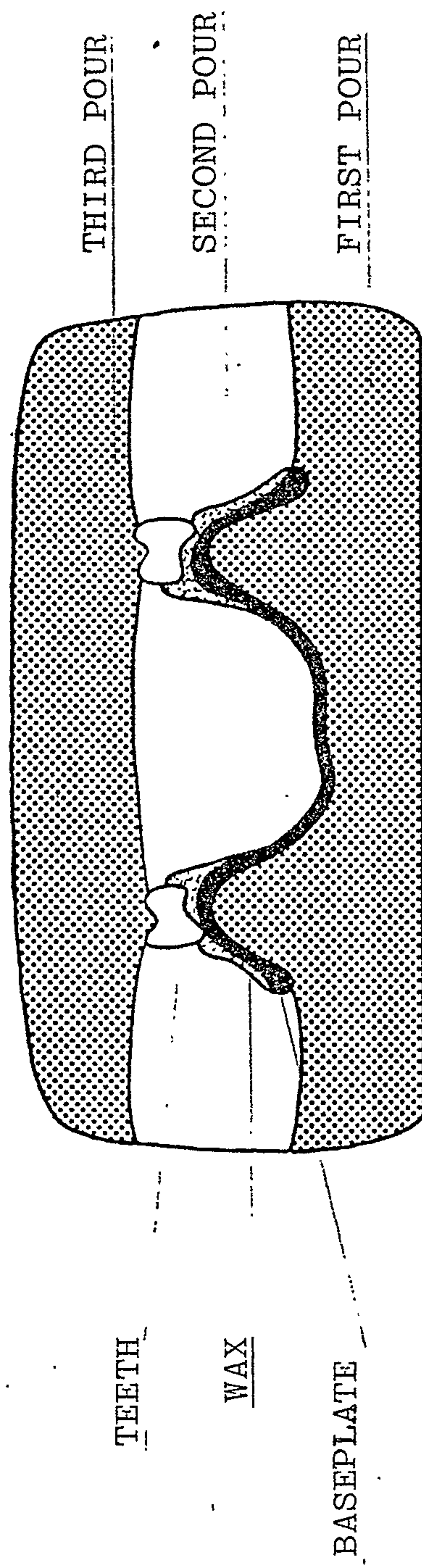


FIG. 1.2.

POUR - TYPE RESIN

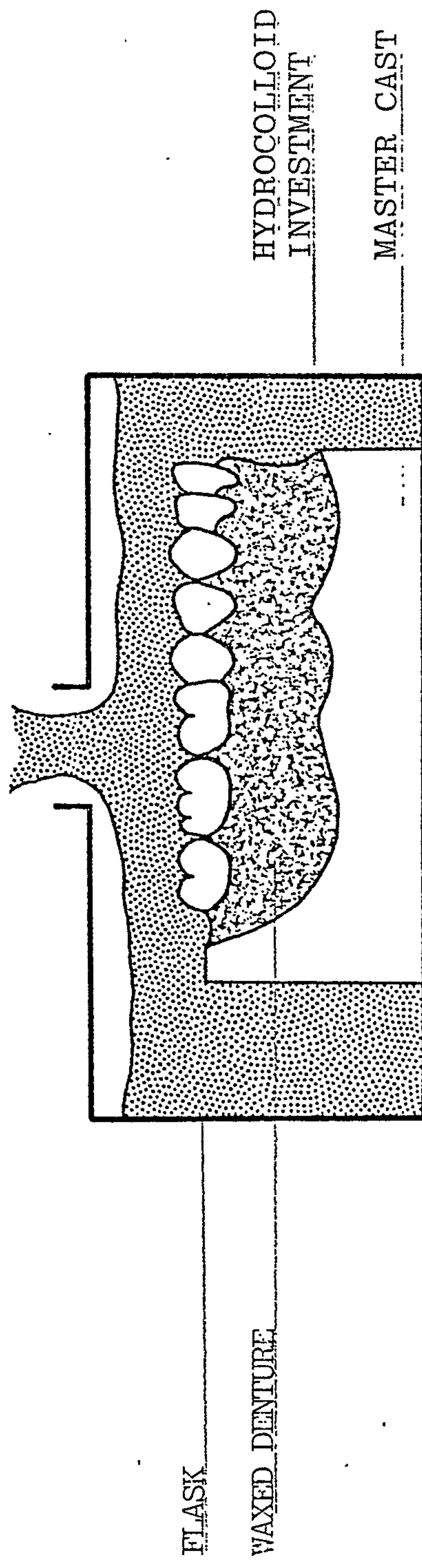


FIG. 1.3.

TWO POUR GYPSUM, INVESTMENT WITH
SILICONE MOULD LINING

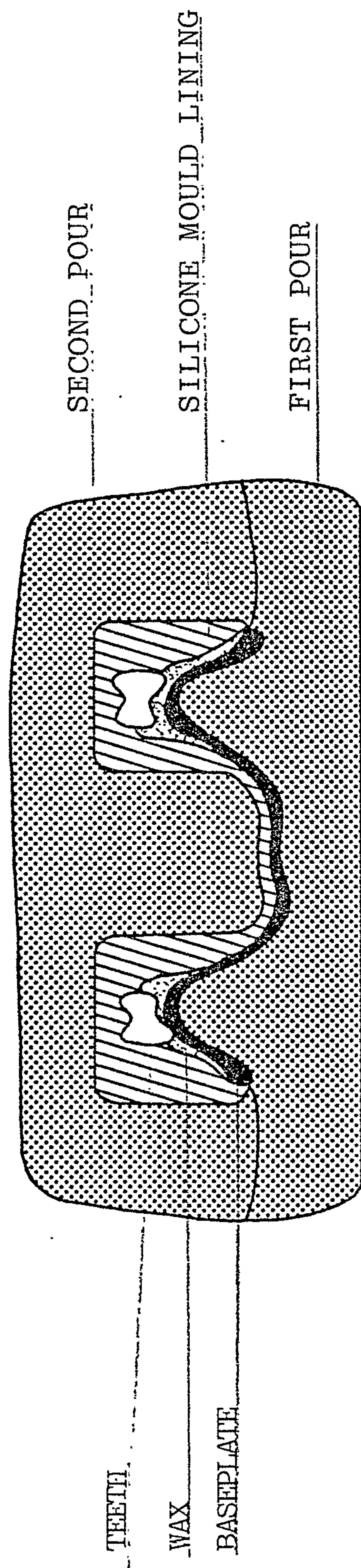


FIG. 1.4.

CHAPTER 2: PROCESSING TECHNIQUES

2.1 The method of processing acrylic resins in a gypsum mould lined with tin foil or an alginate or lacquer based tin foil substitute has wide acceptance⁵. It is suited for heat-cured or cold-cured acrylic resin, although difficulties have been encountered where inattention occurs or inadequate skills have been applied:

1. Air and impurities may be included in the investment resulting in a loss of accuracy of the wax contour (Fig. 2.1, 2.2).
2. Movement of the teeth resulting from investment expansion may occur to produce occlusal inaccuracy^{6,7}.
3. It is necessary to apply a mould liner to the surface of the investment to prevent the adhesion of acrylic and to control contamination.
4. During packing, the pressures often generated in the mould by rapid application or excessive pressure cause deformation or fracture of the gypsum investment, allowing tooth movement^{8,9} and significant loss of occlusal accuracy¹⁰.
5. Particles of investment which have fractured during wax elimination or packing procedures may enter the mould to be incorporated in the denture base (Fig. 2.2).
6. During deflasking, the investment must be removed from the denture. Where there has been inadequate application of separating medium or sealing, investment adheres to the denture.
7. Voids present in the investment become filled with resin and need to be trimmed.

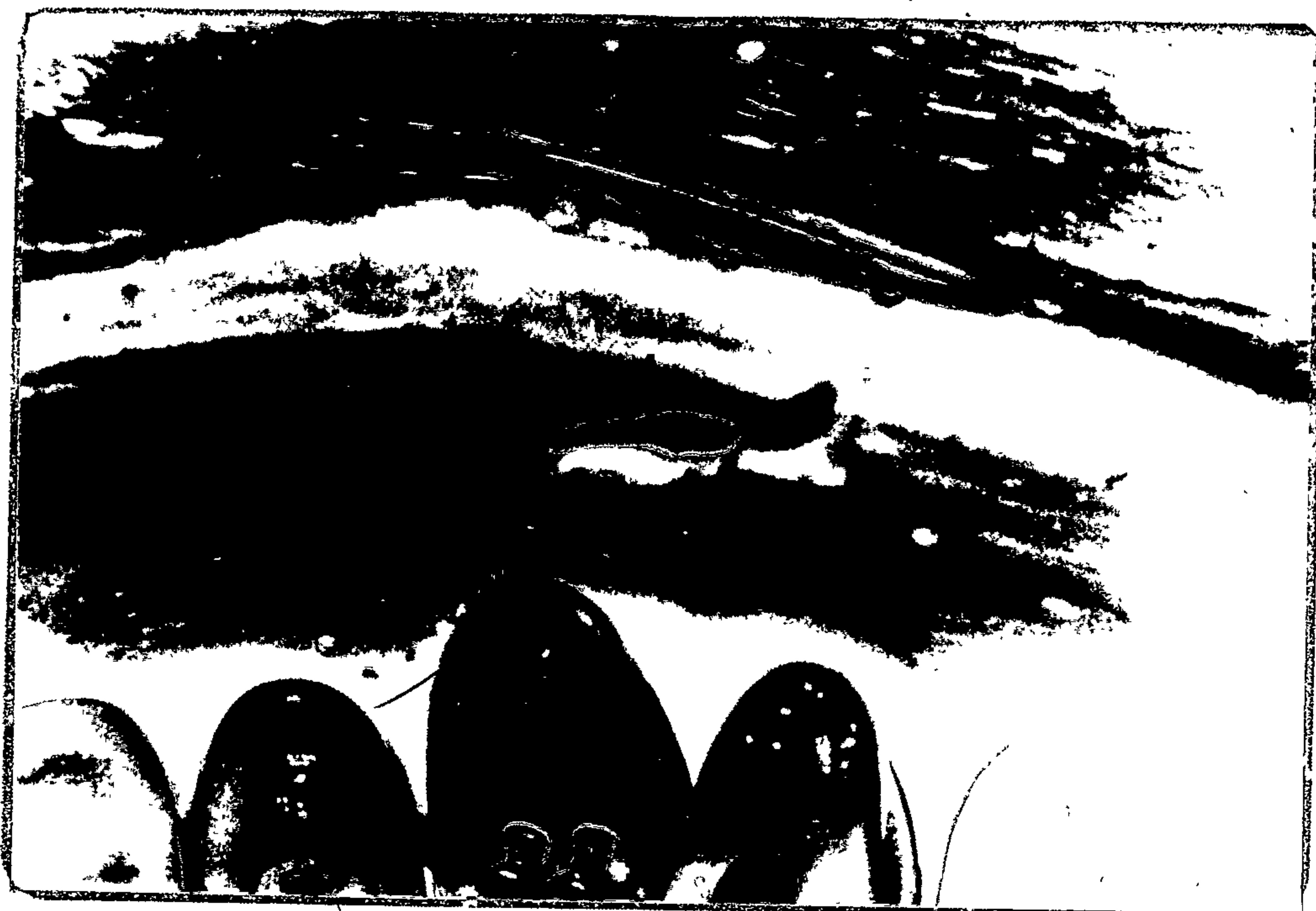


Fig. 2.1. Air inclusion in investment.

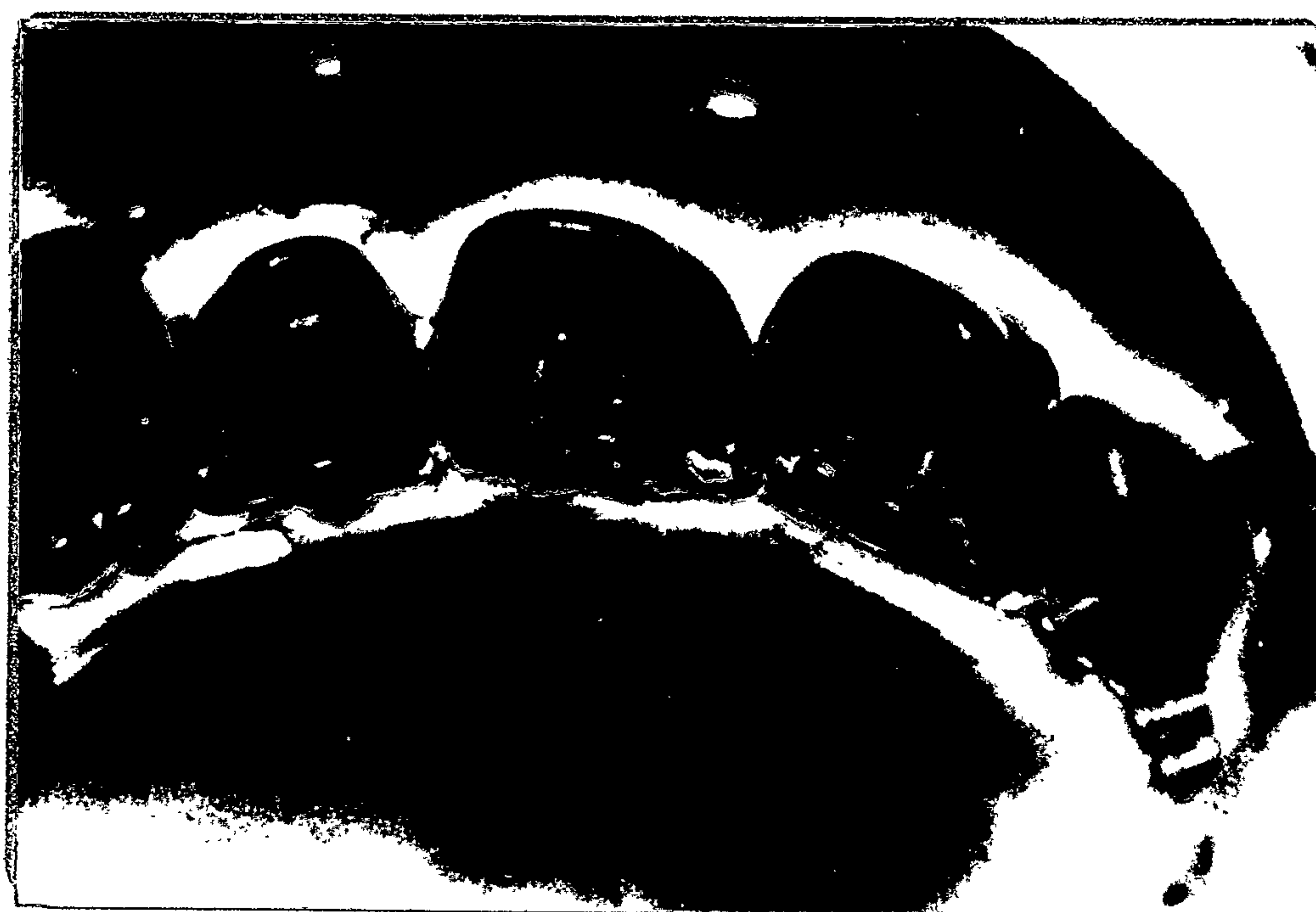


Fig. 2.2. Investment particles in mould.

8. Volumetric change in the resin at the polymerization temperature¹¹ and differential cooling contraction of the resin and investment from that temperature produce internal stresses which are expressed as crazing or warping or loss of occlusal accuracy⁴.

2.2 All of these manipulative problems can be overcome by application of a silicone mould liner. In this technique, the waxed model is invested in the lower half of the flask (the drag) in gypsum. As would be expected no change in the relationship of the tooth to the cast is detectable in this step⁷.

A layer of silicone investment is then applied by moulding it in putty form or by the paint-on technique (Fig. 2.3). The part of the drag remaining uncovered is then sealed with petroleum jelly, liquid soap or model-sealing agent. The remainder of the upper half of the flask (the cope) is then filled with gypsum. (Fig. 2.4).

A conventional boil out technique may then be applied, the flask being immersed in boiling water for six to eight minutes. Wax elimination is completed by using boiling water or wax solvent, and several coats of separating medium are applied to the surface of the cast.

It is not necessary to apply surface treatment to the silicone investment.

The application of separating medium to the cope surface is unnecessary. Thus the teeth will not be contaminated

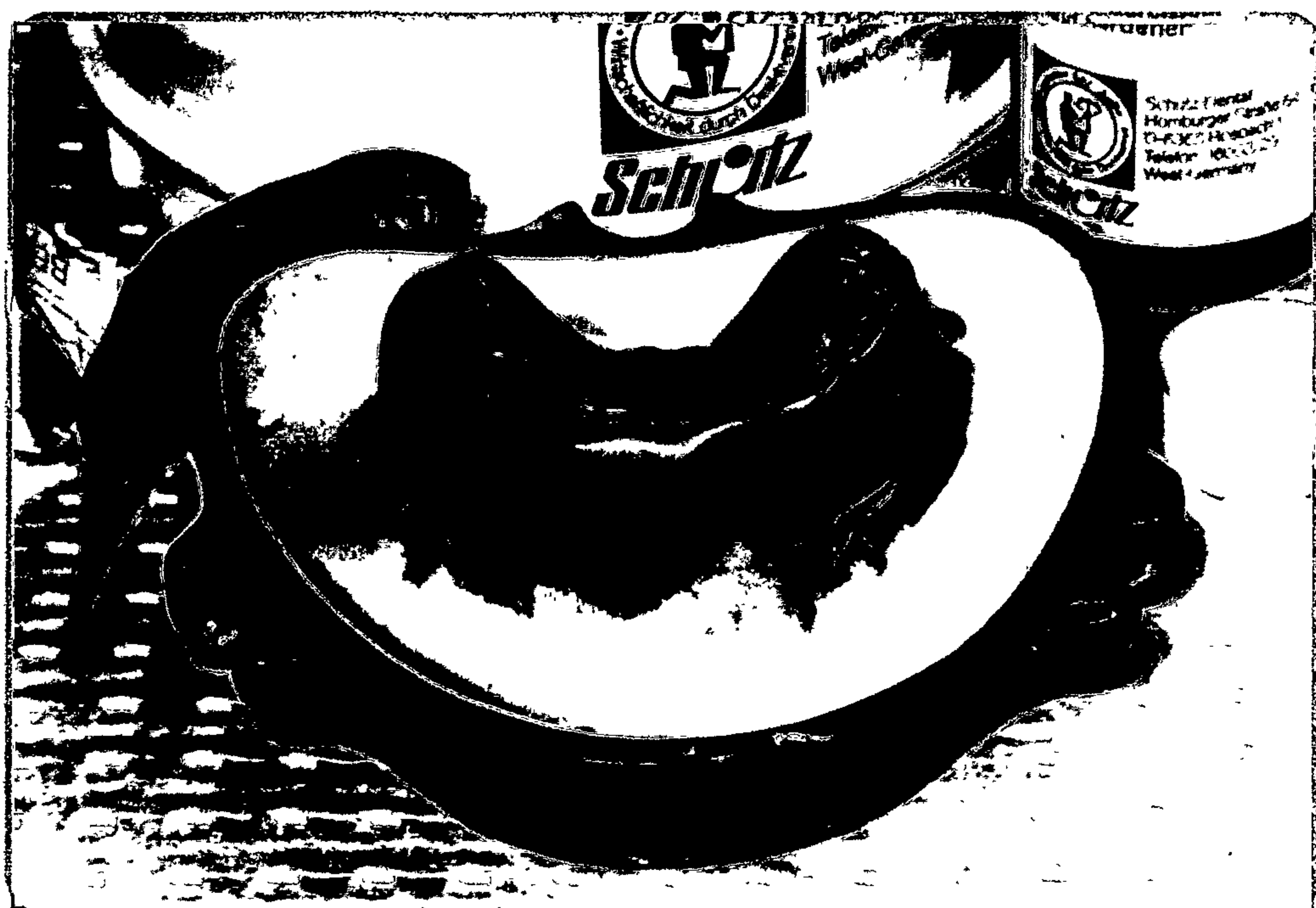


Fig. 2.3. Silicone mould liner adapted to waxed denture.

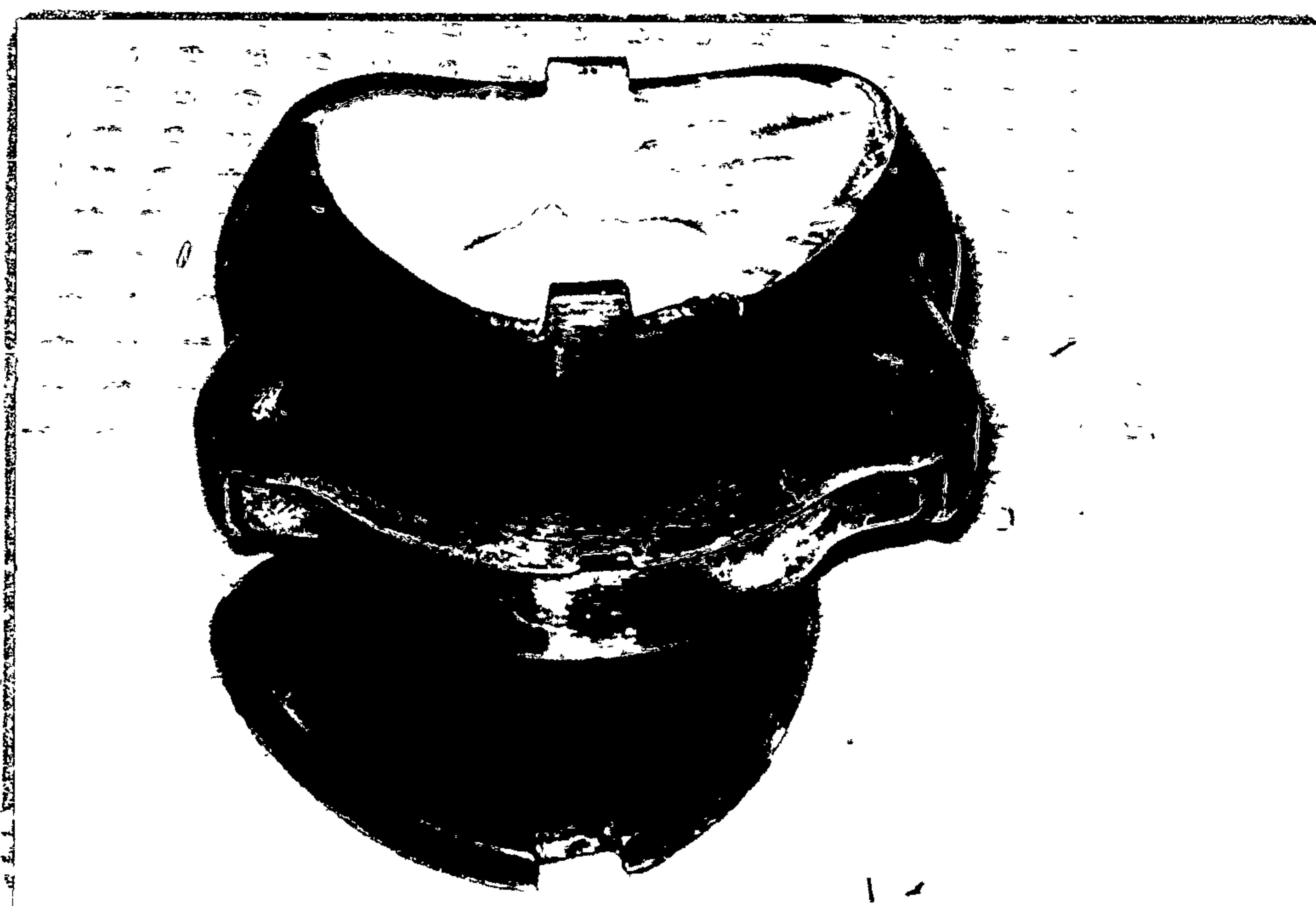


Fig. 2.4. Remainder of cope filled with stone.



Fig. 2.5. Polythene film is placed between teeth and resin to reduce the tendency of the teeth to be displaced from the investment; the teeth are not held as firmly by the elastomeric mould lining as by gypsum investments.

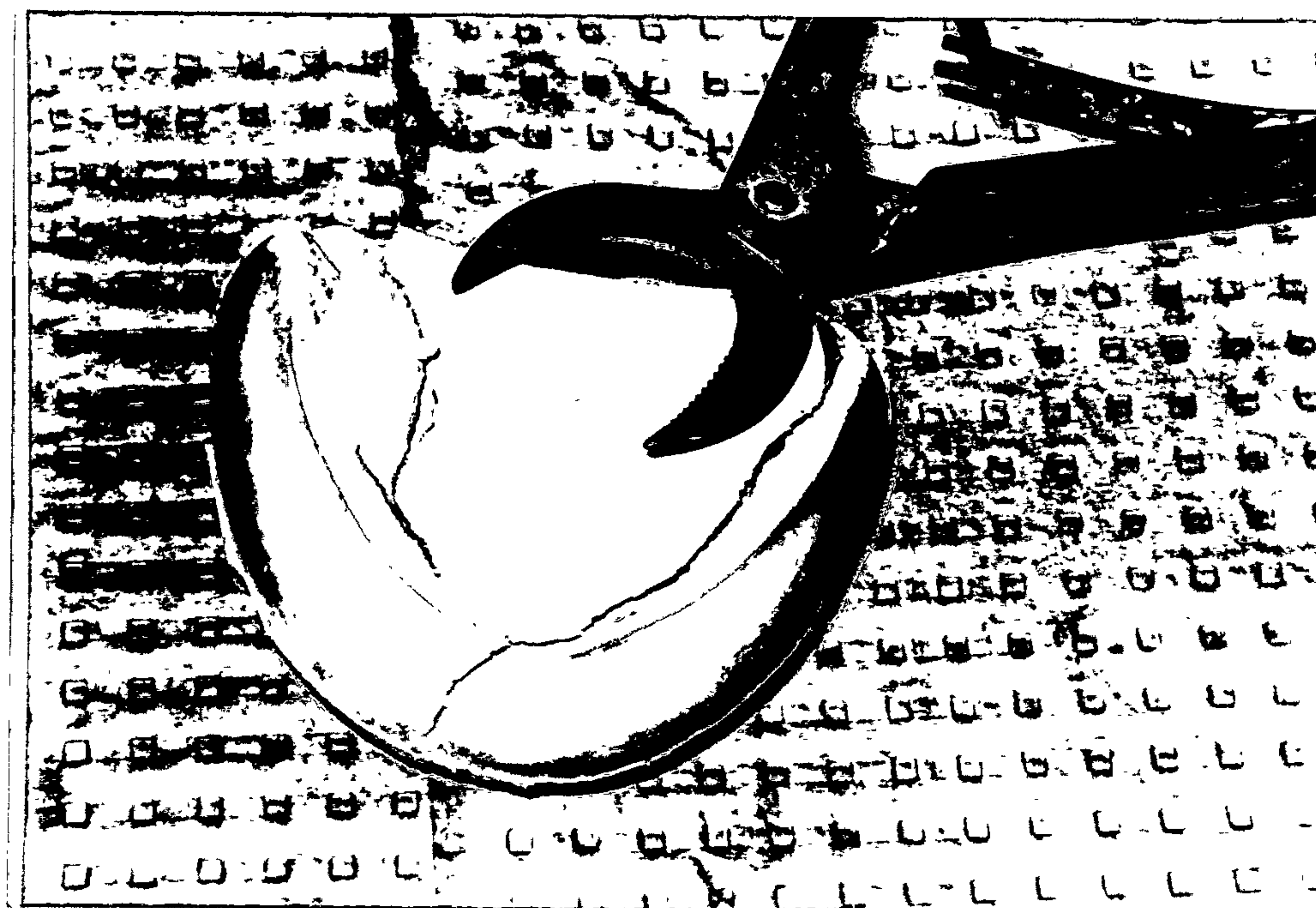


Fig. 2.6. After processing the gypsum cope is readily fractured away.

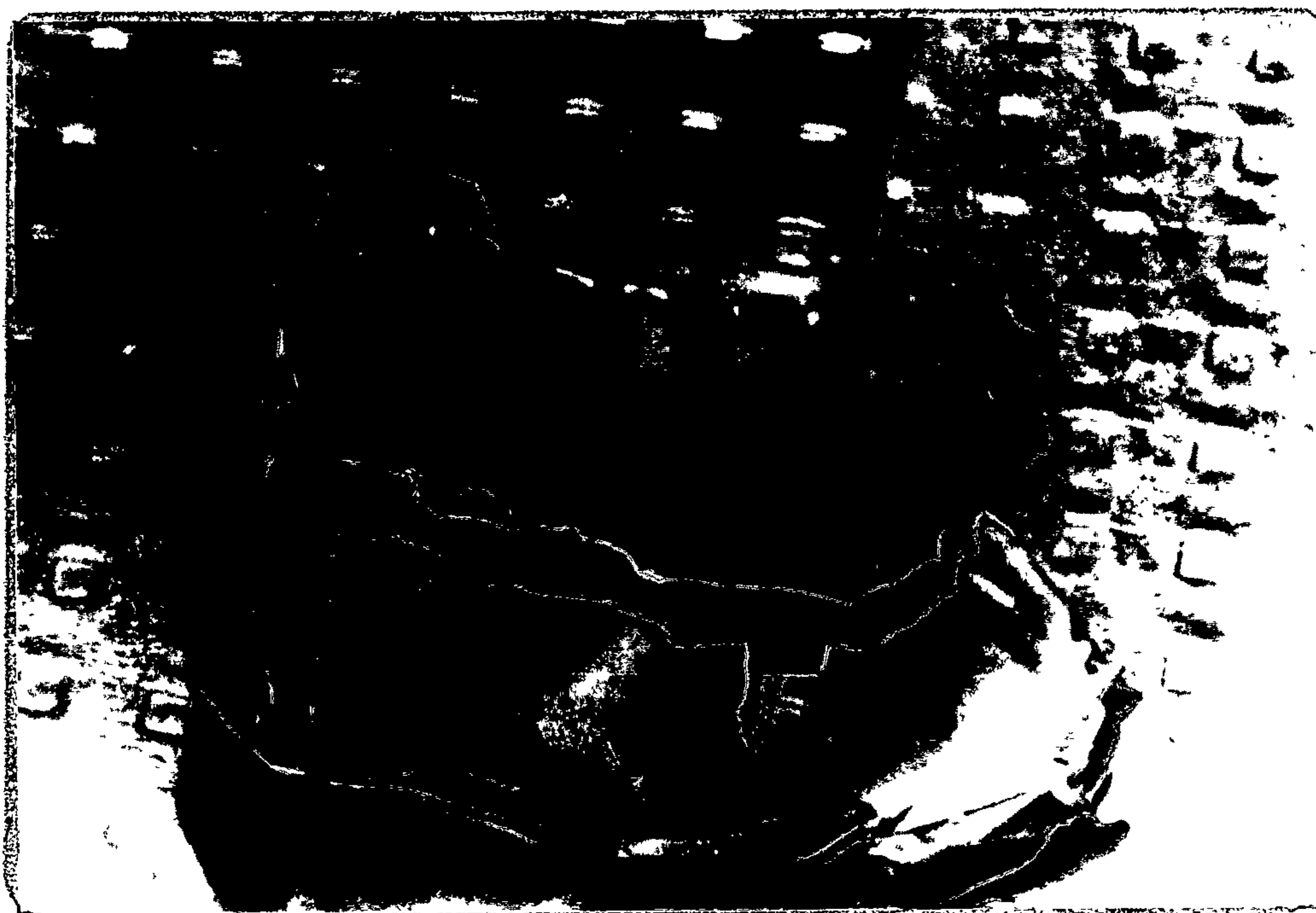


Fig. 2.7. Accuracy of reproduction of surface of waxed denture reduces finishing procedures and thus minimises distortion from heat generated during cutting and polishing.

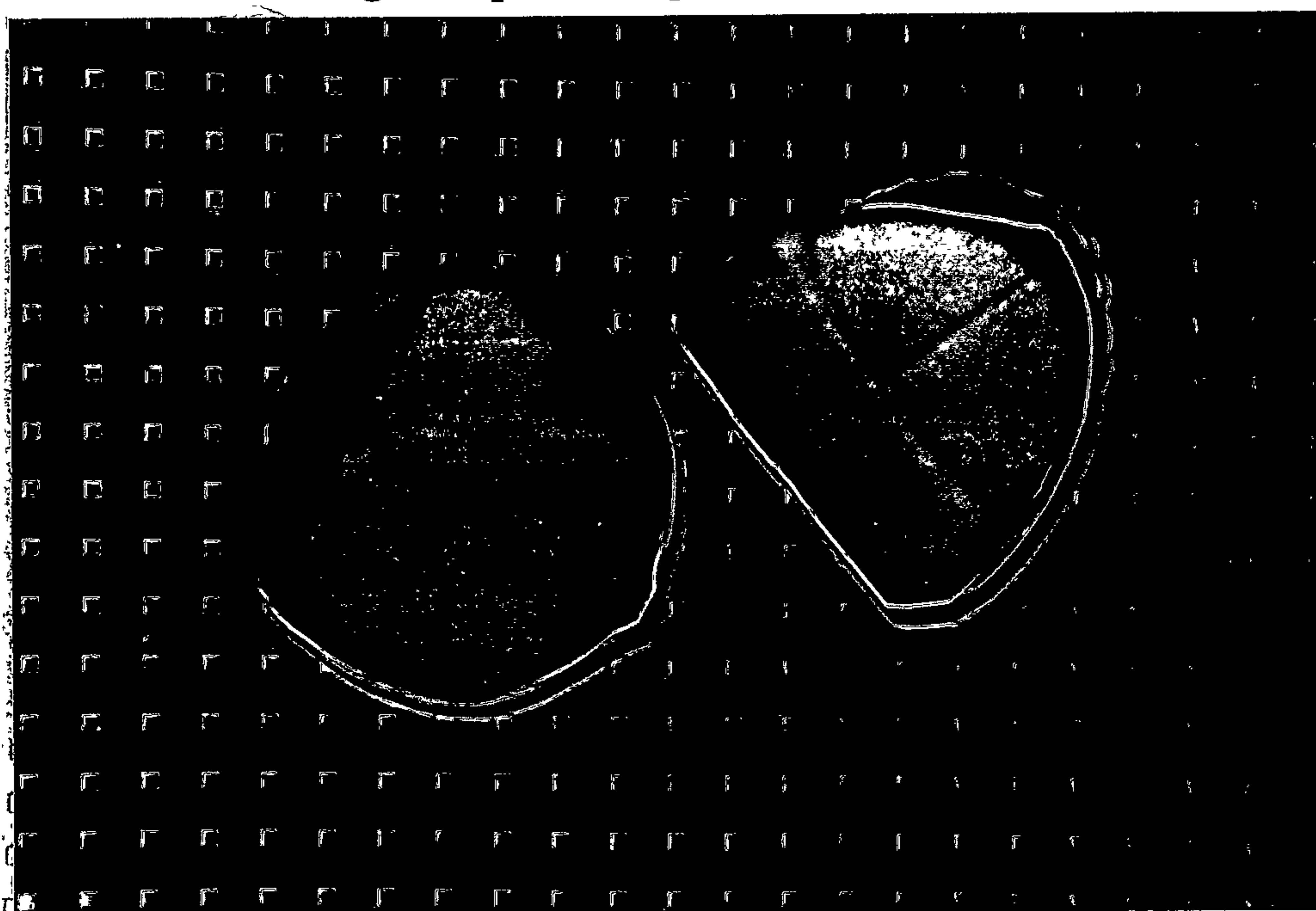


Fig. 2.8. The split-cast and remount technique may be used to eliminate occlusal errors occurring as a result of processing.

by separating medium; the bond between tooth and denture base cannot be compromised, nor will a residue of alginate or other material remain around the gingival margin of the finished denture.

During trial packing of dough type resins, polythene film is placed in the cope rather than on the cast side of the mould. After the usual trial packing procedure and removal of excess resin, polymerization is carried out via the cycle of choice (Fig. 2.5).

Upon completion of this cycle, deflasking is carried out with the utmost simplicity. The gypsum part of the cope may be fractured away, and the remaining silicone material is readily peeled from the surface of the denture. (Figs. 2.6, 2.7).

Finishing procedures are carried out in the usual way, and are greatly minimised as a result of the accuracy of reproduction of the wax contour. The avoidance of excessive cutting and shaping of the set of acrylic minimizes any distortion which may be caused by heat released stress¹³.

2.3 By modifying the standard gypsum investment technique to include a silicone mould lining, the accurate reproduction of the waxed denture or base could be compromised in one or all of three ways:

1. There could be movement of teeth in the investment during packing or polymerization, producing occlusal inaccuracies in the denture.
2. There could be a resultant instability of the denture base contour, producing loss of fit.

3. The physical properties of the resin might be compromised by the presence of silicones and a reduction in strength, hardness, elasticity or other property might result.

A review of previous experimentation which is reported in chapter 6 demonstrates that there is no loss of accuracy of the occlusal relations of dentures processed in this manner. Furthermore, reports of studies of dimensional accuracy based on linear measurements are available and indicate that this technique produces dentures and bases of quite comparable if not improved dimensional stability.

The present study will involve a comparison of tissue-fitting surface and cast contours. A series of test dentures was constructed on duplicate casts, the dentures mounted on a tripod and a series of co-ordinates of right-to-left and anteroposterior sections of contour were measured. These co-ordinates were entered into and plotted by a micro-computer. The resultant graphs could be superimposed on a light-box and an analysis of the fit made.

CHAPTER 3: PREVIOUS STUDIES - BEHAVIOUR OF GYPSUM INVESTMENTS

3.1 The fact that changes in vertical dimension will occur in the two-part mould procedure has been recognised for some time. Steck¹⁴, in 1950, devised a method for fabricating specimen denture bases in which metal caps were embedded in the waxed denture. Change in height as a result of processing could be measured by replacing the bases on a metal master model and measuring the height of the caps using a micrometer. An average reading of 0.15 mm expansion (0.006 inch) was recorded for the series of eight test blanks, equivalent to a 5% expansion in a 3 mm denture base. When this result was compared with the 0.4% contraction seen in similar measurement of a flat blank, it was suggested that the shape of a full denture base and particularly the presence of undercuts had a significant effect on distortion and increase in occlusal vertical dimension. It seemed that the investigator had identified the effect of stress relief upon deflasking of processed sections of acrylic resin, and found a strong correlation between this stress and the complexity of the denture base section. Steck also identified the significance of flash thickness and the influence of distortion of the mould by excess packing pressure.

3.2 One investigator, Lam¹⁵, used a photographic technique and double exposure of each plate to illustrate that changes in vertical dimension of 0.02 to 0.50 mm could produce corresponding distortions of the horizontal occlusal relationship. When the orientation of the occlusal plane of the denture was not parallel with the rim of the investing flask, the "flash" and other effects

introduce horizontal and vertical occlusal discrepancy. The lower half of a processing flask containing the partially-invested waxed-up denture was photographed, then moved vertically through a distance equivalent to the thickness of the flash when a second exposure was made. A photographic depiction of the change in the relationships of tooth to cast resulting from change in the vertical relationship of the upper and lower halves of the flask was thus produced. Where flash thickness was 0.3 mm, lateral distortion of the occlusal plane ranged from 0.2 to 0.4 mm with increasing angulation of the occlusal plane to the base of the flask.

Although this must be seen as a simplification of denture processing, some indication is given of the direction and scale of occlusal inaccuracies which may be introduced into the finished denture.

- 3.3 In a further study of the accuracy of gypsum investments Perlowski⁶ in 1953 investigated the movement of teeth produced after heat-curing of dentures in a gypsum mould. The height of the occlusal pin was registered before and after processing and a comparison drawn between:
1. Three-pour mix of plaster/stone/plaster (Fig. 2.2).
 2. Modification of the second pour to use only a thin matrix of stone which was applied by brush.
 3. Second pour modified as a paint-on matrix of plaster, followed by conventional third pour.

Changes in pin height recorded in this experiment were up to 1.5 mm for the first method, while the second and third methods gave pin height increases of 0.8 and 0.7 mm respectively. The experiments gave some indication of

inaccuracies of the three-pour investment method and demonstrated that the method of investment can materially influence vertical distortion of processed dentures.

7 Perlowski saw the strength of the investment as being less significant than the technique applied, although it will be seen in later studies by Grant⁷ and Mahler⁸ that strength of the investment is most significant during packing of the resin, with regard to tooth movement.

3.4 Extending the study of Perlowski, Grant⁷ devised a simple mechanical system to observe movement of the tooth relative to the cast during investment. A brass pin approximately 70 mm long was embedded in the cast, and another of similar length placed in the tooth so that both would protrude above the cope or upper half of the flask. Holes were drilled in the flask top, and the pins embedded in a free-fitting plastic sleeve to allow movement. Measurement of the height of these pins compared to that of the flask enabled comparisons to be drawn and the change in relative height of the flask, cast and waxed-up denture teeth to be observed.

Results indicated that both cast and tooth moved vertically after the first pour, but there was no change in position relative to each other.

On the second pour the tooth moved away from the cast up to 0.05 mm, a distance which correlated with the setting expansion of gypsum. This movement was greatest when the flask was not clamped closed. When the paint-on plaster matrix technique was used tooth movement equalled that occurring when the flask lid was not clamped.

To eliminate the possibility that thermal expansion of wax caused this tooth movement, the cope was filled with water and its temperature raised to simulate temperature increase during the exothermal phase of the setting of gypsum. The tooth moved upward 0.07 mm, and returned to its original position upon cooling. As the peak of the exotherm did not occur until after the gypsum had set (as tested by the Gillmore needle) it was concluded that thermal expansion of wax did not contribute to that distortion of the tooth cast relationship occurring during investment. Further, the three-pour or paint-on matrix techniques for investment produced the greatest distortion of this relationship as the setting expansion of the gypsum could proceed unhindered by the confinement of the flask. The contribution to increased vertical dimension could be up to 0.05 mm where this technique was employed.

- 3.5 Atkinson and Grant¹⁶ reported on an investigation of tooth movement during packing and polymerization of acrylic resin denture base materials in 1962. The basis of the study was the observation of vertical change in tooth position. The initial part of the study involved mounting the waxed denture and the processed denture on a tripod and recording the height of each tooth. It was seen that all teeth had moved away from the cast by 0.15 to 0.55 mm as a result of processing.

A more complex experiment required the fabrication of a special flask to enable recording of pressure and temperature changes within the mould while also measuring tooth movement.

Use of this device identified a strong correlation between packing pressure and tooth movement. Under the pressures which might be generated during over-packing or late packing, the gypsum mould fractured or was permanently distorted. The tooth displacement was shown to also involve rotation, being governed by local planes of weakness in the set investment such as air inclusions.

The accuracy with which this experimental determination was carried out clearly demonstrates the stages of the polymerizing process as occasions for the introduction of dimensional inaccuracy. The need to control packing pressure and to ensure the maximal investment strength by optimal water-powder ratio is also evident.

3.6 In 1951 Mahler⁸ published experimental results which provide some insight into the behaviour of gypsum materials under compressive loads..

The author used the Rockwell Superficial Hardness Tester, outlining the techniques and their selection for examination of various materials. He described the procedure for preparation of standardized specimens and for their physical properties, particularly hardnesss and plastic deformation.

The latter property seems to be of great significance where gypsum is used as an investment. In this application it may be subjected to high pressures for some time and plastic deformation is to be expected. As a result of these experiments, Mahler was able to predict plastic deformation of

the order of 0.3 mm (0.012 inch) at packing pressures, where the load was applied over 10 minutes. The contribution to loss of accuracy during this phase of polymerization is identified.

- 3.7 Realizing that the polymerization process could introduce such distortion into the denture, Lerner and Pfieffer¹⁷ developed a modification of the investment procedure to minimise vertical displacement between teeth and denture base.

A layer of 22 gauge wax was adapted to the borders of the casts covering the area of the land to the inner edge of the flask. (see Fig. 3.1). The flasks were trial packed and cured at 68°C (155°F) for ten hours. In order to study the effect of this modification, the bases of the casts were keyed to allow remounting and the pin height of the articulator was recorded before and after processing using Vernier calipers.

While ten of the eighteen cases had no increase in pin height, five had 0.4 mm and three had 0.5 mm increases. The sites of major distortions were identified by the placement of shimstock between the occlusal contacts as being sites where teeth had moved in the investment.

This modified investment technique to include a "diaphragm" for resin flow during packing was seen to be a useful adjunct in the maintenance of occlusal accuracy during processing. It is noted that the three-pour technique was used for investment and that the experimental procedure did not allow for the investigation of the influence of this on increased vertical dimension.

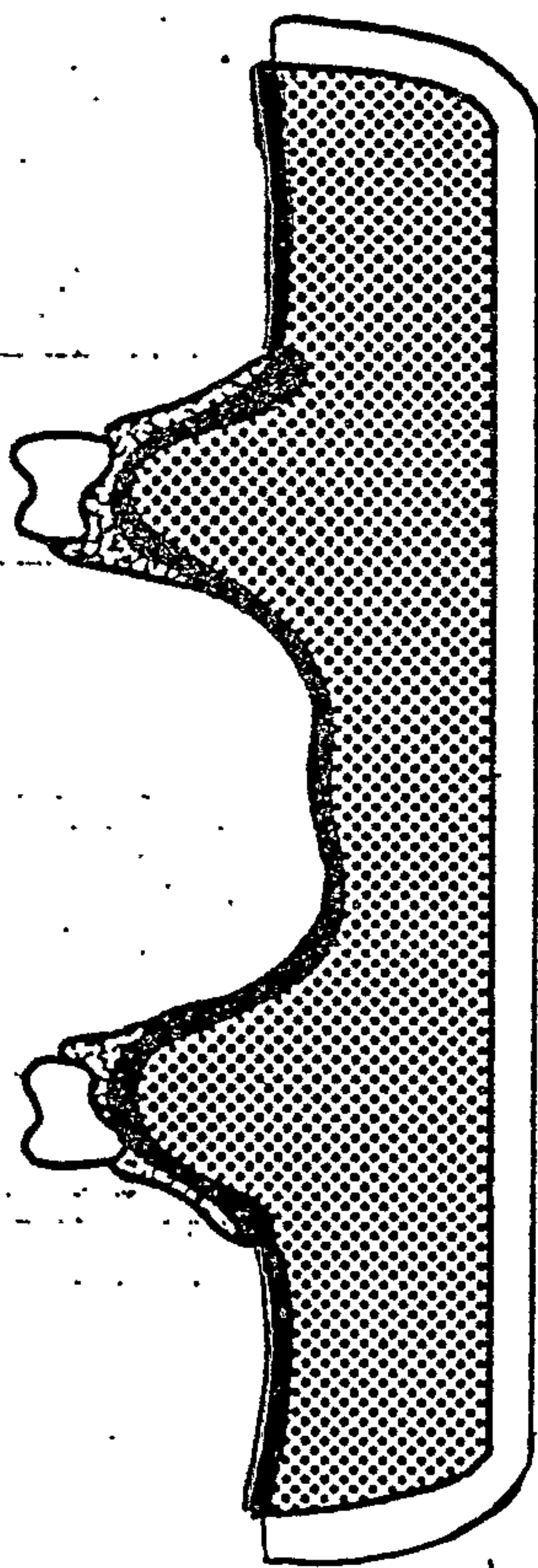


Fig. 3.1 A layer of casting wax adapted to the lower half of the flask during investment provides a "diaphragm" of resin and minimises separation of flask halves during packing and processing.

CHAPTER 4: ACRYLIC RESIN PROCESSED IN GYPSUM MOULDS

4.1 The behaviour of methyl methacrylate resin in its application as a denture base resin has been observed from the aspects of mechanical properties, biological response and behaviour during polymerization.

McCracken¹⁸ reported in 1952 on tests of the properties of hardness, strength and permanent deformation of heat-cured and cold-cured acrylic resins. Blocks of resin were prepared from heat-cured resin using a standardized proportion of monomer to polymer, and under standard conditions of temperature. Flask closing was carried out at 270 MPa (4000 lbf/in²). Samples of the cured resin were machined and tested for hardness using the Rockwell Superficial Hardness Tester. The readings showed good reproducibility and were averaged to give a representative value for hardness for the heat-cured resins of 95. The Rockwell scale to which this refers was not specified, hardness numbers have no absolute value but a comparison indicates the degree of polymerization.

A series of blocks was processed from cold-curing resin. One group of blocks was stored in water while another group was stored dry. Hardness was evaluated one hour after deflasking and again at daily intervals for one week, then at 15, 30 and 60 days. Hardness numbers at one hour ranged from 77 to 86 for four different products. These increased considerably over the first 24 hours, and thence increased slowly to be within 3 to 4 hardness numbers of heat-cured resin after 60 days. Values for samples stored in water were consistently lower than the values for the dry specimens.

McCracken prepared some samples of cold-cured resin by keeping them in the mould press for two and a half hours, immersing them in boiling water for 15 minutes and bench cooling before deflasking. Using this cycle, the specimens showed Rockwell hardness numbers of about 94 after 24 hours, similar to those of heat-cured specimens, and did not increase further after this.

A series of tests for permanent deformation were also carried out using Rockwell Superficial Hardness Tester and a load of 30 kg. Results of these tests demonstrated a high capacity for permanent deformation initially upon deflasking the cold-cured specimens, decreasing to approach the values for heat-cured resins after approximately three days.

McCracken carried out tests of transverse strength in which the deflection of samples of heat- and cold-cured resins under loads were measured. The cold-cured samples deformed more than the heat-cured samples initially, although the deflection of the cold-cured samples decreased after they were boiled for 15 minutes. The property which these tests measured was Young's modulus of elasticity, expressed as stiffness under bending loads and this does not give a direct indication of strength. The increased stiffness measured after boiling the samples of cold-cured resin indicates that polymerization is often incomplete until the resin is heated.

A study was then made of temperature within the resins during polymerization. Thermocouples were placed centrally and at the periphery of the test denture blocks and recordings made at one minute intervals. Peak temperatures of 50°C were reached at about 13 minutes after mixing. Dimensional changes occurring

as a result of processing could also be measured by the insertion of brass screws in the wax pattern. Readings indicated a shrinkage of 0.14% although there is no information given about the shape of the test dentures.

The author concluded:

1. That the cold-curing resins were generally less completely cured than heat-cured samples when deflasked.
2. That immersing these resins in boiling water for a period after curing but before deflasking improved their physical properties.
3. That, in general, there was less residual stress in the cold-cured resins because of the lower curing temperature. Thus it was felt that the cold-cured resins, although not quite as strong as the heat-cured resins, had some advantage in greater dimensional accuracy and stability.

4.2 Grunewald, Paffenbarger and Dickson¹⁹ reported also in 1952 on their observations of acrylic and other resins processed by what the authors described as "injection moulding". A comparison with the more conventional compression "moulding" was made. The term "moulding" in this context implied packing the mould with an unpolymerized dough. The authors tested the resins for accuracy of horizontal dimensions in processing. They measured the separation of indentations made by markers on the surface of the steel die on which the bases were processed, using a measuring microscope to accurately determine this distance.

An observation of accuracy of the vertical dimension was also made. A split-cast technique was used which allowed remounting of the dentures after fabrication and recording of changes in pin height.

The authors compared the temperature and the flow of the resin during polymerization. A cylinder was invested, filled with uncured resin under pressure and slowly heated. The temperature was observed by means of a thermocouple, and pins which had been placed in the cylinder were withdrawn at stages in the thermal cycle. The uncured resin flowed into the holes left by withdrawal of the pins but exhibited no further flow after curing had been completed.

The authors then weighed samples of resin before and after storing in water baths to determine variation in water sorption at different temperatures.

Hardness and transverse strength were also tested for injection "moulding" (including injection packing) and compression moulding techniques and an observation made of the clarity of the samples of resin to assess the degree of porosity present.

The results indicated that there was no significant difference between injection and compression moulding in the change of dimension in the occlusal plane. The greatest change in dimension occurred immediately upon removal from the flask when a shrinkage of up to 0.9% was seen. Change in height of the incisal pin was found to be greater when additional resin was added to the flask after the final trial pack, or when flask closure was too rapid. A contribution to vertical error was made by plastic deformation and/or fracture of the investment where it had not set completely or was mixed with an excess of water.

The assessment of flow during polymerization of the dough demonstrated that no further resin was injected into the

mould after rapid polymerization had occurred as evidenced by the peak of the exotherm. This indicated that the presence of a well or reservoir of resin as used in the injection packing technique would not provide compensation for polymerization shrinkage. The resin ceases to flow at the time when rapid polymerization occurs and polymerization shrinkage is greatest at that time.

All of the dentures took up water during the sorption test, the rate of sorption being greater when the temperature of the water bath was increased. There was a correlation between water sorption and dimensional change, each being greatest during the initial ten days after deflasking and being minimal thereafter. Dentures stored in water at up to 60°C showed little dimensional change, but showed significant distortion when stored above 80°C. If the dentures were processed on a metal die this distortion was effectively zero until 80°C was reached. No clear advantage in physical properties was seen for injection or compression packing of the test dentures.

A method of applying heat by incorporating an 80W soldering iron in the flask/investment was tested. Dentures processed in this way demonstrated warping and porosity, attributed to high temperatures and uneven heating.

Porosity or loss of translucency of the denture bases was rarely seen in either technique. The authors made no comment about the clinical significance of their findings.

The injection packed dentures did not emerge as providing any real advantage or improvement when compared with compression moulding, and cost of the additional equipment required does not seem justifiable. In addition, the problems of dimensional stability and occlusal accuracy of heat-cured acrylic resins remain. The use of a steel die for the processing of the denture bases could well have influenced the results obtained particularly in dimensional changes in directions in the occlusal plane.

- 4.3 Physical properties of heat- and cold-cured resins were compared in a study carried out in 1953 by Peyton, Shiere and Delgado⁹. A.D.A. standard tests of working time, transverse strength and bonding strength were applied to a series of acrylic resins. Doughing time for cold-cured resins were generally reported as being about half of that for heat-cured resins. Transverse strength was initially up to 15% less in cold-cured resins but was improved a one-hour cycle in boiling water. Tooth bonding was significantly weaker for the self-cured resins, particularly where there had been incomplete wax elimination.

The hardness of cold-cured resins was lower than that of the heat-cured samples, particularly immediately after deflasking but this improved with time. Colour stability of both resin types was similar.

Adaptation and dimensional stability of cold-cured resins were seen as being superior to that of the heat-cured resin, although details of the tests for these were not supplied. The authors felt that cold-cured resins did not display any overall advantages when compared with heat-cured resins.

- 4.4 A comparison between cold-cured resins processed at 20° and at 37°C was made by Skinner and Jones in 1955⁴ to enable observation of the influence of the temperature of the curing cycle on dimensional accuracy.

The authors surveyed dimensional changes in denture bases by measuring changes in the separation of marks made on the flanges by an indexed cast. The bases were measured immediately after deflasking and then at weekly intervals for six weeks.

The bases processed at 20°C were initially more accurate but were observed to change shape if stored in air. When stored in water they increased in size. This was thought to be caused by water sorption although the bases were not weighed to support the contention.

Heat-cured denture bases fabricated under the same conditions showed curing shrinkage of about 0.4% upon deflasking but had improved their fit after six weeks storage in water to be quite similar to cold-cured bases.

The authors added teeth to the waxed dentures and processed them but found that dimensional changes were little different from those observed with bases only, the maxillary denture showing a slightly increased distortion. There was no difference observed between acrylic and porcelain teeth in terms of horizontal dimensional change. Based on linear observations, the conclusion was drawn that dentures processed from cold-curing resins at 20°C had greater dimensional stability than those processed at 37°C , irrespective of the duration of the curing cycle. Heat-cured dentures were seen to have greater warpage initially

but these approached the values given for cold-cured dentures after several weeks of water sorption.

The results of this study are generally comparable with those seen elsewhere, illustrating the reproducibility and thus the reliability of tests for dimensional change in the processing of acrylic resins.

- 4.5 Atkinson and Dennis¹¹ reported in 1959 on the design, construction and use of a device for the study of the polymerization of heat-cured acrylic resin.

Their apparatus consisted of a glass walled polymerization chamber 50 mm long and 12 mm diameter, into which samples of acrylic resin dough could be placed for curing. Thermocouples and a manometer attached to the chamber monitored temperature and pressure as samples of resin were observed during the polymerization cycle. The transparency of the dough could be observed and the influence of heating rate, temperature and pressure on the production of voids was thus observed. These were seen to form when the temperature of the water bath reached 62-65°C. At this time temperatures within the resin mass were often greater than 100.3°C, the boiling point of the monomer at atmospheric pressure. Furthermore, as the peak of the exotherm was reached, pressure within the curing chamber was seen to decrease abruptly often reaching atmospheric.

It seemed apparent from this information that the application of high packing pressures to the resin dough initially prohibited the acrylic monomer from exceeding its boiling point. However, as the resin contracted at the polymerization stage, this pressure decreased. A high rate of heat applic-

ation could produce rapid polymerization, volumetric contraction and consequent loss of pressure to allow the formation of monomer vapour within the resin mass. These vapour inclusions would be seen in the polymerized resin as cloudiness or bubbles, depending on their size and number.

In their conclusion the authors recommended that a slow application of heat be used with a low temperature cycle to avoid gaseous porosity in polymerized resin.

- 4.6 Woelfel and Paffenbarger published a review of studies of dimensional change in dentures, also in 1959²¹. By this time acrylic resin had long supplanted the hard rubber formerly used and cross-linking agents and cold-curing resins had improved performance and simplified handling.

Dimensional inaccuracy in replication of the impression of the denture bearing area began, however, when the gypsum cast was poured. The setting expansion of this material was given as 0.12 to 0.44% producing an expansion of up to 0.1 mm over the widest part of a cast.

This cast could be distorted during the packing phase of resin polymerization. Further, during heating, the packed resin could expand volumetrically by up to 4% and contract during polymerization by up to 7%. Subsequent cooling before deflasking could produce changes of -2% in volume, and stresses set up as a result of differential thermal contraction (gypsum 11×10^{-6} K, acrylic 110×10^{-6} K).

Most polymerization shrinkage occurred towards the fitting surface. The concave shape, particularly of undercut casts, resulted in a locking into the cooling mass of complex residual stresses.

Upon deflasking immediate elastic recovery produced a variable contraction over the heels of the cast, with a movement away from the palate in the post-dam area. The linear dimensional change upon deflasking had been measured as 0.5-1.2% for heat-cured dentures, a little less for cold-cured dentures.

Clinically, the significance of such distortion was hard to establish. Furthermore, in the first three months of denture wearing there was some reversal of the initial distortion. The authors quoted a study of Mowery and Woelfel⁴³ where there was no correlation between subjective experience and the degree of distortion of the denture base even where inaccuracy of up to 0.75 mm had occurred. The authors concluded that in spite of the additive nature of the distortions introduced during processing of dentures, they were of such small magnitude as to be insignificant clinically.

4.7 In 1960 Woelfel, Paffenbarger and Sweeney²⁰ published a further report on dimensional changes occurring during denture processing. One hundred and eighty-six clinical dentures were measured for increase in vertical dimension by recording the height of the incisal pin before and after processing.

Changes in dimension in the occlusal plane were measured by the movement of steel marker pins set in the molar

teeth of each denture. The temperature at which the measurements were made was standardized, as a difference of 1°C meant a variation of 0.004 mm over a 50 mm span. Dentures were measured before and after removal from the casts, and again after the dentures had been polished and then stored in water for one day.

In addition, some technique dentures were sectioned before deflasking to demonstrate adaptation of the resin to the investment. This was carried out to observe the influence of sprue placement for the injection-packed type of denture.

Average values for molar-to-molar shrinkage were 0.40% for full upper dentures (approximately 0.2 mm at the flanges), and 0.12% for lower dentures. Pin-height changes were up to +0.5 mm for injection-packed resins, less for pour-type resins. Epoxy resins showed some advantages in dimensional stability, offset by their poor attachment to the denture teeth.

The study supported the wide acceptance of heat-cured compression moulded acrylic resin for denture construction. As has been stated elsewhere, the dimensional inaccuracies of heat-cured resin dentures are not large enough to be of clinical importance.

- 4.8 In 1961 Mirza²² published a report on an investigation comparing the fit of dentures on the cast with their fit in the mouth. Thirty three dentures were made with resin heat-cured at 75°C in gypsum moulds and 31 were processed

at room temperature in hydrocolloid moulds.

An assessment of dimensional stability was made by measuring the separation between indentations made on the casts and the corresponding marks made in the denture base. A visual appraisal of the degree of fit of the base to the cast was also made by trimming the casts to a plane 2 cms from the heel, and replacing the cast in the denture base.

In the clinic the dentures were subjected to manual unseating pressure and a subjective level of fit was deduced from the retentiveness. The appraisal was conducted after the dentures had been worn for three months when the fit on the casts was also checked.

The cold-cured dentures were initially a better fit but a shrinkage of the flanges began after deflasking and continued beyond the three month measurement. Heat-cured dentures were initially less accurate but tended to approach the original contour of the casts over the first week, after which time they changed very little.

Curing shrinkage of the heat-cured group was around 0.30% and of the cold-cured dentures 0.26%. After one day this had changed to 0.40% for heat-cured, 0.55% for cold-cured. Overall loss of accuracy of fit to the trimmed casts was less than one millimetre after three months when the heat-cured dentures were better fitting.

Clinically, the manual and subjective appraisal of retention revealed no difference between the groups. In the light of current beliefs about denture retention, however, the

height and contour of the denture periphery as recorded during impression procedures would have more influence on this factor than discrepancies of fit of the order reported in the study.

Although the author indicated that fit of dentures in the mouth is an important area for study, the results reported could only give a general indication of clinical suitability.

- 4.9 Anthony and Peyton²³ used a modified comparator to plot the contour of the tissue surface of denture bases, making recordings of height at 0.025 inch (0.02 mm) intervals. Transverse sections were made in the second molar region from left to right and from the mid-incisal region to the posterior border. Using this device a comparison was drawn amongst denture bases made of cold-cured acrylic, heat-cured acrylic, vulcanite, epoxy resin, heat-cured "injection-moulded" (i.e. injection packed) acrylic, porcelain and cast metal. Each base was made on a model duplicated from a master, silver-plated die, and comparison measurements were made at twenty-seven selected sites for statistical analysis. Each denture base was stored at room temperature for 24 hours after deflasking then plotted at 37.8°C.

These measurements showed that the all-porcelain denture base was the most accurate. This was followed in order by the cold-cured acrylic, epoxy resin, vulcanite and some cobalt-chromium alloys, heat-cured acrylic and least accurate the injection-moulded resin. Although the curing cycle for the heat-cured acrylic resin was not specified by the authors, it seemed that the dentures were cured by boiling.

The authors felt that differences between the resins resulted from their different curing temperatures, and thus the range of temperature through which the hardened denture cooled before deflasking. The greatest distortion was seen in the injection-moulded resin cured at 200°C. Polymerization shrinkage was also identified by these authors as a factor in dimensional accuracy. Errors in the cast cobalt-chromium arose during duplication and because of the effect of investment expansion during heat-soaking.

The dentures were re-evaluated after eight months' storage in water at room temperature, when the heat-cured dentures had improved their fit. However, the cold-cured resins were preferred as they were the more accurate. The authors recommended that a wax spacer be placed in undercut areas where the contraction would be expected to be greatest, e.g. on the vertical surfaces of the buccal aspect of the maxillary tuberosity. The use of indicator wax to identify pressure areas caused by distortion of the denture bases during polymerization was also recommended. The need to adjust the occlusion of dentures at insertion was described and thickening of denture peripheries at the wax-up stage was suggested.

This study used an accurate method of comparison of fit via the contour plot. The results obtained supported information derived elsewhere, but provided more detail about the sites where distortion occurred. However, use of a lower curing temperature would have produced heat-cured bases of better fit which would have then compared more favourably with the cold-cured bases, the authors themselves

stating the curing temperature to be significant.

- 4.10 Woelfel, Paffenbarger and Sweeney²⁴ published their report on clinical evaluation of complete dentures made of eleven different types of denture base materials in 1965. In a regular review of a series of seventy-three clinical dentures, sixty-three dentures were re-examined yearly over a period of five to six years. Changes in occlusion, retention and stability were observed, as were changes in the tissues of denture bearing areas. An appraisal of the serviceability of each denture was made and the opinions of the patients also recorded.

Molar-to-molar shrinkage was measured directly across the teeth after processing, after removal from the cast and again after finishing procedures and storage in water for one day. This was then remeasured over the period of clinical use. In general, each material behaved in a characteristic way, vulcanite dentures shrank continuously over the period of the study, while the epoxy resin dentures swelled. Acrylic resin dentures had greater distortion if the wax pattern were thin than if it were thick. Dentures processed at higher temperatures also had greater distortion. Values ranged from 0.06% to 0.97% for curing contractions observed after one day's storage in water.

When remeasured, seven of the sixty-three dentures had changed by not more than 0.05% in molar-to-molar measurement. Flange-to-flange values ranged from 1.27% expansion to 0.74% contraction. Cold-cured acrylic resins and epoxy resins

were the most accurate initially, with the injection moulded and vulcanite dentures being least accurate.

Changes in occlusion were observed and controlled by remounting and occlusal equilibration before issuing the dentures. A rating was assigned to each denture at each review for stability of occlusion in centric and eccentric positions. Retention and stability were also assessed and a numerical rating assigned for each.

The condition of the tissues supporting the dentures was appraised according to colour, consistency and mobility. A pressure indicating paste was used to disclose fit of the dentures and areas of heavy contact.

The patients and one of the authors adjudged the serviceability of each denture overall. There was little correlation between the opinion of dentist and patient regarding serviceability, and no correlation between the condition of the supporting tissues and the patient's opinion. All of the dentures had deteriorated in stability, retention and serviceability, although there had been little change in the dimension of the dentures. Patients' ability to accommodate to changes resulting from residual ridge resorption and the gradual nature of this change allowed it to go on unnoticed by them. In only four of the sixty-three dentures in this study did the condition of the denture supporting tissues improve.

The decline in adaptation of the dentures was seen most clearly when tested with pressure-indicating paste. Although the indicating paste patterns demonstrated good adaptation when tested in the first twelve months, over the following five years a deterioration in fit was seen. The greatest discrepancy in the dentures themselves was an expansion of 0.35 mm (0.0014 inch), so that the deterioration in fit was the result of change in tissue contour.

It is clear from the results of this thorough and well-recorded study that

1. dentures may be made of a variety of materials and by a variety of methods and may be suitable clinically when issued but
2. although the dentures may fit well for the first twelve months, a continuous decline in fit will occur in most cases. The information provided seems to emphasise the need to review and adjust dentures regularly.

4.11 Atkinson and Grant²⁵ reported in 1966 on experiments carried out on heat-cured acrylic resin, to study the behaviour of this resin during curing. Samples of resin dough were packed into hard glass Petri dishes, with thermo-couples embedded in each sample at the edge, midway to the centre and at the centre so that temperatures at differing sites could be recorded during polymerization.

Resin samples were heated in a pressure chamber in

water-bath at 75°C and 690 kPa (100 lbf/in²). A gradual rate of heating of the dough was observed at first until a sudden rise in temperature indicating the beginning of the exothermic curing reaction was seen, initially at the centre of the mass and soon after in the periphery. This was taken to indicate that the polymerization reaction had begun at or near the centre of the resin sample.

When the water-bath temperature was raised to 100°C the more rapid increase in dough temperatures produced an exothermic peak at the periphery of the resin sample before the central part had been heated. If the polymerization procedure was interrupted by filling the pressure chamber containing the mould with ice-water, the dough was seen to be firm at the edge but soft in the centre, confirming that polymerization had commenced at the periphery.

These experiments demonstrate a difference in the polymerization reaction of heat-cured acrylic according to the rate at which the dough was heated. Slow heating caused the exothermic reaction to commence at the centre of the resin mass. Rapid heating caused the reaction to commence at the periphery and move inwards, causing a build-up of heat at the centre. The higher temperature in the centre of the mass caused porosity unless high pressures of the order of 690 kPa (100 lbf/in²) were applied.

Although the authors did not state this, it would seem that the experiments supported the concept that gaseous

porosity was the result of boiling of acrylic monomer and could be prevented by slow application of heat or by pressure polymerization.

The results of these observations on the curing of acrylic may provide some insight into the benefit of elastomeric mould linear in eliminating porosity.

- 4.12 In 1977 J.B. Woelfel²⁶ published a review of techniques and materials used for denture bases, describing the continued acceptance of acrylic resin, its suitability in comparison with polystyrene, epoxy resin, polycarbonate, polyamide and vinyl co-polymers (Luxene).

Injection moulded resins had greater density and toughness but greater dimensional change during processing and they required elaborate equipment. Cold-cured resins were less stiff, less brittle and initially better fitting. However, the presence of free monomer made them more susceptible to dimensional change and solubility. Fluid resins poured into hydrocolloid moulds did not require boiling out of the mould, were easily invested and deflasked but had lower strength and showed poor bonding to acrylic teeth. Vinyl co-polymers were tough but hard to polish and had greater dimensional change in processing.

On the other hand, heat-cured resins demonstrated a small but acceptable dimensional change (about 1%) which was reversed over the first month of service. No complex curing equipment was required and heat-cured resins could be finished readily to a high standard. Of

three million dentures issued in the U.S.A., there were fifty recorded cases of denture base allergy. Heat-cured acrylic resin was seen as being the most acceptable of the denture base materials available.

4.13

The dimensional change seen in heat-cured acrylic resin denture bases after deflasking continues to be investigated. Lorton and Phillips¹³ devised a method for observing dimensional and thermal changes in acrylic resin denture bases during the procedures of relining with cold-cured resin and while the bases were being trimmed by a carbide bur and an arbor band. Metal markers were implanted in the molar regions of experimental denture bases and their separation measured with a travelling microscope. The bases were subjected to a reline procedure while temperature was monitored. An increase of 3°C was observed where the blanks remained in contact with the stone cast, but a greater increase of up to 9.5°C was seen when the dentures were removed from the cast.

As the dentures were cut with a carbide bur, the temperature rose by up to 22.5°C , although the increase was up to 42°C when an arbor band was applied to the peripheries. As the cutting surface approached the thermo-couple, this temperature rose by up to 100°C . The denture bases were placed in a water-bath for six minutes at varying temperatures up to 100°C , and dimensional change was noted. They were measured again after storage in water for 24 hours.

Changes of 1.1 to 1.4% were detected in the separation of the metal markers.

It was evident that significant distortions can be introduced into the acrylic denture base by cutting and finishing procedures; further distortion can occur when self-curing resin is added to a processed denture base. Stresses set up in the bases during processing and during finishing procedures can produce distortion if the dentures are subsequently exposed to temperatures near 100°C.

- 4.14 Halperin³ has suggested cast aluminium as a denture base material; compared with acrylic resin it is harder, dimensionally more stable and has three times the tensile strength. Thermal conductivity of aluminium is high and corrosion can be controlled, e.g. by anodizing.

The author described testing of aluminium bases by measuring processing errors. The discrepancy between cast and denture base in the mid-palatal region was up to 0.50 mm for the acrylic and 0.01 mm for aluminium. Comparison using the Surface Meter developed by Eder⁵³ showed aluminium to fit best. A comparison of the force required to dislodge denture bases of various materials was also made. Aluminium bases required 7.02 kgf while Ticonium required 5.98 kgf, porcelain 6.01 kgf, cold-cured acrylic 5.85 kgf, and heat-cured resin 5.57 kgf. In a test of deformation during loading, the metal bases were on average 8.5 times stiffer than acrylic.

Aluminium compared favourably with acrylic in all of its physical properties. This study did not make any reference to biological compatibility, however, and long-term tolerance tests would have to be carried out before it could be widely accepted. Furthermore, the ability of acrylic resin to be repaired and rebased by simple procedures gives it a clear advantage in the management of continuous alveolar resorption in the edentulous patient.

CHAPTER 5: POUR TYPE RESINS

The technique of pouring a slurry of denture base material into a hydrocolloid mould was developed as an alternative to the gypsum investment method of processing and its advantages have been stated as "faster curing, simpler mould construction and easier deflasking"⁴⁸. The waxed denture is sealed in the base of the flask. Agar duplicating material is poured over the denture and the flask filled. The model is removed when the agar has cooled, the wax is removed from the model and from the teeth, which are then replaced in the mould. Sprue holes are cut through the agar, so that the fluid resin may be gently poured into the mould. Polymerization is carried out in a pressure vessel at about 200 kPa (30 lbf/in²) for twenty minutes. No heat is applied (Fig. 1.3).

The cured denture separates easily from the mould, and the model may be resealed on the articulator to identify and eliminate occlusal error. Removal of the sprues and final polishing are the only finishing steps necessary provided the wax-up is accurate.

5.1 Shepard²⁷ reported in 1968 on the clinical application of a pour-type resin. A series of fourteen thousand dentures had been processed with this material and its advantages were seen as:

1. Greater accuracy than conventionally invested, heat-cured resins
2. Elimination of difficult steps in investment

and mould preparation

3. No need for expensive or complex processing equipment
4. No movement caused by expansion of gypsum investment during flasking
5. Reduction of time in deflasking and finishing.

The problems which had been encountered over a two year period were occasional loss of vertical dimension observed when the casts and dentures were remounted, and the occurrence of voids or air-inclusions in the denture base. Movement of the teeth was restricted because of the adhesive properties of the hydrocolloid investment.

Although this report was largely favourable, the problem of loss of vertical occlusal dimension is difficult to correct. Remounting and grinding will eliminate the premature incisal contact usually occurring as a result of this loss, but aesthetics will often be compromised. Furthermore, there is a reduction in occlusal height overall as a result of the grinding procedure.

There was no appraisal of clinical fit of these dentures in this study although later investigations have found the pour-type resins to be satisfactory and dimensionally stable²⁶.

- 5.2 Goodkind and Schulte²⁸ carried out a laboratory study on the dimensional accuracy of pour-type acrylic resin, to compare it with conventional dough-type cold-cured

resin. A measure of the dimensional accuracy was made by observing changes in separation of index markings on the denture bases in the tuberosity region and in the incisive papilla. These index markings, made in the surface of the Invar alloy master die, were reproduced in the duplicate stone casts on which the resin bases were processed. A Nikon optical comparator was used to measure the distance between the markings on the steel die and on the base plates.

Fifteen base plates of each type of resin were made. Measurements were taken shortly after deflasking and were repeated after six months' storage in water at room temperature. Results range from 0.11 to 0.39% shrinkage for the pour-type resin and from 0.10 to 0.26% for the dough-type resin. The repeat measurements after storage showed a small further change in dimension, usually reducing the distortion.

The authors concluded that although both resin types produce bases which shrink after deflasking, the dough-type resin is marginally more accurate. In addition, the authors felt that changes in dimension of this order would be difficult to detect clinically, and therefore that either material was quite satisfactory with regard to dimensional accuracy for clinical use as a denture base resin.

- 5.3 In a further study of pour-type resins²⁹ Winkler, Morris, Thongthammachat and Shaw compared the effect of two types of investment, reversible hydrocolloid and alginate, on dimensional accuracy. Steel pins were

embedded in the tuberosity region of an edentulous cast to provide index markings for measurement of dimensional change. The separation of these markings was observed at deflasking and again after 72 hours, one week and 30 days, the casts being stored in distilled water at 72°F (22°C).

Upon deflasking, the shrinkage ranged from 0.20 to 0.25 mm, increasing after one day to 0.55 - 0.57 mm, and then generally decreasing to 0.46 mm at 30 days.

The latter part of this study investigated occlusal accuracy of the pour-type resins, using a split-cast remount technique to observe change in height of the occlusal plane after processing. This proved to be of the order of 0.05 to 0.10 mm shrinkage in the incisor region and 0.19 to 0.30 mm shrinkage in the posterior occlusal table.

It would seem clear as a result of this study:

1. that dentures processed from a fluid resin will demonstrate occlusal prematurities in the incisor region; elimination of such prematurity could compromise the aesthetics of a denture where reduction of the incisal edges was required, and
2. that adaptation of pour-type resin denture bases would be clinically satisfactory, being similar to the adaptation of the heat-cured and dough-type cold-cured resins.

The study does not indicate the nature of the discrepancies of adaptation of the bases, however, as linear measurements do not indicate areas of greatest distortion.

- 5.4 Antonopoulous³⁰ reported in 1978 on dimensional and occlusal changes in fluid resin dentures. A series of twelve technique dentures and ten clinical dentures were constructed using the pour-resin method, and were compared with a series of five heat-cured clinical dentures. Measurements of molar-to-molar linear dimensional change were made using a travelling microscope, while comparisons of tooth height were made using the remount and dial guage procedure. A Ney surveyor was adapted for this purpose. The dentures were observed at intervals of one week, one month, two months and three months after processing.

Dimensional changes observed were about 0.66% contraction initially upon deflasking but this distortion was seen to have decreased to approximately 0.40% at the end of the third month. In comparison, the heat-cured laboratory dentures demonstrated a shrinkage of 0.44% upon deflasking.

Additional shrinkage was observed after the dentures were polished although distortion of the dentures decreased by at least half during the period of storage in water.

Tooth movement of the pour-type resin dentures was characteristically toward the cast, ranging from zero to 0.24 mm. The dentures were replaced on the split-cast mountings and routine occlusal refinement was carried out. Reduction of vertical dimension was less than 0.50 mm.

All of the heat-cured dentures demonstrated tooth movement which increased vertical dimension by 0.012 mm to 0.020 mm, the mandibular dentures demonstrating virtually the same increase as the maxillary group.

All of the clinical dentures were felt by patient and dentist to be of similar fit, retention and comfort.

No statement was made of the method of assessing the clinical effect of the inaccuracies measured, although the author felt that the adaptability of the soft tissues could conceal such inaccuracy. The pour-resin technique was held to be a satisfactory method of processing dentures where the remount procedure was used to eliminate occlusal inaccuracy.

CHAPTER 6: ELASTOMERIC MOULD LINERS

The moulds in which acrylic and other resins are cured may be lined with elastomeric materials. Many of the advantages of the pour-type resin technique are incorporated, and some of the disadvantages eliminated. The method is suitable for heat-cured and cold-cured acrylic resins, and reports of investigations are presented.

- 6.1 Marcroft, ten Cate and Hurst published their report in 1961 on the use of layered silicone rubber moulds³¹. One hundred and six dentures were processed against a silicone mould liner, and some properties compared with a control group of fifty dentures processed in gypsum moulds. While some of the control dentures were trial packed, those in the test group were not.

Denture teeth are not held so firmly in the elastomeric investment as they are in a gypsum mould, so that teeth are readily removed from the mould liner during trial packing. Therefore the trial pack stage is omitted by some laboratories.

Incisal pin height was measured before and after processing as an index of occlusal vertical dimension. Some test group dentures were processed in an all-silicone mould while a mould liner in a gypsum cope was used for the remainder. A vent was cut into each flask to allow release of excess resin during packing.

The dentures were processed in cold-curing resin,

being held in the flask for at least two hours. Mean vertical occlusal change for the all-silicone invested dentures was 0.56 mm, for the silicone mould liner 0.14 mm, for the test packed gypsum-invested dentures 0.65 mm, and for the non-test packed specimens 0.70 mm. A clear advantage for the silicone-lined mould is evident.

The authors identified other advantages and applications. A duplicate denture was readily made by re-using the cope and investing a duplicate cast. A second set of teeth of the same-mould and shade could be placed into the elastomeric mould and the duplicate denture processed. A tin foil substitute is not required, contamination of the bond between teeth and denture base does not occur. Porcelain teeth are protected during deflasking. Split-casts are readily remounted for adjustment. The deflasked denture is free of gypsum, accurately reproduces the wax contour and is readily and simply finished.

The authors reported that they had carried out a pilot study using a heat-cured resin, but gave no details.

- 6.2 A series of tests of heat-cured acrylic resin samples processed in different mould liners and subjected to various laboratory misuse was carried out by Molnar, Gruber and Sawyer, and the results reported in 1968³².

In this study, reproducible dumb-bell-shaped specimens 50 mm long were fabricated with clear heat-cured acrylic resin. All were processed in a stone mould, the test specimens having silicone liners and the control specimens having alginate mould lining. Specimens were polymerized by plunging the flasks into boiling water for one hour. In further tests the resin was misused, being contaminated with water, or by the addition of excess monomer or by exposure of polymer to 100% humidity for three days before packing.

In all tests, those specimens packed in silicone mould liners were clear, but those packed in alginate-lined moulds had cloudiness, porosity and voids. The authors felt that these results did not consolidate existing theories on internal porosity in denture base resins; they do support the effect of elastomeric mould liners in reducing or eliminating porosity, however.

6.3 This effect was examined in greater detail in apparatus designed by Harcourt, Lautenschlager and Molnar³³. In the tests resin was processed in a steel cylindrical die 79.4 mm high and having an internal diameter of 25.4 mm which had a gypsum base at one end and a movable steel plunger at the other. Thermo-couples were embedded in the resin dough and a manometer recorded pressure during curing of the resin. Curing was carried out at different temperatures and under different pressures; silicone discs of 5.6 mm, 3.0 mm and 1.6 mm thickness were interposed between the stone and the resin at the end of the curing chamber and another series of curing cycles

was carried out.

It was seen that porosity occurred where a rapid rate of heating or a high temperature cycle was used, so that temperatures above the boiling point of the monomer were reached. The monomer boiling point could be elevated by increasing packing pressure, but the volumetric contraction during polymerization relieves the packing pressure, allowing monomer to boil. Silicone mould linings would act as a pressure reservoir to maintain pressure generated during packing, and would also increase the pressure in the mould by virtue of their own high thermal expansion. Discs of silicone as thin as 1.6 mms suppressed porosity.

This accurate and well designed instrument provided significant information into factors involved in the production of porosity-free methyl methacrylate resin.

- 6.4 Feldman and Jameson reported in 1970 on the use of a silicone elastomer as a mould liner³⁴. A full denture relined impression was cast in gypsum, silicone mould release (Silastic 388 Denture Release) was painted over the denture to a thickness of at least 5 mm, and the remainder of the mould poured in gypsum. The mould thus formed was suitable for a standard heat-cured relined, and could also be used for the addition of a silicone semi-permanent soft denture liner.

The report described application of this technique in the addition of the elastomer Silastic 616 Oral Cure

Liner to a denture base; the authors further stated that the cast and mould were retrieved after deflasking so that a duplicate denture could be made, to be worn while repair or relining of the first denture was carried out.

This method of investing a relined impression is now in common use. Heat-cured relining may be carried out in this way with little loss of accuracy of occlusal relationship.

- 6.5. A study measuring the fit of denture bases to the casts was reported by Reisbick in 1971³⁵. Twenty duplicate casts were made from a rubber mould and baseplates of even thickness constructed on these. Ten were invested in gypsum and ten in gypsum with a silicone mould liner. These were packed with dough and cured at 75°C for nine hours.

The deflasked bases were left on the casts and sectioned at two standard reference planes, 15 mm and 25 mm, from the posterior border. A comparison of fit was made by measuring the separation of base from casting using a travelling microscope. Silicone-lined moulds provided a statistically significant improvement of fit, the average discrepancy at the ridge crest being 0.26 mm for stone and 0.20 mm for the silicone-lined mould.

A further series of test dentures was constructed to enable comparison of the surface of the dentures processed in a silicone mould with those processed in stone moulds. Half of each waxed denture was therefore coated with the

A brass test die was constructed (Fig 6.1) to enable observation of changes in thickness, Rockwell hardness and reproduction of surface detail; a series of fine grooves was machined into the surface of the test die, and flanges were added to its edge to simulate the peripheries of a denture base. The die formed a pattern which was invested by each method and resin replicas were fabricated.

Results showed significant changes in thickness of the samples, an increase in the central area and a shrinkage of the flanges. The increased thickness was greatest for pour-type resin, amounting to 0.05 mm (15%) in a 3.22 mm section, compared with 0.04 mm (1.1%) and 0.02 mm (0.6%) for silicone and gypsum respectively. Shrinkage at the peripheries was 0.06 mm (2.5%) for silicone, and less than 0.01 mm (1.25%) for pour resin and stone investment.

The authors measured surface hardness before and after polishing, and found the samples processed against silicone to be harder than those processed against stone; Rockwell hardness numbers were 108 and 85 respectively (Scale not specified). Hardness tests carried out after polishing gave higher values. Stone moulds reproduced better detail than silicone although detail to 0.025 mm was reproduced by the silicone.

The authors believed that a clinical trial of silicone-invested dentures was warranted, based on the results of these measurements, to include recordings of dimensional stability.

6.7 Zani and Vieira³⁷ used a silicone compound to invest the upper half of a series of test dentures for processing with a heat-cured acrylic resin; changes in the separation of pins set into the mesial marginal ridges of the upper first molars and the incisal edges of central incisors were measured by travelling microscope. A shrinkage of 0.1 mm to 0.3 mm was noted, which was little different from the shrinkage seen for gypsum investment and alginate-based mould liner.

The authors processed acrylic blocks, 40 mm x 20 mm x 8 mm, in silicone-lined moulds, and compared surface smoothness with that of blocks processed against alginate and tinfoil mould linings. The surface processed against tinfoil was adjudged smoothest, there being no significant difference determined between surface smoothness given by alginate-lined and silicone-lined moulds. The facilitation of flasking and deflasking procedures led the authors to promote use of the silicone mould lining.

6.8 Maineri, Boone and Potter³⁸ determined accuracy of fit gravimetrically. A series of technique full dentures was made using a silicone mould liner technique and compared with those made in all-gypsum moulds. Assessment of fit was made by taking a relining impression of the master cast in each denture, using a standard seating force. The impression material remaining in each denture was weighed, to provide a means of comparing the two groups. No significant difference was

found.

Increase in vertical dimension was also measured. An occlusal key was made to orient the cast and waxed dentures before processing.

Measurement of the vertical movement of this key was made by means of a modified Hooper duplicator and dial gauge. Changes of tooth position produced a more lingual tooth placement for both types of investment, which was slightly greater in the silicone-lined mould group.

The authors supported the use of the silicone mould lining. Errors of fit or occlusion arising from the investment were not held to be clinically significant while the processing was greatly simplified, and wider use of this technique for processing heat-cured and cold-cured acrylic resin was advocated.

CHAPTER 7: MEASUREMENT OF DENTURE BASES

Many workers have devised ways of measuring the fit of denture bases, but there is yet no totally satisfactory method. The difficulties arise when comparisons of contour are made between a relatively inflexible denture base and the soft tissues of the denture bearing area which are readily distorted by the denture base, by the measuring medium and by seating pressure.

7.1 Krogh-Poulsen and co-authors³⁹ identified the problem of obtaining comparable contour lines of the surface of plaster casts, with reference to the plane of the section. They adapted a Hooper duplicating jig to enable alignment of casts. Three anatomical landmarks were identified and engaged by pin markers, so that each cast was oriented in the same plane. A plaster base was then poured to provide an index surface from which a contour could be plotted by means of a travelling microscope, or to enable casts to be ground or sectioned in equivalent planes.

The technique provides information on cast contour, but has limitations. If casts are sectioned or ground, they are no longer suitable for the addition of baseplates, nor can sections be made sagittally and coronally on the same cast.

7.2 Regli and Gaskill⁴⁰ placed electronic strain gauges in denture bases made of acrylic, acrylic with metal inserts and metal, to demonstrate that dentures distort during function.

Deformation of denture bases as measured by the strain transducers was seen to be variable, related to the material of which the denture was constructed, the phase of a masticatory cycle and also to the contour of the denture bearing area. In spite of selection of designs and materials for stiffness in the base-plate there was an outward distortion of lower dentures during swallowing and an inward distortion during chewing.

Accuracy of adaptation of denture bases must be considered in the light of this information, in addition to the adaptation of soft tissues to changes in functional loading.

- 7.3 Fairhurst and Ryge analysed the effect of residual stress in acrylic resin dentures on distortion upon deflasking¹². Measurements were made across the heels of the casts, and photographs taken to compare the fit of denture bases made in moulds lined either by alginate tinfoil substitute or by tinfoil. The authors painted a solvent over the surface of the denture bases, and used the degree of crazing and warping thus generated to indicate the incidence and nature of internal stress within the baseplate.

The burden of this report was the decreased warpage and crazing of acrylic resin denture bases processed in tinfoil-lined moulds, but a subsidiary finding was relevant to the present treatise; the authors found little correlation between linear measurements made across the heels of the bases and the fit of these bases on the metal master die. It was clear that more information than that obtained by simple linear measurements was

needed in order to fully describe and understand the effects of denture base distortion.

- 7.4 Rupp, Dickson, Lawson and Sweeney reported in 1957⁴¹ on a method for measuring mucosal surface contours of impressions, casts and dentures, identifying a dearth of such information. Their device incorporated a pantograph in the form of a parallelogram. Ball shaped pointers, 3.7 mm in diameter, could follow the contour of a surface, an impression at one side and a cast made from it at the other. A gauge gave a record of lateral movement of the pointers while a dial gauge measured vertical differences between the two.

It was important that the cast and impressions be oriented correctly so that equivalent contours were compared. The finite size of the pointer tip introduced an error particularly when comparing vertical surfaces. Vertical differences between cast and impression of 0.013 mm could be measured, however, with an accuracy of lateral movement of 0.25 mm.

When used in a preliminary survey, the instrument demonstrated dimensional changes in heat-cured and cold-cured acrylic resin dentures and related both to the contour of the edentulous cast. Average results for high temperature curing cycles were 0.5 mm distortion compared with 0.2 mm for low temperature curing cycles. The instrument was not destructive in its application and could be used to measure contour changes over a period.

7.5 Szmyd, McCall and Allen⁴² described a method for measuring topographic changes of the maxillary denture bearing area.

Requirements for topographic analysis were identified as:

1. An easily performed accurate procedure for mounting successive dental casts in an identical position.
2. A means of reducing mounting errors.
3. A way of expressing topographic changes in successive casts, for example as a reduction in cross-sectional area.

To this end the authors devised and constructed the "Contourator", in which a central index was designed to fit that part of the maxillary denture bearing area which did not demonstrate continuous residual ridge resorption. A stylus and pantograph device inscribed a contour on transparent paper, and a comparison was made of contour drawn after the index regions were aligned revealed the effects of ridge resorption.

The technique suffers from inaccuracies inherent in pantographic devices from the inertia and flexion of the tracing arm, lack of concentricity of the stylus and the shape of the stylus head. Accuracy of the "Contourator" was claimed to be 0.8%, however. While this technique may be applied to observe the progress of ridge resorption it may not be used to compare casts and denture bases, as distortion of the bases occurs

in the central palatal area, which would preclude the use of this area as an index.

- 7.6 Linear measurements have often been used to assess dimensional stability of denture bases. Mowery, Burns, Dickson and Sweeney⁴³ determined the distance between cross marks on stainless steel pins cemented into the molar teeth of acrylic resin dentures, using a travelling microscope. The information formed the basis of a comparison between heat-cured and cold-cured dentures polymerized in gypsum moulds, and recordings were made before investment, after removal from the cast and then at 30 day intervals.
- Results of this survey supported those seen elsewhere^{24, 26, 53}; heat-cured dentures demonstrated greater distortion initially but had improved in fit after 30 days, while the fit of cold-cured dentures deteriorated with time. Linear measurements of this kind are made quite quickly and accurately and do not change the denture contour. They give an indication of the occurrence and degree of change in denture contour but do not identify the sites of distortion nor of its consequence. In this survey, as elsewhere, no correlation was found between the patient's appraisal of the fit of the denture and the measured change in size of the denture base.

- 7.7 Ryge and Fairhurst⁴⁴ identified the limitation of the travelling microscope method of "assessing dimensional accuracy of denture bases" when they reported in 1959 on the design and application of a Contour Meter.

This device was a two-dimensional plotter, in which a stylus was constrained to move on two trolleys aligned at right angles to each other. The denture base could be moved vertically and rotated, so that contours might be plotted in parallel sections or in more than one plane. Casts were oriented in a mounting index by a tripod to ensure that sections were made in comparable planes. The authors noted the necessity for a correction factor where the surfaces plotted were not perpendicular to the stylus, since it had a ball-shaped tip. Readings were inaccurate or unobtainable in vertical or undercut regions of dentures or casts. This limitation applies to all systems which use a stylus, and is unfortunate since the areas of the denture base where distortion is greatest are those nearest the direction of the path of insertion. An area of frequent pressure irritation seen by clinicians and readily demonstrated with indicator paste is the buccal surface of the tuberosity region.

- 7.8 A subsequent report from the same authors⁴⁵ gave the results of contour plots carried out using the Contour Meter on ten technique dentures made on duplicated casts. Comparisons were made amongst dentures processed from an ordinary powder-liquid acrylic resin dough, both by normal compression moulding and by the Hydrocast technique, from a predoughed gel by injection packing (Tilon) and from an injection moulded high impact polystyrene (Jectron). Contour Meter readings were plotted immediately upon deflasking and then at intervals of ten days, one month and one year, the denture bases

being stored in water at 37°C for this period.

Results of this plotting technique supported the general trend, recording changes in contour of 0.1 to 0.4% initially followed by an improvement after one month's storage in water. Demonstrating that more information was given by this two-dimensional plot than by linear measurements, the authors observed an improvement in fit in the midpalatal region. Successive plots of one denture showed a decrease of the discrepancy at the post dam from 0.38 mm to 0.27 mm after one month.

- 7.9 Anthony and Peyton⁴⁶ modified the National Bureau of Standards comparator, as used by Rupp et al⁴¹, by substituting a level glass plate for the master die, and adding a dial gauge of greater range to the second arm of the machine. Provided the plane or surface below the second arm had been indexed and oriented correctly, a plot of its contour could be drawn up to enable graphic comparison of impressions, casts and denture bases.

Index markings made on the surface of the master cast were reproduced in the duplicate casts and in baseplates. A mounting tripod engaged these markings while a base was poured below each cast or baseplate to be surveyed. In this manner the casts and baseplates were correctly oriented in the comparator. Measurements of contour were plotted at 0.64 mm (0.025 inch) intervals, and baseplates were plotted at 37.8°C to give contours near body temperature.

When contour plots were compared, it was seen that heat-cured denture bases had discrepancies of about 0.5 mm at the flanges and 0.2 mm in the palatal area. Statistical analysis of readings given by this device indicated its accuracy to be around 0.03 mm.

- 7.10 In order to observe the clinical significance of denture base distortion, Woelfel and Paffenbarger subjected a denture which had been worn comfortably for nine months to a series of procedures designed to distort the base and worsen the fit⁴⁷. The degree of distortion was indicated by the fit of the denture on a cast made inside it before the procedures commenced, and also by recording changes in molar-to-molar width.

The authors made the following observations:

1. Molar-to-molar shrinkage from wax-up to finishing was less than 0.4 mm.
2. Heat treatment at 82-85°C for 30 minutes produced no appreciable change.
3. Boiling the denture for 30 minutes introduced a shrinkage of 0.51 mm molar-to-molar and 0.33 mm flange-to-flange.
4. The denture remained serviceable after the boiling phase, although it was possible to disclose areas of pressure on the tissues by use of marking paste.
5. The areas of pressure decreased in size over a 24 hour period.
6. Further boiling produced no further measurable change in dimension.

7. The denture warped further by investing it in plaster, boiling the whole and then cooling it rapidly.
8. Distortion of the order of 0.9 mm contraction across the flanges was then measured, and this was discernible by the patient. The denture at this stage did not fit the cast which had been poured into it before the distortion was carried out.

Significant aspects of this elementary test were the continued acceptability of the denture to the patient and rapid adaptation of soft tissues to this dimensional change. Of some consequence to present day techniques of reprocessing of acrylic resin denture bases was the distortion produced by subjecting the denture to investment, boil-out and rapid cooling. When one considers the effect of exposing denture bases to resin monomer and subjecting them to packing pressures during "double curing" it is not surprising that distortion of the bases of clinical significance results.

7.11 A report published by Woelfel⁴⁸ on contour variations of the residual alveolar ridges of edentulous patients illustrates a further method of comparing denture base contours. Although the study was directed towards a comparison of impression techniques, the latter part investigated the dimensional accuracy of the impressions. Using a toolmaker's microscope, the author recorded 100 elevations in a plot of contour between some anatomical land-marks on the casts. The plots were compared by

superimposition. Qualitative data was supported by making direct measurements where greatest discrepancies were noted, at the peripheries and in the vertical zones of the tuberosities. The technique of focussing the travelling microscope on the surface of the cast eliminates the geometric error of a pointer but it cannot produce a plot of an undercut region, as the author has noted.

A subsequent publication by Woelfel, Hickey and Berg⁴⁹ reported on the application of this plotting technique using elevations measured at 0.75 mm intervals, and depicted at a scale equivalent to a ten times magnification. The contours of impressions made of one patient by seven dentists were plotted and compared, to reveal differences ranging from 0.5 mm to 7 mm.

7.12 Atkinson and Johnson⁵⁰ described the use of the "Dento-Contourograph" of Lisowski and the microscope method of plotting denture and ridge contour. The authors identified the central area of the hard palate as a region which is very resistant to change. A cast of this area was used to orient successive casts, and to allow pouring of a base to maintain this orientation. A survey of the cast could then be made by placing it upon a measuring table below an overhead traveller which in turn supported a vertical micrometer. Heights were surveyed at 2 mm intervals to provide a plot of the cast contour. Maximum variation between successive contour readings was 0.1 mm.

This study illustrated another method of making comparable contour surveys of casts made of one patient over a period. Because correct orientation of the casts is dependent on the constant contour of the central palatal region, the technique is not readily applicable to surveying baseplates under the same conditions.

The authors have illustrated the reproducibility of contour plotting in the recording of denture contour, however, and the principle of micrometer and overhead traveller has been applied in the present study.

- 7.13 Bruce observed changes in contour of edentulous ridges during tissue conditioning⁵¹. Analysis of contour was carried out in this instance by use of a pantograph. As the investigation was of the general change in contour the author did not attend to accurate orientation, other than to ensure that the sections plotted passed through the same anatomical landmarks.
- The casts were also sectioned and the sections compared with the contours produced by the pantograph. The two groups of contours did not coincide exactly, the differences being attributable to errors of orientation and inertia in the pantographic tracing device. However, the report indicates that qualitative information may be readily obtained by comparing pantograph tracings such as these.

- 7.14 Carlsson described the application of the Zeiss comparator⁵² to plotting cast contours. Casts were

oriented by observation of the highest points of the maxillary tuberosity and the ridge crest in the incisive papilla. The cast orientation was adjusted until these points were in the same focal plane. By moving the eyepiece along its traveller and re-focussing, a series of co-ordinates could be drawn up and plotted graphically to depict cast contour. The plots produced in this way were extremely accurate (Carlsson⁵² has stated the order of accuracy to be 0.05 mm), and did not disturb the surface of the cast, but the method is extremely time-consuming.

This method is not applicable to observations of denture base contour because of the difficulty of obtaining reliable and accurate orientation of the plane of section.

7.15 As has been noted earlier, aluminium has been proposed as an alternative material to acrylic resin. Barsoum, Eder and Asgar⁵³ compared the accuracy of fit of cast aluminium bases and acrylic resin bases. They used a device, developed from a milling machine, which traced the surface contours of a series of five bases made from each of the three materials, cast aluminium, cold-cured acrylic resin and heat-cured resin. A mounting guide similar to that of Anthony and Peyton⁴⁶ was used to standardize orientation of these bases.

In this experiment, the best fit was obtained by the cast aluminium bases, and the cold-cured bases fitted better than the heat-cured. The authors made no comment

regarding the time factor in their observations, although it is presumed that aluminium would be more stable in the long term than polymeric materials. The application of metals or alloys to denture base fabrication is not without difficulty, however, as the inability to reline or repair them may negate any advantage in strength or dimensional stability.

The measuring device applied in this instance gave accurate and reproducible data, although the examination of denture contour was carried out in selected areas only.

- 7.16 In order to appraise denture base stability other than from the aspect of stability of contour, De Furio and Gehl⁵⁴ devised and built a machine for measuring the force required to unseat maxillary dentures made of different materials. In this clinical study, trial denture bases were made of cast cobalt-chromium alloy, cast aluminium, cast gold alloy, and acrylic resin. The method of curing the acrylic resin was not stated here, and might have been significant. Twelve denture bases were made with a series of hooks placed in corresponding positions so that loads could be applied to the denture base via a series of levers passing outside the mouth.

Cobalt-chromium gave the highest readings for retentiveness as measured in this test, then aluminium, acrylic resin and gold alloy. The authors stated that duplication methods for each fabrication technique could have

resulted in different denture contours. The experiment did seem fraught with possible errors, although the concept of clinical testing was relevant. Results of this investigation might have been of greater value had a contour plot been made for each denture base material.

- 7.17 Yarmand and Gehl⁵⁵ published a report in 1971 on the use of a pressure-formed thermosoftened denture base blank for transferring inter-occlusal records. The tooth-bearing section of the dentures was added to this blank with heat-cured or cold-cured resin.

The authors plotted the contour of the cast and denture base by using a dial gauge mounted on a stand which could be traversed by a micrometer screw. The dial gauge spindle moved in the horizontal plane. Orientation of the cast and base was carried out by mounting each on a tripod, the latter engaging three steel balls which had been embedded in the cast and had produced an indentation in the baseplate.

The contour readings thus derived were superimposed on plotting paper and differences measured. Comparisons between denture base and cast surface were made after deflasking the denture and then after storage in water at 37.8°C for three months and six months. A statistical analysis of five regions of the bases was made, a small improvement of fit being noted after six months. There was no attempt to register or rate the clinical fit of dentures made in this manner, although they were stated

to be of satisfactory fit. Mean dimensional change was 0.16 mm, with a standard deviation of 0.01 mm.

- 7.18 In 1972, Atkinson and Johnson reported on a modification of their earlier apparatus⁵⁶, to include a circular spirit level in the cast orienting device. This was set into the palatal alignment key or "frog" at the time of casting the first model; successive casts were aligned to the same orientation before mounting on the surveyor by adjusting the cast base to reproduce the same level as that of the initial cast.

This technique was used to examine and compare long term changes in ridge contour. The use of the spirit level and "frog" device produces a simple and reliable alignment for cast plotting as applied in this technique. The use of the overhead bar and micrometer gauge to plot cast contours is accurate but time-consuming. Furthermore, the problem of plotting undercut areas had not been solved.

- 7.19 Schoenmakers⁵⁷ reported on his method for optical determination of dimensional changes in 1973. The technique was initially used to observe the accuracy of duplicate stone casts of various manufacture made in a silicone rubber mould. Average change in position of ball-bearings embedded in the specimens was 0.021 mm with a standard deviation of 0.003 mm.

The author went on to measure denture bases using the same technique. Linear shrinkages of 0.050 to 0.080 mm were observed when the dentures, made of heat-cured

acrylic, were measured one week after deflasking. A secondary observation was that the stronger or harder investments allowed less dimensional change of the dentures.

7.20 Measurements of changes in contour in one plane have limited clinical implication. De Gee, ten Harkel and Davidson⁵⁸ devised a system of measurement involving four points on a denture base, so that a more accurate assessment of distortion could be made. The contour of the denture base can be described by the lengths of the sides of a pyramid whose apices were at the incisive papilla, the crest of each tuberosity and the centre of the palatal vault.

After dimensions of the pyramid were measured, a computation could be applied to these values to produce a direct percentile value for dimensional change. The technique was used to compare a series of denture bases processed by various methods and stored in air or in water.

The mathematical analysis of the dimensional changes recorded in this way gave results similar to changes recorded by other means^{28,50,53}. The dimension of the height of the palate was seen to be a sensitive index of accuracy of fit. Cold-cured dentures had shrunk by about 0.1% upon deflasking, but continued to change in shape. Heat-cured resins boiled for 20 minutes during polymerization showed a shrinkage of 0.9% after 60 days. The fit of heat-cured dentures improved after storage

in water but all of the dentures distorted when stored dry.

There is a distinct advantage in this method of surveying dentures and casts in that the measurements are readily taken and repeated, the bases are not disturbed or distorted by the measurement and the information may be stored and utilized in the microprocessor. Some of the shortcomings of the linear technique are eliminated.

7.21 Summary of literature:

1. Heat-cured acrylic resin remains as the most widely used and accepted material for denture bases in spite of many alternative materials and techniques⁵⁹.
2. Complex stresses may be introduced into acrylic resin denture bases as a result of polymerization, cooling and water sorption.
3. These stresses may be expressed as distortion upon deflasking, when the effects of finishing procedures and water sorption may make a further contribution towards loss of fit.
4. This distortion is reduced over a period of fifteen days to one month in the case of heat-cured resins, but may be seen to increase slightly in cold-cured resins.
5. The distortions are rarely greater than 0.5 mm across the heels of the maxillary denture base, and are apparently not detectable by denture wearers at this level. When distortion approaches one millimetre, subjects may detect some loss of fit.

6. Studies which quote measurements of distortion to or beyond tenths of a millimetre do not have any clinical significance.
7. Distortion of the occlusion of acrylic resin dentures may occur as a result of investment expansion, tooth impaction during packing, plastic deformation of investment, polymerization contraction and cooling procedures.
8. Occlusal discrepancies may be detected and readily eliminated by the use of a split-cast and remount procedure.
9. The use of a silicone mould lining facilitates investment, processing, deflasking and remount or split-cast procedures. Reduction of finishing procedures decreases distortion otherwise generated at this stage.
10. Linear measurements of distortion of denture bases or tooth movement as a result of processing are not as clinically significant as contour plots and remount procedures respectively for the detection of processing inaccuracies.

CHAPTER 8: THE PRESENT STUDY

8.1 An investigation has been made into the dimensional accuracy of complete maxillary dentures processed in heat-cured acrylic resin, using contour plots of the fitting surfaces.

Contours were plotted in two planes:

1. A coronal plane passing through the maxillary tuberosities.
2. The mid-sagittal plane.

The variables studied were:

1. The effect of using a silicone mould lining compared with a gypsum mould lined with alginate separating medium.
2. The effect of the "double-cure" technique of full denture fabrication. In this method, an acrylic resin "permanent" baseplate is fabricated, used for maxillo-mandibular relationship recording and try-in, then incorporated into the final denture when tooth-bearing sections are processed on to it.

The advantage of this method is the stable and retentive base provided for clinical procedures. Amongst the disadvantages are:

1. The possibility of distortion of the fitting surface of the baseplate when subjected to a second curing cycle during the addition of a heat-cured tooth-bearing section.
2. Because the cast is usually destroyed during the processing of the baseplate, a second cast is usually

poured into it for the purposes of mounting on the articulator and for the addition of the tooth-bearing section.

There have been no studies reporting the effect of either of these variables on the dimensional accuracy of complete dentures using contour plotting methods.

In the present study, denture bases were processed from heat-cured acrylic resin at 70°C and 100°C, in silicone and gypsum moulds, and the contours of their fitting surfaces were plotted. Tooth-bearing sections were added in heat-cured acrylic resin processed at 70°C, and the contours plotted again so that comparisons could be made by superimposition of the plots.

CHAPTER 9: APPARATUS

9.1 Initial contour plots were made with a pantographic tracing device previously used and described by Lechner and Bevan (Fig. 9.1). A significant feature of this device was the jig used for orienting casts and impressions to enable the selection of equivalent contours for comparison.

The jig, illustrated in Figs. 9.2 and 9.3, consisted of a horizontal base carrying three posts on which a cast or denture may be supported. Three stainless steel spheres are embedded in an edentulous impression, one in each tuberosity and one in the incisive papilla region. When it is poured, these spheres become attached to the cast. The posts on the base of the mounting jig are adjusted so that their cup-shaped ends engage the spheres on the cast. One post is fixed while the others may be moved so that they accurately fit the spheres.

The upper member of the mounting jig carries a further three posts which engage the base. A screw-on mounting plate is attached to the upper member, and upper and lower members fitted together. The cast, supported by the base of the jig, may be luted to the mounting plate attached to the upper member of the jig, with plaster.

The stainless steel balls were removed from the master cast to leave hemispherical depressions. When baseplates were processed on duplicates of the master cast, the hemispherical elevations thus produced were fitted into the ends of the rods on the base of the mounting jig.

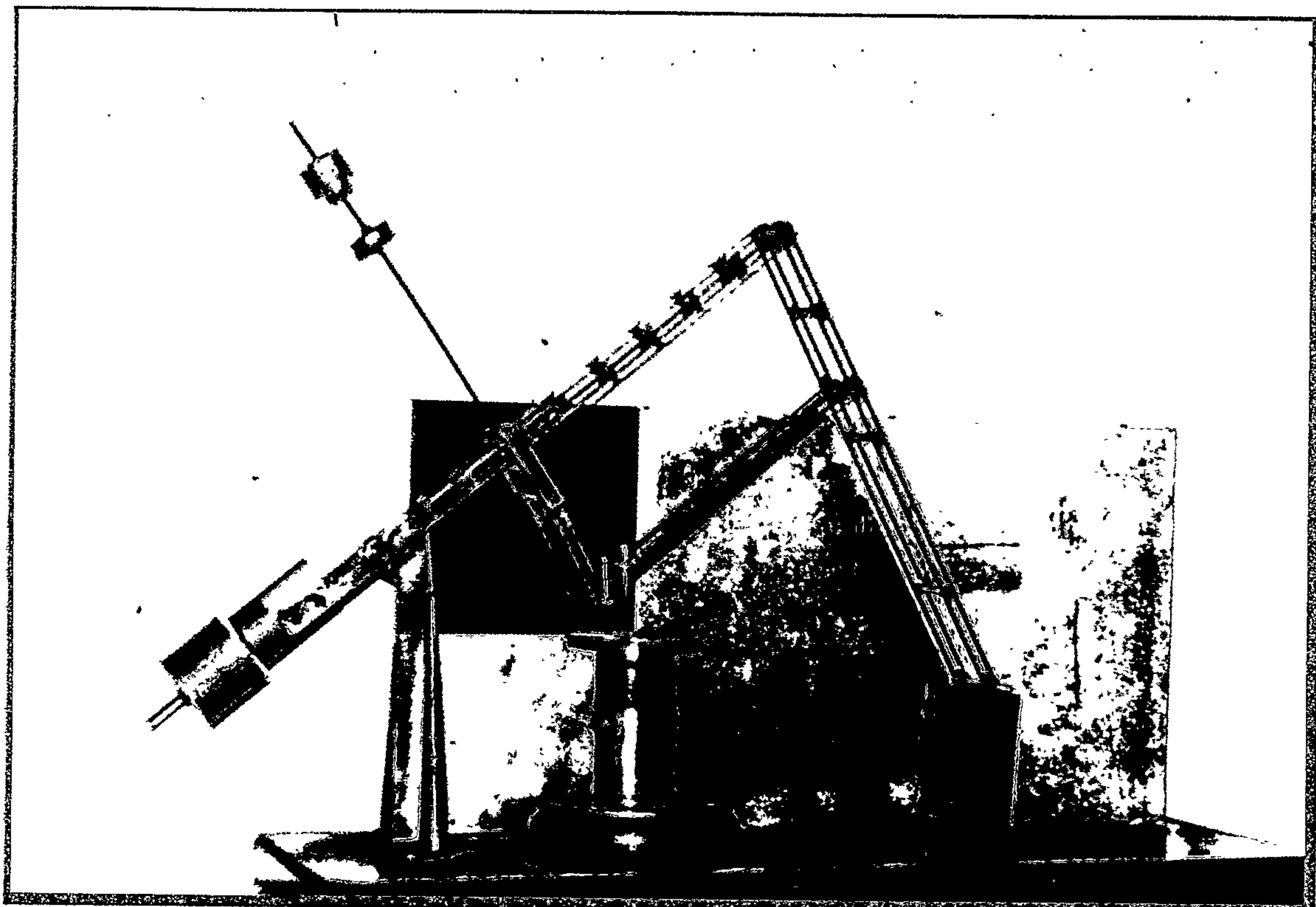


Fig. 9.1. Pantographic Tracer as used by Lechner & Bevan⁶⁰ and in the first part of the present study.

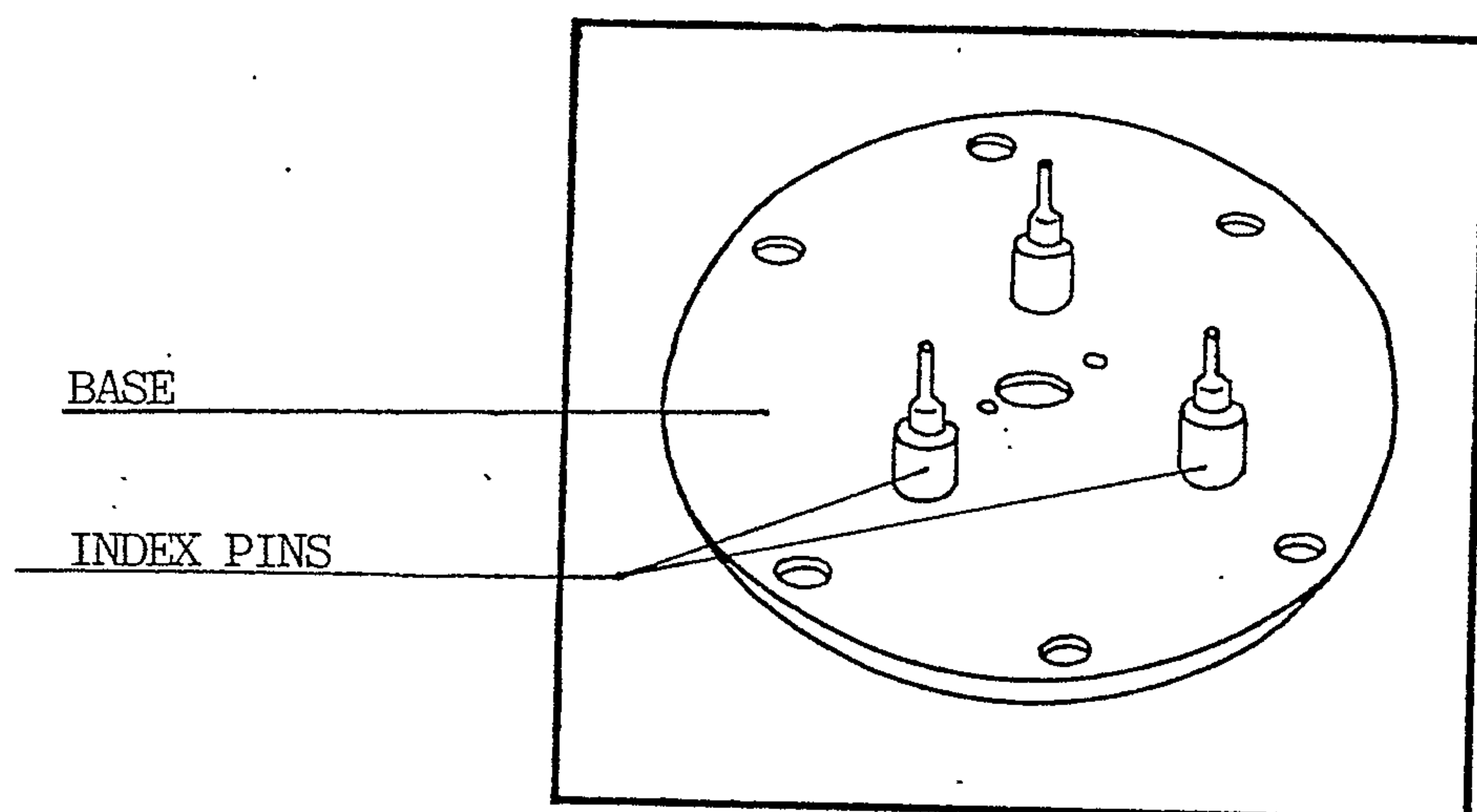


Fig. 9.2.

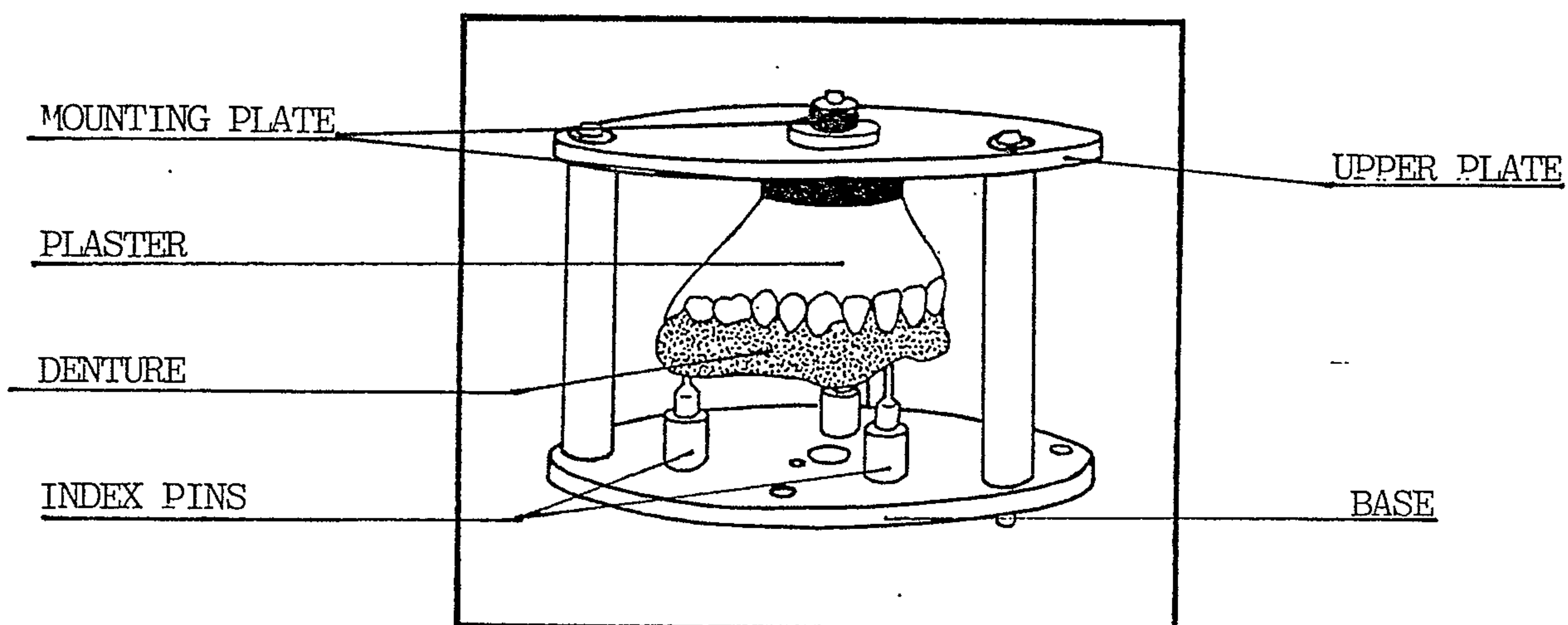


Fig. 9.3.

The baseplates were then luted to screw-on mounting plates with attached cast or denture base placed on the pantographic tracing instrument. A micrometer attachment was used so that the baseplate or cast could be moved in a horizontal plane and rotated to select the desired contour.

As the stylus on the end of the pantograph arm was traversed across the selected contour, a pen mounted on the pantograph traced a plot at x3 magnification. Subsequently tracings could be superimposed for comparison.

A fourth depression was made in the master cast in the mid-palatal region at the post-dam (Fig. 9.4) and produced an elevation on the fitting surface of the baseplate which provided a reference point for the mid-sagittal plot.

9.2 This apparatus was used in a study of 24 specimens prepared as described in Figs. 11.1-11.5). Four groups of specimens were subjected to differing processing conditions and contour plots made. However, when the plots were compared it was evident that experimental errors in contour tracing were too great for reliable comparisons to be drawn. Variations in contour within the groups were as large as those found when different groups were compared.

9.3 To derive a more accurate plot, a more rigid and precise measuring device was developed, based on an instrument previously used by Baetz in a study of the reproducibility

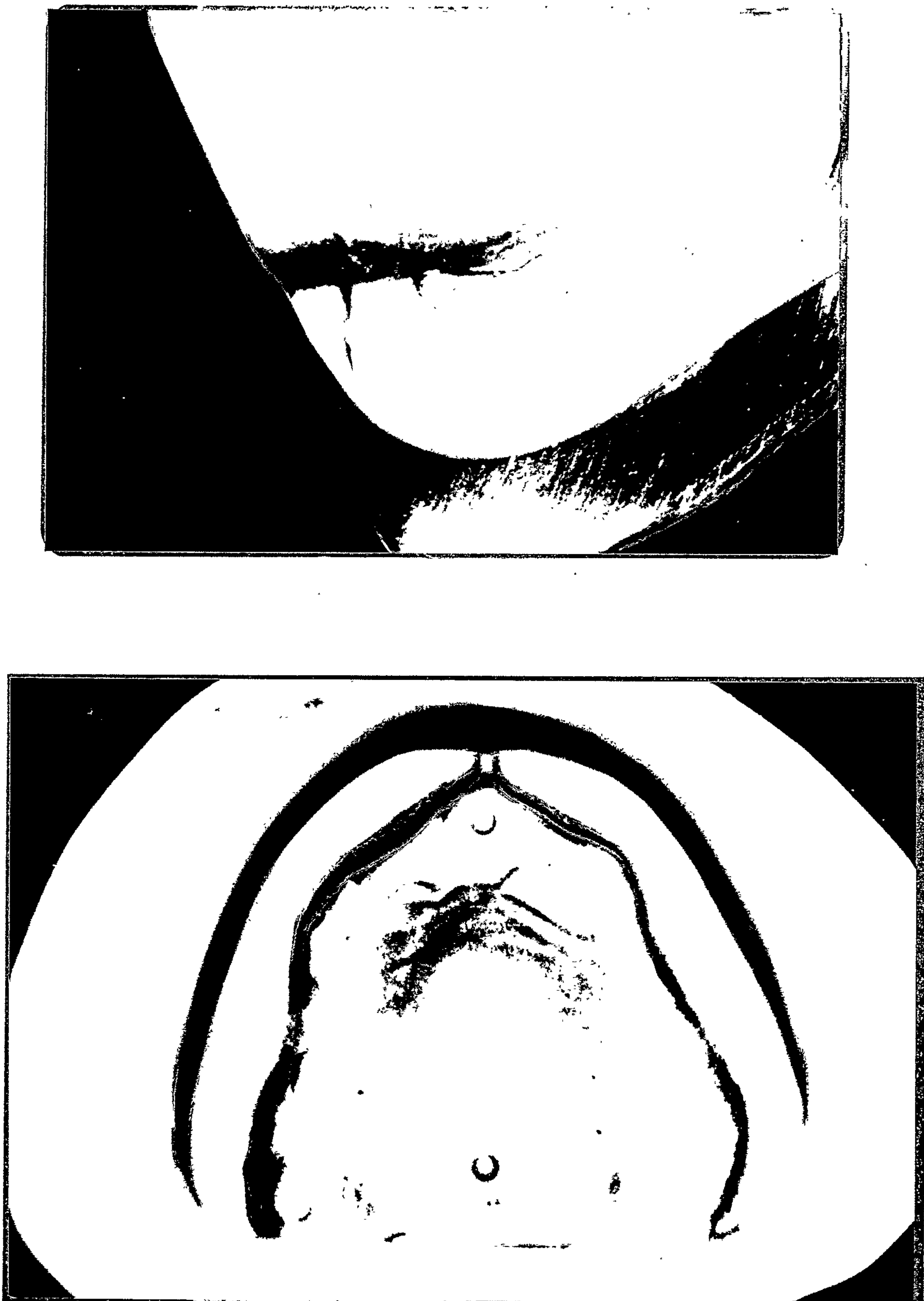


Fig. 9.4. Master mould used for present study, showing reference points in incisive papilla region, mid part of post-dam area and over the tuberosities. Close-up shows reproduction of reference marks in duplicate cast.

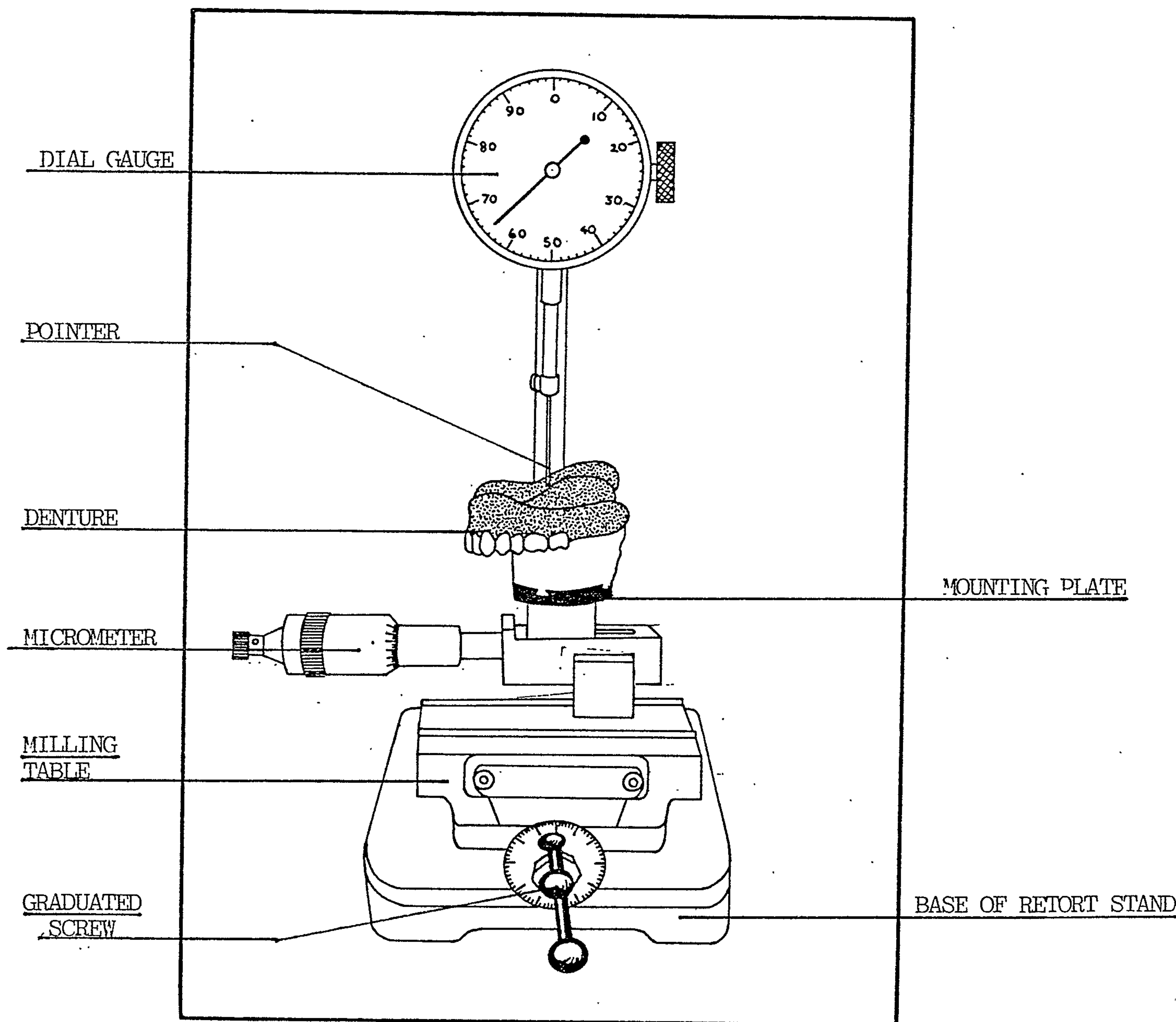


Fig. 9.5. Diagram of apparatus use to derive contour plots.

of stereographic recording methods⁶¹. The table from a milling machine, which could be traversed by a graduated screw, was adapted to carry the mounting plates used by Lechner and Bevan⁶⁰ and by the author in the previous experiments. This incorporated the micrometer screw used to align the cast or baseplate (Fig. 9.5).

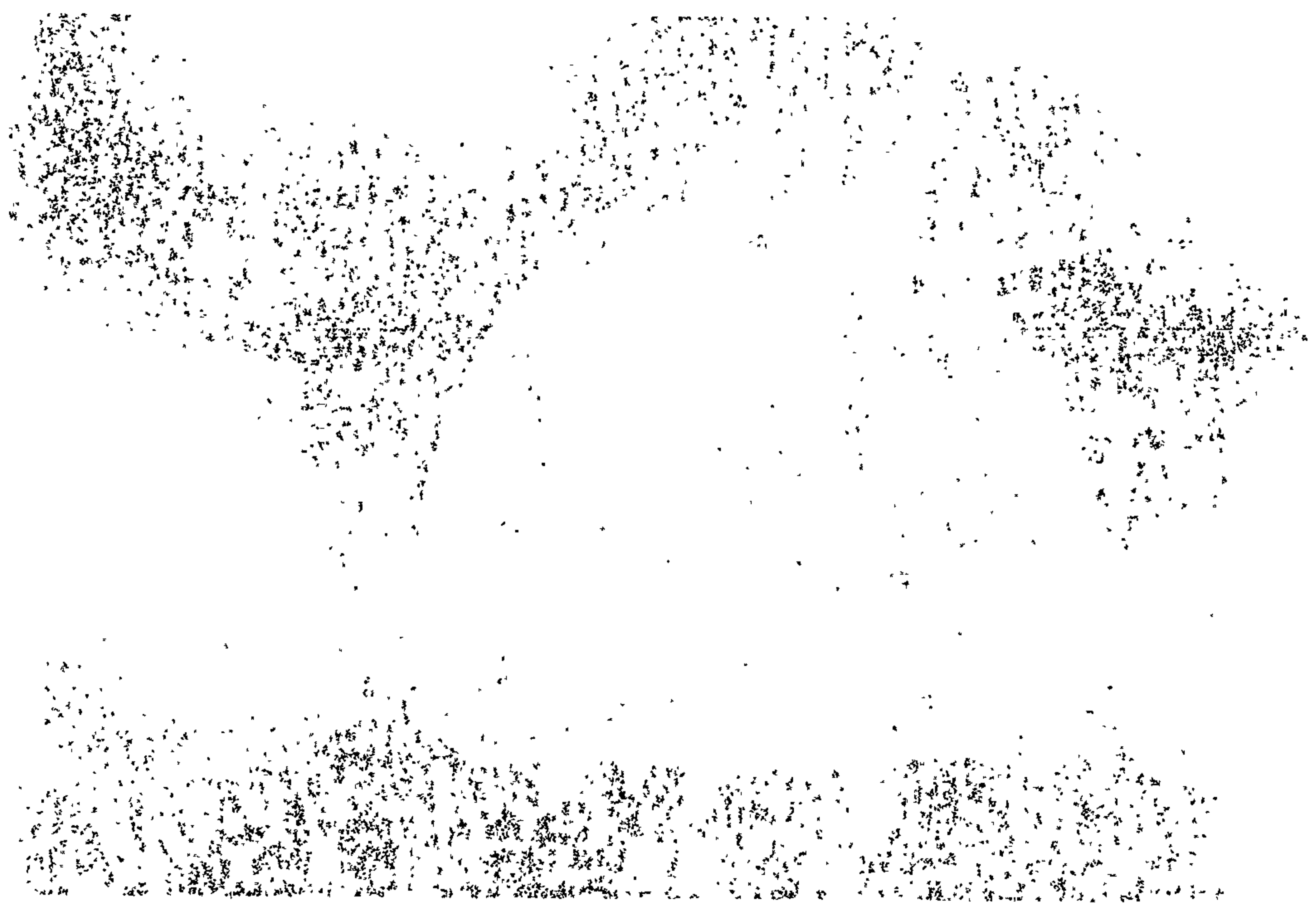
The milling table was attached to a heavy base, and a horizontal arm which carried a dial gauge was clamped to a vertical rod. The spindle of the dial gauge moved vertically and carried a specially constructed anvil having a fine tapered point and an angled shank. This enabled undercut or near-vertical sections of the denture surface to be engaged with minimal inaccuracy. The main tension spring was removed from within the dial gauge to reduce loading of the spindle and hence to reduce the tendency of the anvil to score the denture base or to be deformed by the measuring force.

To use the apparatus, each specimen was luted to a mounting plate using the jig described in section 9.1. The mounting plate was fitted into a sliding block on the milling table. The plane of section was selected by advancing the micrometer screw and rotating the mounting plate until the dial gauge anvil could be made to pass through the reference points selected by traversing the milling table.

Contour heights were read from the dial gauge as the milling table was traversed by means of its graduated screw, and the heights were recorded at 0.5 mm intervals. The planes of section were:

1. A coronal section passing through the two posterior reference points on the maxillary tuberosities.
2. A midline sagittal section passing through the reference points in the incisive papilla and central post-dam area (Fig 9.6).

Contour readings were entered into a data recorder (Hewlett-Packard 9825 B). A print-out of the programme used to store, retrieve and depict the data is appended (Table 9.7), as is the data chart plot (Table 9.8). The plotter depicted contour graphs at x3 magnification.



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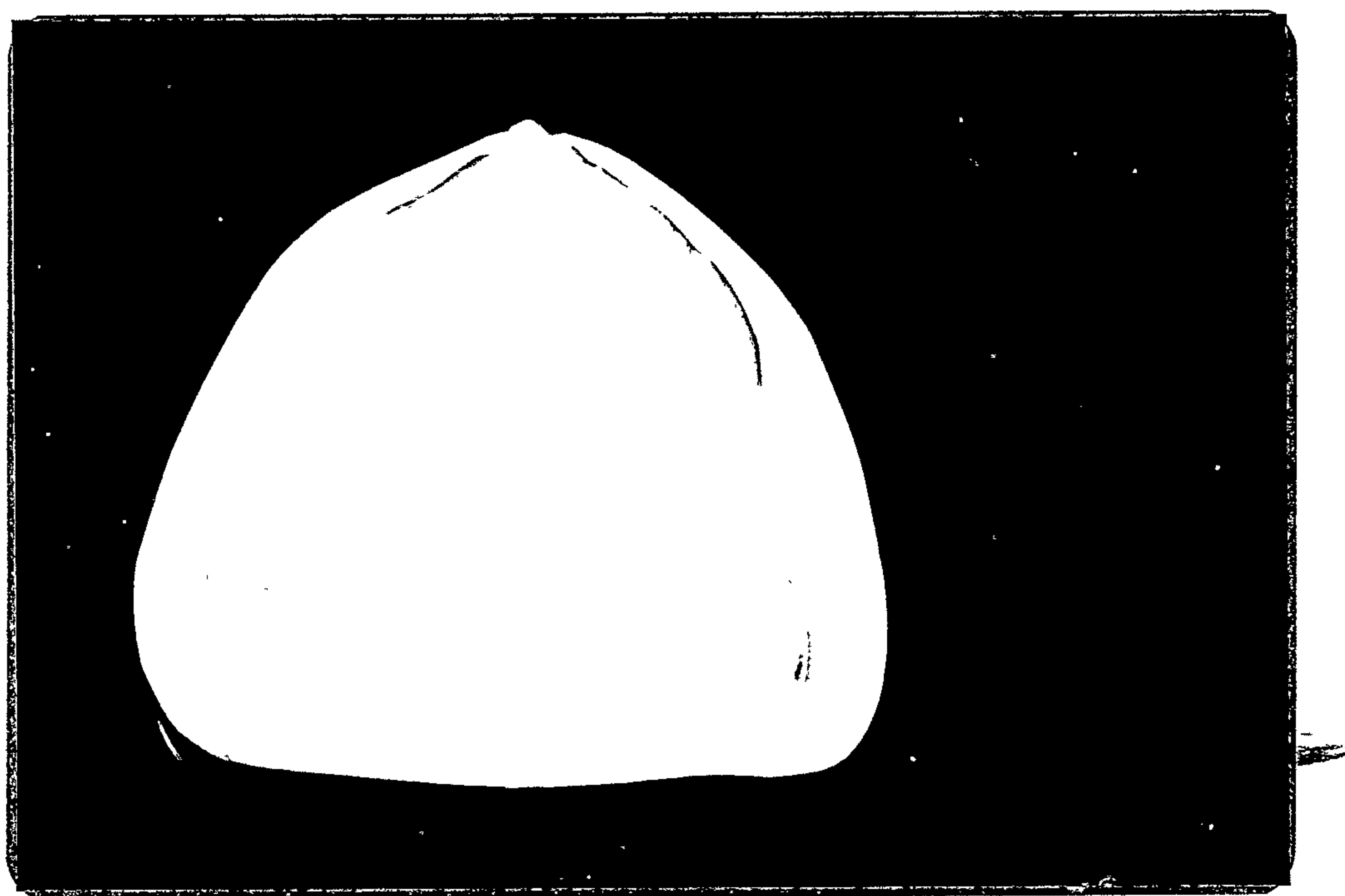


Fig. 9.6. Reference points on master cast.

Table 9.7.

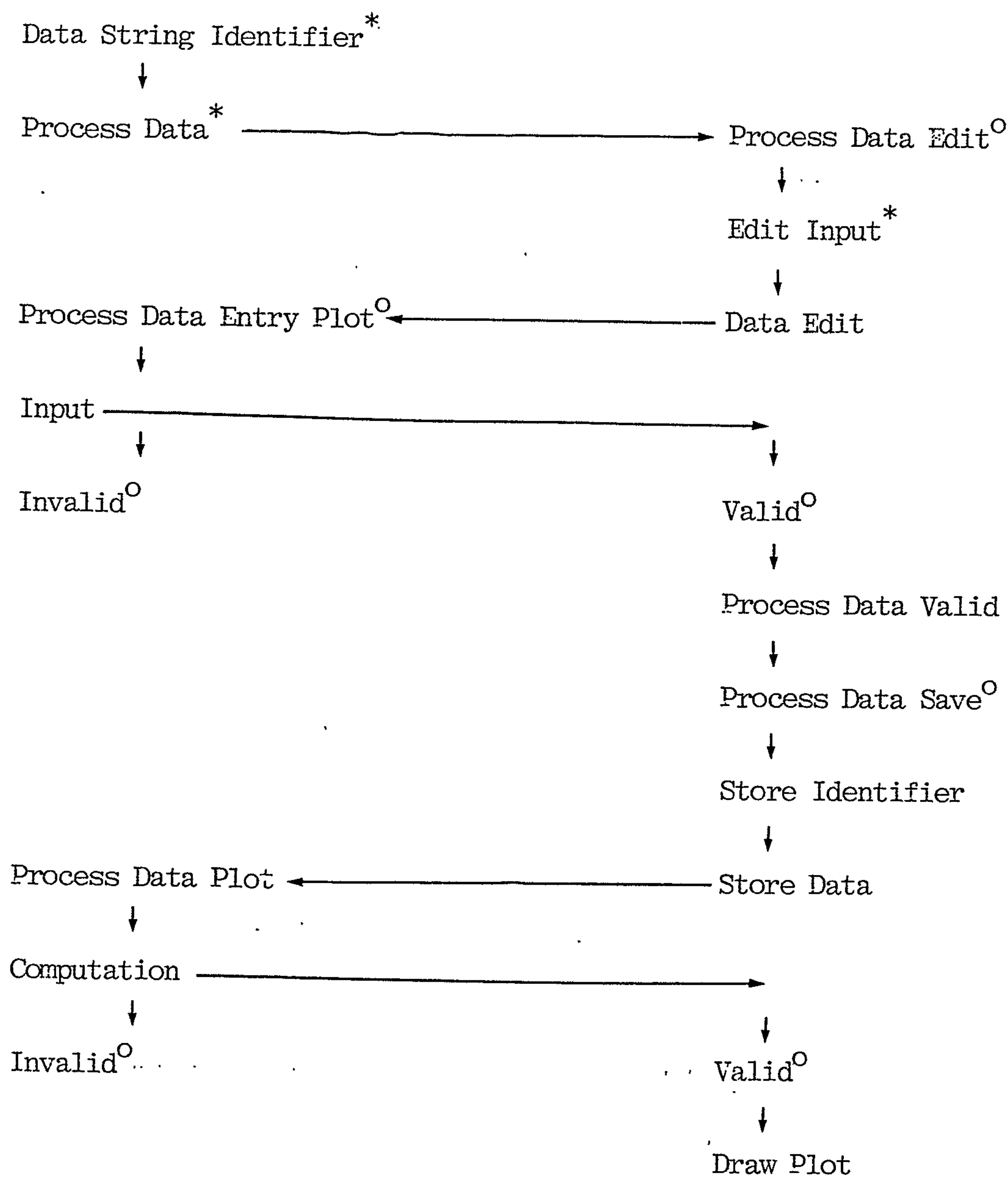
Programme for storage and retrieval of data and plotting.

```

1:rew;trk 0;ldk 1;ldf 2,A(*),B (*), C (*), T (*)
2:disp "SELCT KEYBOARD FUNCTION"; std
3:%
4:" SAVE DATA ": on err "CART ERROR"
5: dsp "SAVING DATA ON TAPE"
6: rew:rcf 2 . A (*),B(*),C(*),D(*)
7: dsp "SELECT KEYBOARD FUNCTION; ret
8: %
9: "ENTER DATA" :
10: ent "ENTER BASEPLATE NUMBER". A
11:if fla13:dsp "SELECT KEYBOARD FUNCTION" : ret
12:ent "ENTER TYPE OF BASEPLATE" . A$
13:if cap (A$)= "CURRED": imp 2
14:if cap (A$)= "CRFAM" :A+1 )A
15:dsp "INCORRECT TYPE" :beep:wait 1000:imp-3
16: ent"ENTER MIXTURE TYPE". B$
17:if cap (B$)#"GYPSUM" or cap (B$)#"SILICONE" : cll OP-ERROR
18: for I=1 to 100
19: ent "ENTER DATA & CONT", A(J,I)
20: if fla13: imp 2
21: next I
22: beep:dsp "HUNDRED POINT ACHIEVED": wait 2000
23: prt"DATA STORED";prt "AS FOLLOWS"
24: prt"BASEPLATE NUMBER". A
25: prt"OF TYPE" . B
26: prt "OF TYPE" . B
27: prt "AT TEMP" . C
28: prt "FOR TYPE". D
29: prt"*****"
30: ato "ENTER DATA"
31: %
32: "DATA CORRECTION" :
33:ent "ENTER STRING POSITION" . A
34: if fla13:dsp"SELECT KEYBOARD FUNCTION": ret
35 : ent "ENTER BASFPLATE TYPE". B$
36 : dsp "OLD DATA": wait 1500
37 : ent "NEW DATA" . C
38.: if not fla13:C)A(B,I)

```

Table 9.8.
Data Chart Plot.



Iteration; *

Selection; o

CHAPTER 10: EXPERIMENTAL METHODS

10.1 Twenty four baseplates were fabricated and used in the initial pantograph study. After pantograph tracings were completed these were stored for some time before the tracings were analysed and so were not suitable for use in contour plotting with the new apparatus; it has been shown that baseplates change shape over a period and according to the degree of water sorption²¹. Therefore a further twenty four baseplates were made for contour measurements with the dial gauge apparatus. To ensure that each wax pattern baseplate was the same thickness, a silicone rubber mould was made of the first baseplate seated on its cast (Fig. 10.1). Subsequent patterns were made by fitting duplicate casts into the mould, and pouring molten wax through a sprue into the intervening space (Fig. 10.2).

In both of these series of twenty four, the baseplates were processed in groups as follows:

1. Base cured at 70°C, gypsum investment.....16 specimens
2. Base cured at 100°C, gypsum investment.....4 specimens
3. Base cured at 70°C, silicone lined mould...4 specimens

Each baseplate was luted to the mounting plate using the mounting jig to ensure correct orientation, and then mounted and plotted in the coronal and sagittal planes as described in sections 9.2 and 9.3.

The master cast was also oriented in the jig, mounted and plotted through the same reference points.



Fig. 10.1. Mould for forming wax pattern baseplates.

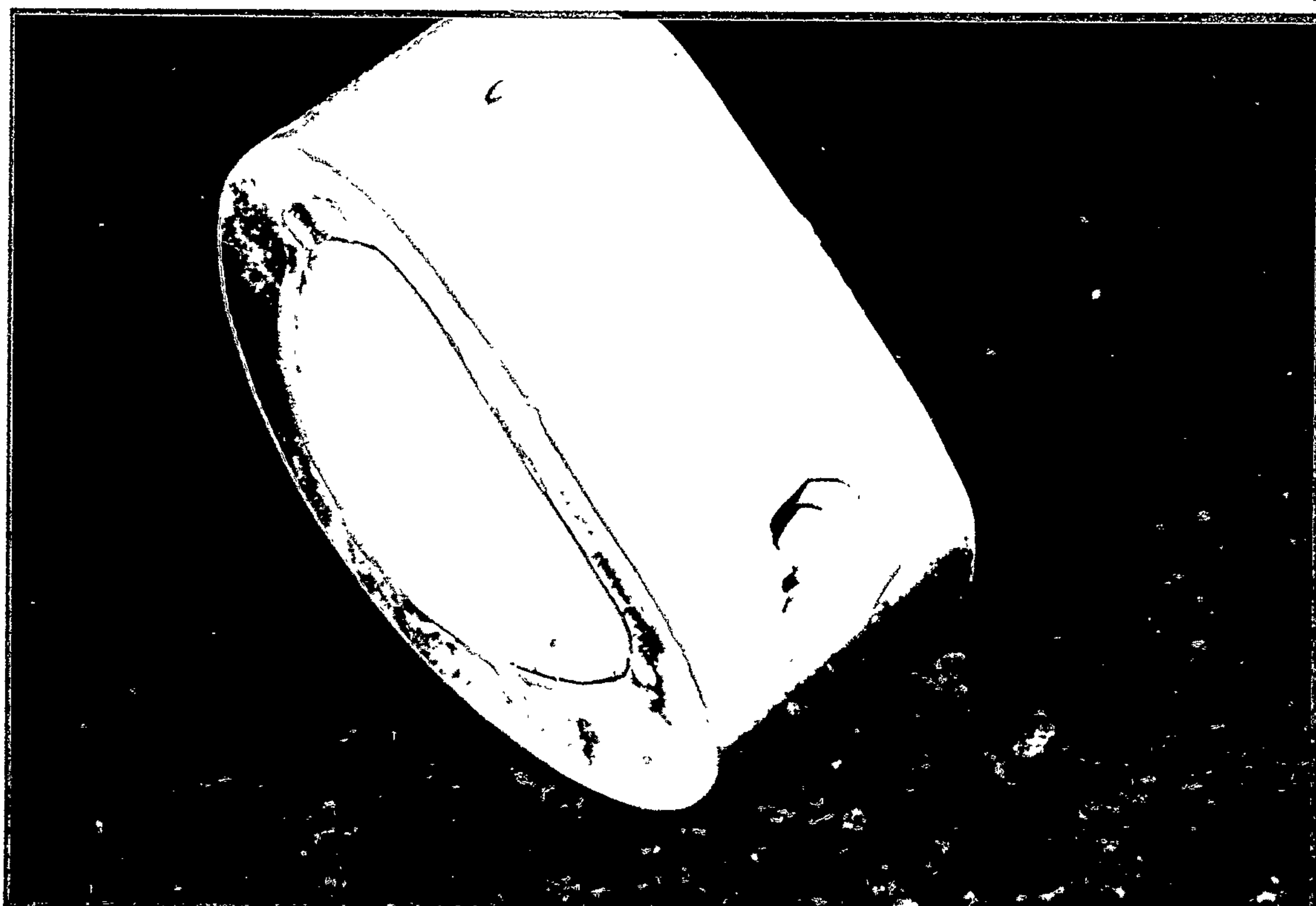


Fig. 10.2. Pouring of standard thickness of wax on cast.

10.2 The master cast and baseplate were mounted on a Dentatus articulator. A cast of an opposing occlusion was fabricated of acrylic resin so that teeth could be set on the twenty four maxillary baseplates in the same position without the danger of abrasion or fracture that could accompany the use of an opposing gypsum cast (Fig. 10.3).

A second silicone rubber mould was made of the waxed-up tooth bearing section to provide a standard thickness of wax for each denture and to facilitate the setting procedure (Figs. 10.4, 10.5). Each baseplate was replaced on the articulated master cast and the occlusion checked and refined where necessary as indicated by the incisal pin (Fig. 10.6).

The denture bases with waxed tooth bearing sections were replaced on their original casts, except for two baseplates which had new casts poured inside them, and the tooth bearing sections processed into place according to the following schedule:

1. Teeth added in gypsum investment at 70°C.....8 specimens
2. Teeth added in silicone investment at 70°C...8 specimens
on original cast
3. New cast poured in baseplate and teeth added,
processed in gypsum at 70°C.....2 specimens

Each baseplate was identified by means of a serial number scribed into the non-bearing surface in the palatal area, to allow the bearing surface to be plotted.



Fig. 10.3. Cast of opposing occlusion on Dentatus articulator.

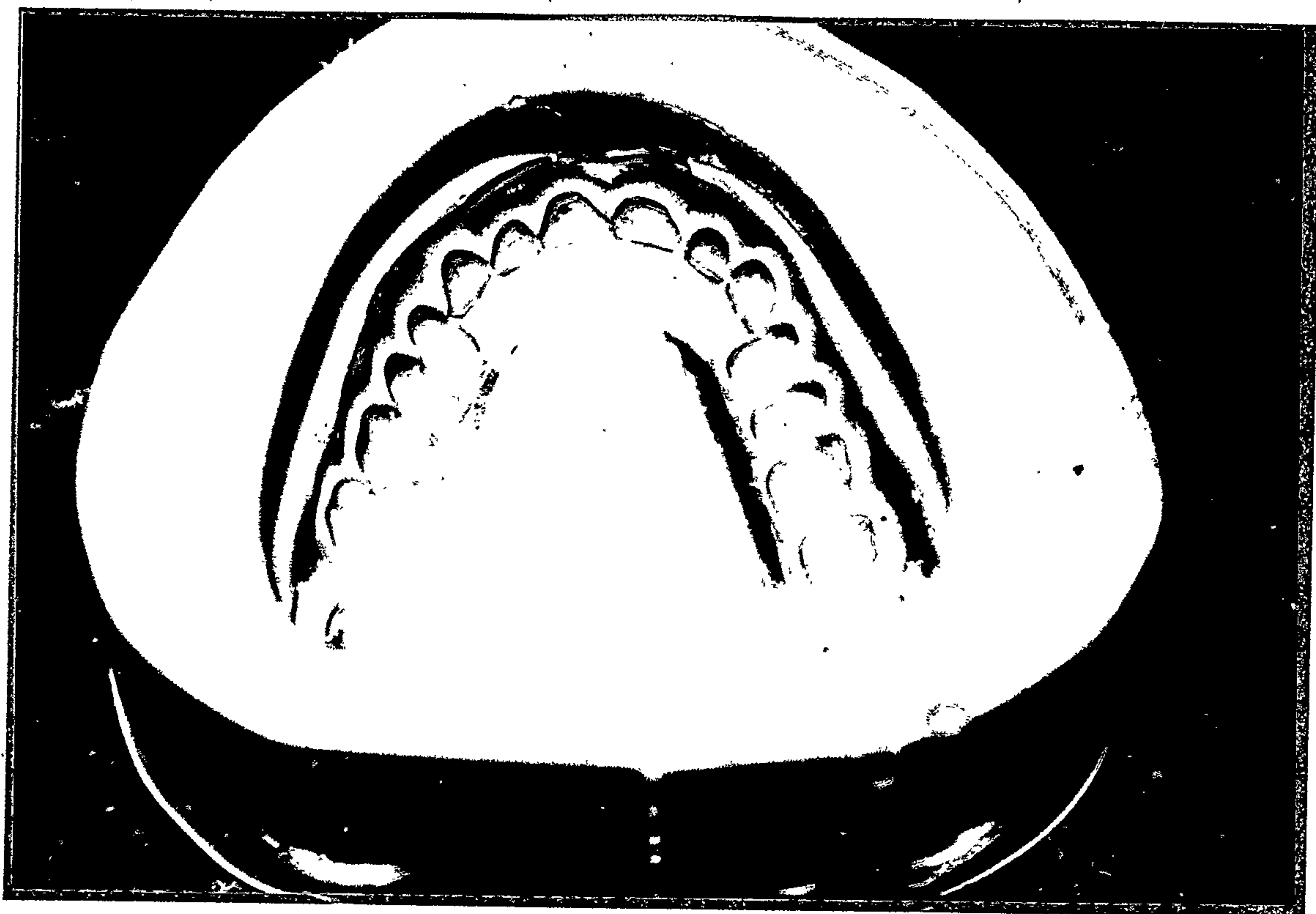


Fig. 10.4. Mould for addition of teeth to baseplate to ensure standard contour of waxed denture and similar setting of teeth.

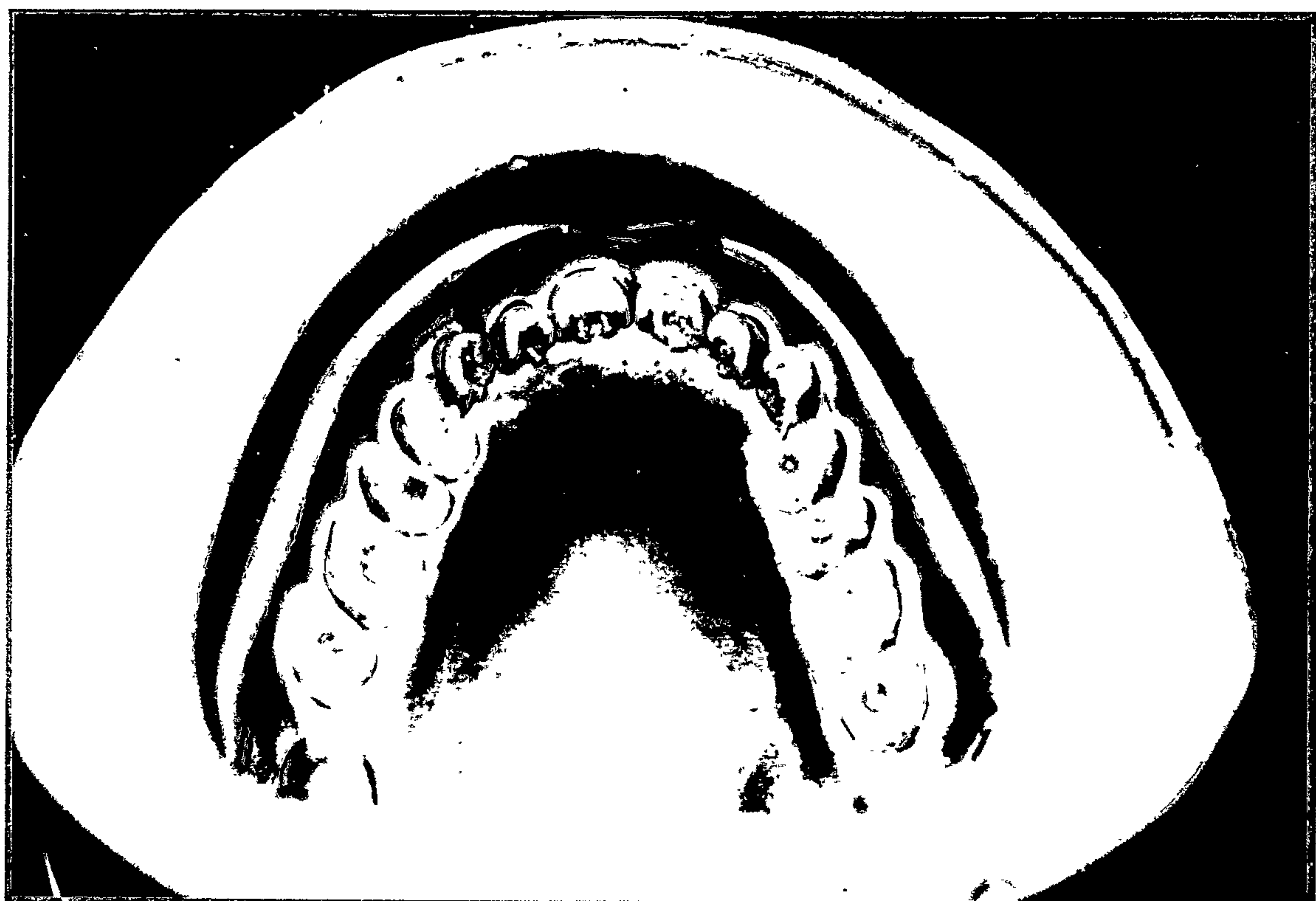


Fig. 10.5. Teeth set in silicone mould before placement of acrylic baseplate and pouring of wax.

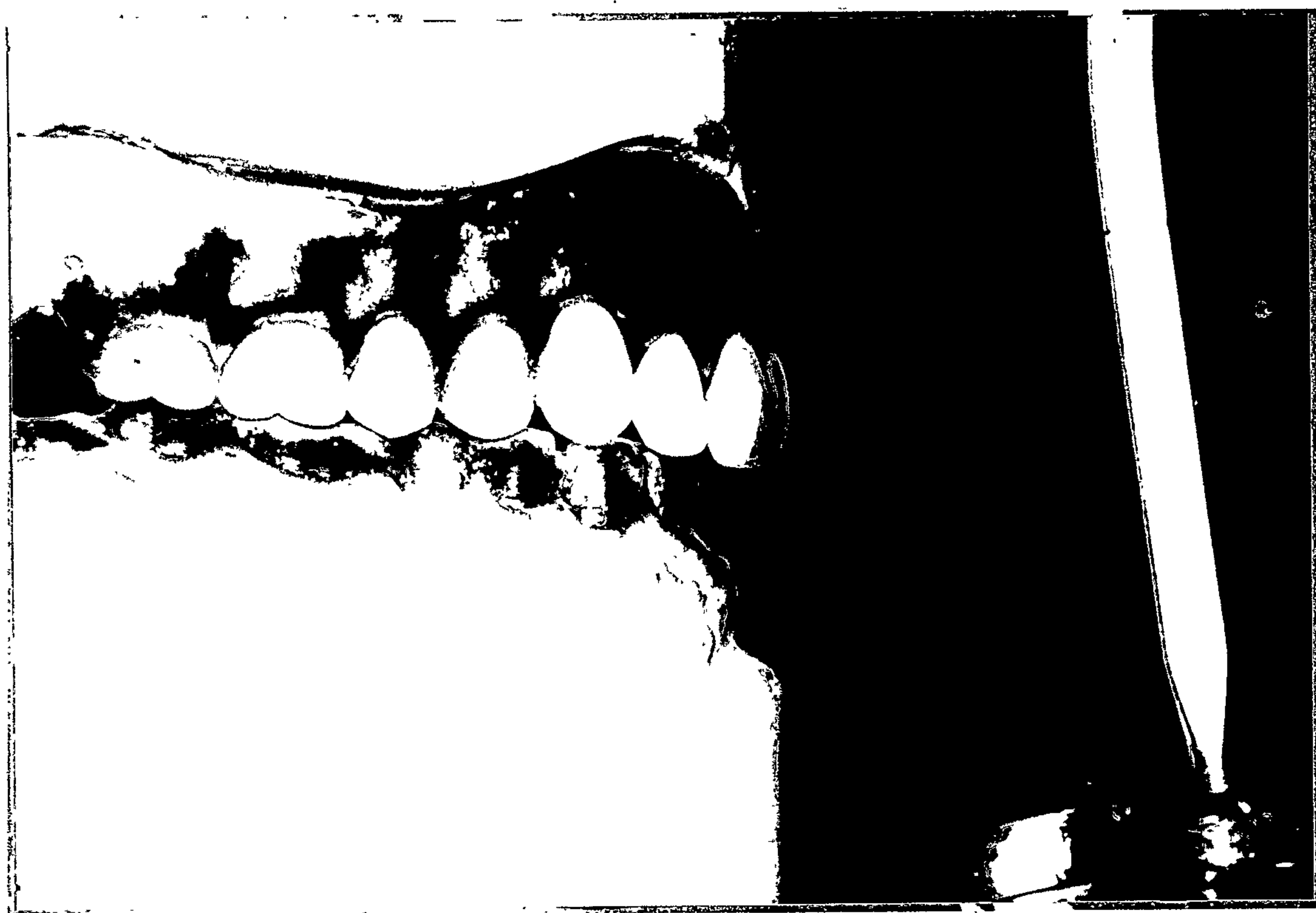


Fig. 10.6. Teeth set on acrylic baseplate in wax.

Table 10.1 summarizes the treatment of each baseplate according to the serial numbers.

After deflasking, each denture was oriented in the mounting jig, luted to the mounting plate with plaster, mounted and plotted as described in sections 9.2 and 9.3. Eight specimens only were plotted by pantograph, but twenty-six were plotted with the dial gauge.

TABLE 10.1.

BASEPLATE SCHEDULE

First cure baseplate

Second cure and invested on original cast, for addition of tooth-bearing section at 70°C

70°C Gypsum Investment	100°C Gypsum Investment	Silicone Investment	Gypsum Investment	Silicone Investment
No. 2	No. 24	No. 19	No. 2	No. 5
No. 3	No. 25	No. 20	No. 3	No. 7
No. 4	No. 26	No. 21	No. 4	No. 8
No. 5	No. 27	No. 22	No. 9	No. 10
No. 6		No. 23	No. 11	No. 15
No. 7			No. 12	No. 16
No. 8			No. 13	No. 23
No. 9			No. 14	
No. 10				
No. 11				
No. 12				
No. 13				
No. 14				
No. 15				
No. 16				
No. 17				
No. 18				

Re-invested in gypsum, without use of original cast

No. 17
No. 18

CHAPTER 11: RESULTS AND DISCUSSION

11.1 The pantograph plots of baseplates processed in alginate-lined gypsum moulds were superimposed and a composite tracing was drawn as in the technique used by Woelfel, Hickey and Berg⁴⁹. The tracing is depicted in Fig. 11.1. The thickness of the curve produced in this way gave an indication of differences in contour within that group of baseplates. When a composite tracing of the baseplates processed in gypsum at 70°C for nine hours was compared with the composite of the baseplates processed at 100°C (Fig. 11.2) for one hour it was apparent that differences between groups were of the same order as the differences within the groups.

Furthermore, different tracings could be produced if the stylus of the pantograph was held at different angles as it was traversed across a baseplate. Different tracings were also produced if the stylus moved at different speeds. Variations of contour thus produced were greater than differences between the groups of baseplates (Fig. 11.6). It was concluded that a reliable comparison could not be made on the basis of these plots and therefore the more accurate method of plotting baseplate contour was developed.

The experiments were repeated using the apparatus described in section 9.3. A second series of baseplates was processed with the same distribution (Table 10.1). The first series, having been stored in conditions of varying temperature and humidity, and for different periods since



Fig 11.1. Baseplates processed in gypsum moulds at 70°C.

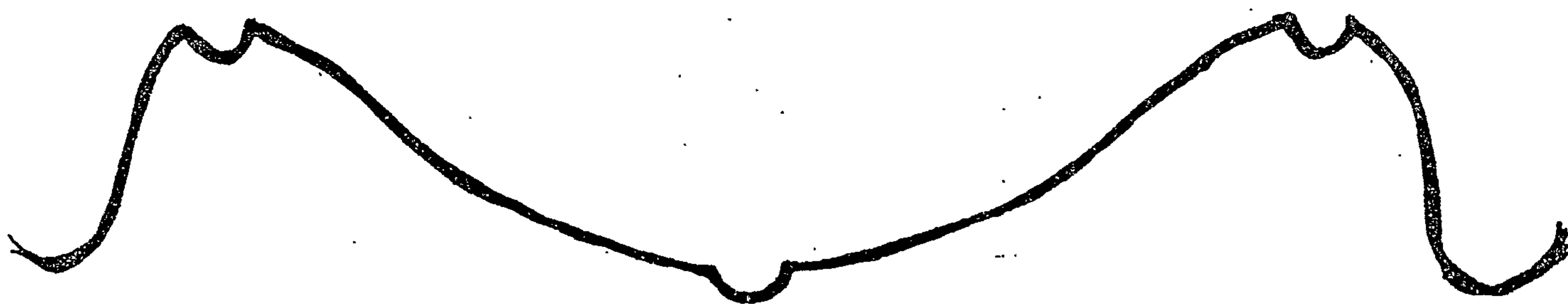


Fig 11.2. Baseplates processed in silicone-lined moulds at 70°C.

Composites made by superimposing traces of base plates processed by various techniques . Differences between baseplates in the same group and resulting from inaccuracy of the tracing machine do not allow meaningful comparisons between groups.



Fig 11.3. Baseplates processed in gypsum moulds at 100°C .

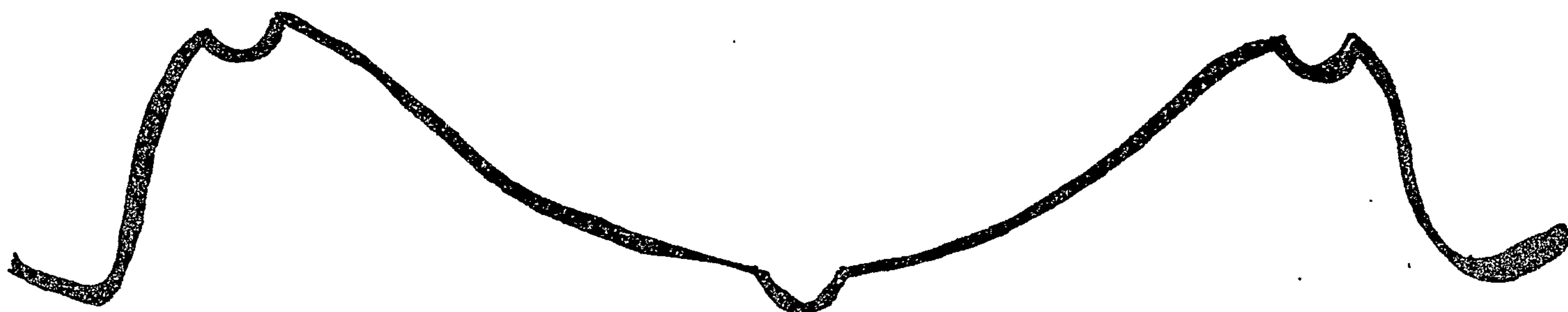


Fig 11.4. Baseplates processed in silicone-lined moulds at 100°C .



Fig 11.5. Baseplates after addition of tooth bearing section at 70°C . Silicone

processing, were not considered suitable for new comparisons of contour.

11.2 The plots produced by the computer programme and plotter (Hewlett-Packard Model 9872 A) were more accurate than those produced by the pantograph, as the effect of inertia of the tracing arm and inaccuracy from wear of the joints of the apparatus and from eccentricity of the stylus were eliminated in the contour measurement system. The contours drawn by the plotter were each superimposed over the plot of the master cast and the reference points aligned to give a "best fit". Measurements were made using dividers and a millimetre rule in critical areas to enable comparisons of fit to be drawn. These areas were:

1. On the anterior posterior plot near the mid-palatal index mark to indicate change in contour in the post-dam region. This measurement would be directly related to a loss of seal in the post-dam and consequent loss of denture retention.
2. Midway between the frenum notch and the reference point at the incisive papilla.
3. On the coronal plot near the palatal reference point.
- 4.) On the lateral walls of left and right tuberosities,
- 5.) where distortion of the denture flange, usually towards the soft tissues, would create areas of pressure in the mucosa of the buccal surface of the tuberosity (Fig 11.7).

These measurements were listed in millimetres in Table 11.1 for each numbered baseplate as plotted after the

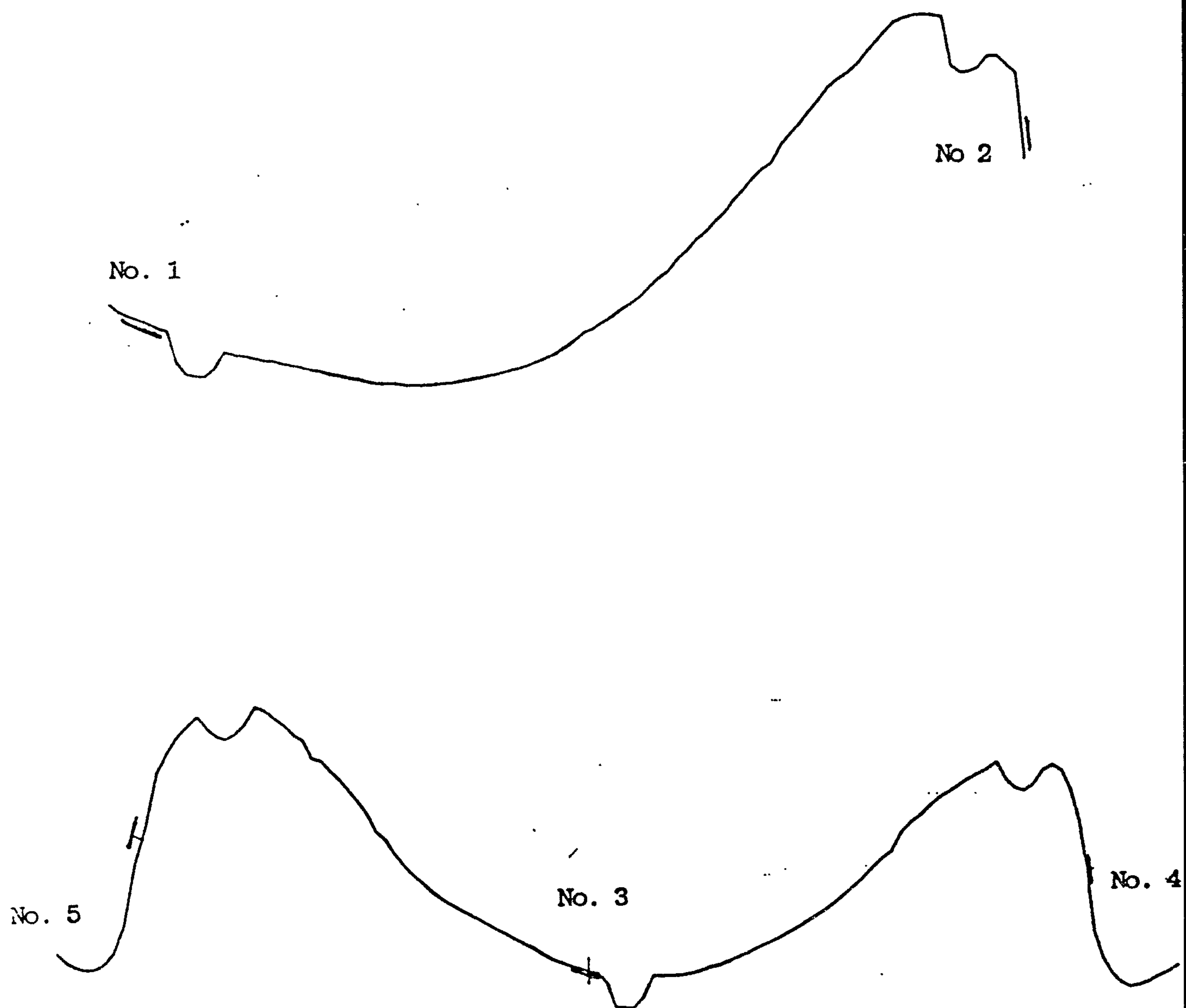


Fig 11.7. Areas where sample measurements were made for analysis of fit.

first cure. When the tooth-bearing part of the denture base had been added and the resin cured, each denture base was re-oriented in the mounting jig and plotted. Measurements were recorded at the same sites as in Table 11.1 and are listed in Table 11.2.

The vertical discrepancy at the post-dam was reduced to scale and tabulated to indicate movement of the baseplate away from the tissues and loss of seal at the point, expressed in millimeters in column 8 of Table 11.1 and 11.2. Some inaccuracy was evident in the plotting, related to areas where the denture base contour was nearly vertical. In these areas the pointer of the dial gauge was easily overloaded and flexed to give an inaccurate contour height, or the baseplate was dislodged from the mounting plate (Table 11.1, column 2, baseplates 11, 12, 23, 24 & 27).

In the following tables, the numeral at the left indicates the baseplate identification number. The measurements of each region described and numbered in section 11.2 and Fig 11.6 are then listed. The discrepancies in the vertical part of the denture base adjacent to the tuberosities were added, and the overall distortion expressed as a percentage of the denture width in column 7 on the right of Tables 11.1 and 11.2.

- 11.3 Distortion of the flanges after deflasking ranged from 0.0 - 1.2% for the gypsum invested group, with a mode of 0.6%. The range for the silicone invested bases was 0.4 to 1.2%. The group processed in gypsum at 100°C ranged from 1.5 to 2.2% shrinkage.

Table 11.1

Sample Measurements of Denture Bases after First Cure

Base- plate Number	Measurements of discrepancies at sites listed in section 10.1 in mm in contour plot.*					Shrinkage at flanges (%)	Vertical change at post-dam (mm)
2	2.5	1.0	0.4	0.5	0.6	0.6%	0.5
3	1.2	1.0	0.2		0.6	0.6%	0.3
4	2.4	3.0	0.3	0.0	0.8	0.5%	0.5
5	1.4	0.8	1.0	0.0	0.0	0.0%	0.4
7	2.2	0.7	0.0	0.2	1.2	0.6%	0.3
8	2.0	0.8	1.0	0.8	0.5	0.7%	0.5
9	2.0	1.0	1.0	0.6	1.0	0.9%	0.5
10	2.4	1.0	0.8	0.4	1.6	1.2%	0.5
11	2.2		0.5	0.6	1.2	1.1%	0.5
12	2.8		1.0	1.5		1.0%	0.6
13	2.2	0.8	1.0	0.8	0.8	0.9%	0.6
14	2.4	0.3	0.8	0.2	0.6	0.6%	0.6
15	2.0	0.0	0.5	0.6	0.0	0.9%	0.4
16	2.5	1.0	0.8	0.0	1.0	0.0%	0.6
17	2.0	1.5	0.8	1.8	1.0	1.1%	0.5
18	1.8	0.4	0.6	0.7	1.2	1.1%	0.4
19	1.8	1.2	1.5	1.8	2.0	1.2%	0.6
20	2.0	1.4	1.5	0.2	1.1	0.3%	0.6
21	2.0	1.2	1.0	0.5	1.6	1.2%	0.5
22	1.5	1.0	0.8	0.6	2.0	0.5%	0.4
23	1.0		0.2	0.5	0.2	0.4%	0.2
24	3.0		1.0	1.2	2.0	1.8%	0.7
25	3.0	1.5	2.0	0.6	2.0	1.5%	0.8
26	3.0	1.5	2.0	1.6	2.2	2.2%	0.8
27	3.0		1.0	0.6	2.0	1.5%	0.7

* Contour plot scale at x3 magnification.

Table 11.2

Measurements of denture bases after addition of tooth-bearing section

Base- plate Number	Discrepancies at sites listed in section 10.1					Shrinkage at flanges (%)	Vertical change at post-dam (mm)
	1	2	3	4	5		
2	2.4	1.0	0.4	0.6	0.7	0.8%	0.5
3	3.0		0.4	0.0	0.3	0.2%	0.6
4	3.5	1.8	0.4	0.4	1.5	1.2%	0.7
5	1.2	1.5	0.2	0.2	0.4	0.4	0.2
7	3.0	1.0	0.3	0.6	1.5	1.2%	0.6
8	2.2	1.0	1.0	1.7	1.8	2.0%	0.5
9	2.2		1.0	1.0	1.8	1.6%	0.5
10	2.0	1.0	0.8	0.2	1.0	0.7%	0.5
11	2.8		1.0	0.2	1.2	0.8%	0.6
12	2.2	0.8	1.2	0.2	0.7	0.5%	0.6
13	2.4	1.2	1.4	0.8	1.4	1.3%	0.6
14	2.0	1.0	0.8	1.6	1.0	0.9%	0.5
15	1.0	1.0	0.7	0.4	0.3	0.4%	0.3
16	3.0	1.2	1.0	0.0	0.0	0.0%	0.7
17	4.0	1.8	2.4	2.8	2.0	2.8%	1.1
18	3.0	2.0	2.5	1.2	2.4	2.1%	0.9
23	2.0	1.4	0.8	0.8	2.0	1.6%	0.5

In the gypsum-invested group, vertical discrepancy of the baseplate at the post-dam ranged from 0.3 to 0.6 mm, with a mode of 0.5 mm. For the silicone invested baseplates, the range was from 0.2 to 0.6 mm. The bases cured at 100°C ranged from 0.7 to 0.8 mm; the modes for these groups were respectively 0.6 mm and 0.7 mm.

When the tooth-bearing section was processed on to the baseplates, the original casts were used save for two cases. Those dentures processed in a gypsum mould showed flange distortion from 0.2 to 1.6%, while the dentures processed in silicone ranged from 0.0 to 2.0%. Distortion at the mid-palatal index for the gypsum-invested dentures ranged from 0.5 to 0.7 mm, while the silicone invested dentures showed a distortion of 0.2 to 0.7 mm.

Two dentures were re-invested in gypsum, a new cast being poured into the denture base. When these were deflasked and plotted, a markedly greater distortion of the baseplate was observed. Palatal contour changed by 0.9 - 1.1 mm, and the shrinkage at the flange was 2.1 - 2.8%.

11.4 The tables of measurements were analysed using Duncan's new multiple range test. A copy of this analysis is appended (Table 11.3). The test enabled comparisons of the groups of measurements to be drawn. The shrinkage of the baseplates after curing was not significantly different at $P = 0.05$ and $P = 0.01$ for the groups processed at 70°C in gypsum or silicone. There was a statistically

Table 11.3

Statistical analysis of results by Duncan's Multiple Range Test.

Shrinkage across tuberosities after first curing cycle.

Least	Gypsum at 70°C	Silicone at 70°C	Gypsum at 100°C	Greatest
P = 0,05				
P = 0,01				
	(statistically similar)		(statistically different)	

Loss of adaptation at post-dam after first curing cycle.

Least	Gypsum at 70°C	Silicone at 70°C	Gypsum at 100°C	Greatest
P = 0,05				
P = 0,01				

Tooth shrinkage - shrinkage of baseplate after curing of tooth-bearing section.

Least	Gypsum at 70°C	Silicone at 70°C	Gypsum at 100°C	Greatest
P = 0,05				
P = 0,01				

Loss of adaptation at post-dam after addition of tooth-bearing section.

Least	Silicone at 70°C	Gypsum at 70°C	Gypsum at 100°C	Greatest
P = 0,05				
P = 0,01				

significant difference between the baseplates cured at 70°C in gypsum and silicone and the baseplates cured at 100°C. Analysis of loss of adaptation at the post-dam yielded a similar grouping, where those baseplates cured at 70°C showed less distortion than those cured at 100°C.

The measurements tabulated for baseplate distortion after the addition of the tooth-bearing section were subjected to Duncan's multiple range test, and the analysis, titled "tooth shrinkage" provides a comparison for shrinkage at the flanges of the dentures. The fourth table in the appended analysis refers to loss of adaptation at the post-dam. In both of these, there was a statistically significant difference between the dentures processed upon the master cast and the dentures re-invested in gypsum, although the dentures processed in silicone were not significantly different from those processed upon the master cast in gypsum.

The tables of results show a statistically significant difference between the fit of baseplates processed at 70°C and those processed at 100°C. It should be noted, however, that differences of tenths of a millimetre in denture base dimensions have little clinical significance as has been attested by a number of authors^{46,47,48}.

It is evident that the silicone invested baseplates demonstrated similar accuracy of fit to those invested in gypsum and processed at 70°C. The bases processed at 100°C showed a greater range of distortion than either

of the other groups.

When tooth-bearing sections were added to the bases previously processed at 70°C, similar ranges of distortion were measured. Some baseplates demonstrated an improved fit after the second curing cycle where they were re-processed on the original cast. Distortion of baseplates during re-processing seems to be greatest when a new cast is poured in the lower half of the flask during investment. Distortion of acrylic dentures occurs when they are dehydrated, and the additional stresses generated in the denture during investment, in addition to the stresses generated during boiling-out, packing, polymerizing and cooling, contribute to warping of the denture upon deflasking.

The least reliable section of the plot recorded in this manner is the most nearly vertical. Lateral distortion of the dial gauge anvil in addition to interference by its tapering shank made accurate recordings difficult. Nevertheless, information having a direct clinical significance can be drawn from the plots.

While the distortions measured in these baseplates are within the range of clinical acceptability, the contour plots carried out indicate that some areas in full upper dentures should be examined for distortion. These are the lateral aspects of buccal and labial flanges, where the surfaces most nearly perpendicular to the axis of contraction of the denture base after polymerization may generate undue loading of the tissues.

CHAPTER 12: CONCLUSIONS

The use of a silicone mould liner is recommended; simplification of investment, boil-out, model sealing, packing and deflasking result from its application. Accuracy of fit is not reduced in comparison with the gypsum technique, and occlusal errors resulting from tooth movement are reduced.

As it is readily retrieved from the silicone-lined mould, the processed denture and cast may be re-articulated to allow elimination of occlusal errors.

Furthermore, the technique of pouring a gypsum cast within an acrylic baseplate prior to the addition of the tooth-bearing segment of the denture will make a significant contribution towards distortion of the denture base with consequent loss of fit.

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