

Ceramic Brackets

Although some of the literature reports that ceramic brackets were introduced in 1986³¹⁴⁻³¹⁶ there is a report of testing the bond strength of a ceramic bracket in 1982³³. The superior aesthetics of ceramic brackets has made them an integral part of orthodontic therapy. Initially there were two types of ceramic brackets, polycrystalline and single crystal alumina, both composed of aluminium oxide. The polycrystalline brackets are manufactured by blending aluminium oxide particles with a binder and moulding the mixture into a shape from which a bracket can be machined. The temperature to burn out the binder and fuse the particles is in excess of 1800°C, with diamond cutting tools providing the slot dimensions. Heat treatment is then performed to relieve the stresses caused by cutting and to remove surface imperfections resulting from the manufacturing process. Single crystal ceramic brackets are made by growing single crystal rods in a special crystal growth furnace at 2100°C. These single crystal rods are milled into the brackets using diamond cutting, Nd:Yag lasers or ultrasonic cutting. The single crystal brackets are also heat treated to remove the surface imperfections and stresses created by the milling process. The manufacturing process plays an important role in the clinical performance of the ceramic brackets. The presence of pores, machining interferences and propagation lines contribute to bracket failure during clinical use³¹⁷. The most apparent difference between the two brackets is their optical clarity with single

crystal brackets being noticeably clearer than polycrystalline brackets, which tend to be translucent. Both brackets resist staining and discolouration³¹⁸. Ceramic brackets have several disadvantages³¹⁹:

- The inability to form chemical bonds with the available adhesives without the use of a coupling agent. Consequently, the early ceramic brackets used a silane coupler to act as a chemical mediator between the base and the adhesive. This resulted in an extremely strong bond that may cause the enamel-adhesive interface to be stressed during debonding increasing the risk of tooth damage^{318,320}.
- A low fracture toughness. Despite the fact that ceramic brackets have a higher hardness than stainless steel a shallow scratch on the surface drastically reduces the load necessary to induce fracture. Fracture toughness of ceramic brackets is 20 to 40 times less than stainless steel. Polycrystalline alumina presents a higher fracture toughness than single crystal alumina³¹⁵. This low fracture toughness can lead to undesirable breakage of the ceramics or enamel during clinical activation³²¹, debonding^{322,323} and accidental impact³²⁴. Broken ceramic brackets can be traumatic, are difficult to remove (increasing clinical time) and possibly prolong treatment.
- Increased frictional resistance between the metal arch wires and the bracket slot.

The force applied during debonding of ceramic brackets is influenced by factors that include the method of enamel conditioning, the composition of the adhesive used, the bracket retention mechanism and the method of debonding.

There are three mechanisms by which a ceramic bracket adheres to the adhesive: (a) chemical, (b) mechanical and (c) a combination of both³¹⁹. Laboratory testing of mechanical retention indicates that adhesive to bracket bond strength of ceramic brackets is lower than those of equivalent sized foil/mesh metallic brackets. Ceramic brackets have considerably less mechanical undercuts than those on a metal mesh base design, and therefore they might be expected to have a greater bond failure rate if they are used without a silane-coupling agent. Viazis *et al.* (1990)³²⁵ compared the shear bond strength and the potential enamel damage on debonding various ceramic and stainless steel brackets *in vitro* using extracted premolar teeth. They found that mechanical bonds (metal foil mesh and grooved ceramic bases) under shear stress fail primarily within the adhesive itself (brittle failure due to localised stress areas), whereas chemical bonds (silane-treated ceramic bases) fail mostly at the adhesive-bracket interface (pure failure caused by a wider stress distribution over the whole interface). Single crystal ceramic appliances tended to be more brittle than polycrystalline ones, especially when there is a chemical bond with the adhesive. Bishara *et al.*³²⁶ compared the effect of different enamel conditioners and adhesives when bonding ceramic brackets. They found that the crystal growth conditioner produced a reduced bond strength compared to etching with 37% phosphoric acid.

However, the bond strength achieved would still be clinically acceptable and it may be therefore advantageous to bond with crystal growth conditioner as it reduces the strain on the enamel surface and may be conducive to safer debonding. When comparing the ceramic brackets with phosphoric acid etch the chemically retained brackets had a higher bond strength than the mechanically retained, the highly filled resin gave debonding strengths twice that of the lightly filled resin and the unfilled resin had comparable strength to the highly filled resin except for the chemical only retained bracket. Osterag *et al.*³⁴ bonded ceramic brackets with 3 different filler concentrations (30%, 55% and 80%) and found that the 80% filler had significantly greater bond strength than the 30% and 55% filler content. However, there was no difference in the site of bond failure for the different filler concentrations, which was dependent on the bracket used and the type of force used to debond. Plasticisation of the adhesive has been attempted to reduce bracket and enamel fracture on debonding. Starling and Love³²⁷ added 0-20% aliphatic phthalate plasticiser to a Bis-GMA resin. They found that adding the plasticiser reduced the bond strength making cohesive fracture more likely. Glass ionomer cements have been shown to be effective at bonding ceramic brackets *in vitro*³²⁸. The effectiveness depended upon the method of retention (mechanical or chemical) and the type of glass ionomer used with Fuji Ortho LC and Photac Bond performing better than Dyract Ortho and Iocomp 20. Larmour *et al.*³²⁹ assessed three resin modified glass ionomer cements, Fuji Ortho LC, Vitremer and Dyract-Cem, in relation to bond strength and mode of failure with ceramic brackets. They found that all three resin-modified cements were effective at

eliminating debond problems with the predominant site of failure the enamel-resin interface (90-100%) but with no evidence of enamel damage. Bracket fracture was eliminated compared to 40% in the control group. The Fuji Ortho LC may be the most reliable in a clinical situation based on the Weibull analysis.

To reduce the clinical incidence of irreversible enamel surface damage a number of methods of debonding ceramic brackets have been suggested: (1) conventional method using pliers or wrenches, (2) an ultrasonic method using special tips³³⁰, (3) the electrothermal method³³¹⁻³³³, (4) lasers³³⁴, (5) applying a "softening" agent, (6) notching the bonding resin³³⁵ and (7) modifying the bracket (polymeric base or collapsible base).

Swartz³¹⁸ recommended that ceramic bracket removal with debonding pliers be performed by squeezing pressure at the bracket adhesive interface, resulting in a tensile bond failure, which is the safest method of removal with respect to enamel damage. He felt that a rotation movement, torsional debonding, distributes the force over the entire base area increasing the load to the enamel-adhesive interface and thus increases the risk of enamel damage. Bishara and Trulove^{322,336} compared the conventional, the ultrasonic and the electrothermal methods of debonding on three types of ceramic brackets. They found that the incidence of bracket failure during debonding was significantly greater for the conventional method (10-35%) compared to either the ultrasonic or electrothermal methods (0%). The site of bond failure varied significantly depending on the method of removal. In the electrothermal

method bond, failure occurred mainly between the bracket and the adhesive. In the ultrasonic method, failure occurred between the adhesive and the enamel and in the conventional method, failure occurred as a combination of enamel-adhesive, bracket-adhesive and within the adhesive. Although the ultrasonic failure occurred at the enamel-adhesive interface, the likelihood of damage is minimal as the force required to remove the bracket is significantly reduced. Sinha and Nanda³³⁷ found that the method of bonding and debonding affected the bracket failure or fracture rates. The brackets bonded by an indirect technique had the lowest breakage indicating that creating a resin interlayer may facilitate easier removal of ceramic brackets. However for the indirect lift off and wrenching techniques there was a significant number of breakages for the monocrystalline brackets compared to the polycrystalline brackets. Boyer *et al.*³³⁰ found that the use of an ultrasonic chisel reduced the force needed to debond the ceramic brackets from 9.2 to 0.8 MPa at an average time of 16.6 seconds. However, they cautioned that although the forces are small they are prolonged and would be uncomfortable for the patient.

It is thought that laser energy can degrade adhesive by three methods: thermal softening; thermal ablation; and photoablation. Thermal softening occurs when the laser heats the bonding agent until it softens. Clinically, this results in the bracket succumbing to gravity and sliding off the tooth. Thermal ablation occurs when heating is fast enough to raise the temperature of the resin into its vaporisation range before debonding by thermal softening occurs. This results in the bracket being

blown off the tooth surface. Photoablation also results in the bracket being blown off the tooth surface. It occurs when very high-energy laser light interacts with the adhesive material and the energy level of the bonds between the adhesive resin atoms rapidly rises above their dissociation energy levels, resulting in decomposition of the material³³⁴.

Considerations for the use of lasers and debonding of ceramic brackets are: what type of lasers can be used? are they effective (do you need less force)? is there a difference between the adhesives or types of brackets and are there any adverse effects?

Strobl *et al.*¹³⁷ removed ceramic brackets after heating with Carbon Dioxide (CO₂) and Nd:YAG lasers. They found that the average debonding force and the risk of enamel damage was reduced. The reduction in force level was 5.2 for monocrytalline brackets and 1.3 for polycrystalline brackets. Tocchio *et al.*³³⁸ debonded monocrytalline and polycrystalline ceramic brackets using three lasers at wavelengths 248,308 and 1060 nm. They used an external stress of 0 or 0.8MPa and found that the brackets were all successfully debonded with no enamel or bracket damage. Ma *et al.*³³⁹ used a CO₂ laser to debond and found that the tensile load was 1.48MPa to debond which was 25% the tensile load of a non laser group. Mimura *et al.*³⁴⁰ compared the effectiveness of a CO₂ laser at debonding ceramic brackets bonded with two different adhesives (Bis-GMA and 4-META MMA). They found that Laser-aided debonding was efficient at debonding with no enamel fracture in the MMA group but 2 teeth had enamel cracking in the Bis-GMA group. The total

energy to debond was less and adhesive tended to remain on the tooth in the MMA group, which suggests that MMA can be debonded more safely than Bis-GMA. It has also been shown that if a minute elapses between applications of the laser and the debonding force then a higher force is required. Therefore the debonding force should be applied immediately before the adhesive resolidifies³³⁴. Laser energy heats up the bracket and adhesive and therefore poses a risk to the pulp. It has been shown that for a CO₂ laser there is a lineal increase in temperature with time³³⁹. However the increase was not greater than 5.5°C with the maximum rise 2.67°C after 3 seconds. Another study¹⁴⁰ confirmed the safety of a super pulse CO₂ laser with a temperature rise in the pulp of 2.1°C with 3 watts power.

It has been suggested that an agent can be applied (Post-debonding agent, GAC, International, Inc) and left around the base of the bracket for 2 minutes to facilitate easier debonding. This agent is a derivative of peppermint oil and promotes failure at the adhesive-enamel interface. However, a similar agent (P-de-A, Oradent Ltd.) was found to have no significant effect on the surface microhardness of resins and therefore did not soften the margins to produce easier debonding³¹⁵.

Larmour *et al.*³³⁵ notched the resin (occlusally and gingivally) on placing the ceramic brackets and found that the notch significantly reduced the mean and maximal debonding forces and that the brackets tended to debond at the adhesive-bracket interface, which should reduce the risk of enamel damage. The notched groups did

not have a problem with fracture compared to 40% of the control. The authors speculated that the notch introduced a point of stress concentration in the bond layer resulting in propagation of a crack throughout its structure diverting the debonding forces away from the bracket structure.

Bishara *et al.*³¹⁹ reported on a new collapsible bracket (Clarity, 3M Unitek), which consists of a metal slot to re-enforce the bracket and minimise the friction between the metal arch wire and the ceramic and a vertical slot to allow consistent failure when the tie wings are pressed on with a Weingart plier. Half the bracket debonded first with the other half remaining on the tooth on compression testing in 38.1% of cases, with Weingart pliers in 14.3% of cases and with the ETM 346 pliers in 4.8% of cases. Olsen *et al.*³⁴¹ measured the shear bond strength of Cerameflex (TP, Orthodontics, Inc) and Transcend (3M Unitek) brackets and found that the mean shear bond strength was significantly lower (8.8MPa) than the Transcend (14.4MPa). However the bond failure was more favourable occurring at the ceramic-polycarbonate base. Bishara *et al.*³⁴² compared the collapsible Clarity bracket with the MXi (TP Orthodontics, Inc) bracket, which is an injection moulded polycrystalline bracket incorporating a polymeric base made of a high strength epoxy resin that adheres to most orthodontic resins. They recommended that to debond the MXi bracket the blades of the ETM 346 plier should be placed between the bracket base and the enamel surface and for the Clarity bracket use the Weingart and apply pressure to the tie wings. Using these techniques to debond most of the adhesive was

left on the tooth surface, reducing the risk of enamel damage. Mundstock *et al.*³⁴³ debonded Clarity and Transcend brackets with debonding pliers and found that the mean shear bond strength for the Clarity was 13.27MPa and Transcend was 21.19MPa. Both brackets failed mostly (75%) at the bracket-adhesive interface.

(N) The Effects of the Light Curing Unit

The use of light cured orthodontic adhesives is now fairly standard as they are a single paste providing consistent handling characteristics, have an increased working time allowing accurate bracket placement and easy removal of excess cement and allow for immediate arch wire placement³⁴⁴.

The first light source used for curing composite resin was ultraviolet light (UV), which required 1 minute per millimetre of resin thickness for curing. The benzoin methyl ether component of the composite resin was sensitive to light in the 340 nm spectrum³⁴⁵. Initially, bracket curing prolonged the time taken for bracket placement as each bracket had to be cured for 1 minute. There were also safety concerns regarding the use of UV light and therefore visible light curing units were introduced in the late 1970's³⁴⁶. Compared to the UV light, visible light has a deeper curing capability, is more effective through enamel and does not diminish with time or with intensity of the light source³⁴⁷.

The most common initiator used in visible light cure adhesives is camphorquinone, which is sensitive to light in the blue region (450-500 nm) of the visible light

spectrum, with the peak activity centred around 480 nm³⁴⁸. For many years the most popular method of delivering the blue light was the use of a halogen-based light-curing unit. Halogen bulbs produce light when electrical energy heats a small tungsten filament to a high temperature. Despite their use in dentistry halogen lights have several disadvantages. The basic principle of light conversion is inefficient because the light power output is less than 1% of the consumed electrical power, the bulbs have a limited effective lifetime of 100 hours due to degradation of the bulb's components and they generate a high heat³⁴⁹. The halogen lights also require a curing time of 20 seconds for composite resin and 40 seconds for resin modified glass ionomers, which can represent a significant amount of clinical time³⁴⁵. Other studies by Wang and Meng³⁴⁷ and Oesterle *et al.*³⁵⁰ have recommended a 40 second cure time for Transbond in a clinical setting.

Attempts have been made to increase the efficiency of the process by increasing the intensity of the halogen lights, increasing the size of the light guide³⁵¹⁻³⁵³ and the introduction of new polymerisation lamps (argon lasers, plasma lamps (xenon arc lamps) and light emitting diode (LED) units).

Staudt *et al.*³⁵⁴ bonded six groups of stainless steel brackets to bovine incisors exposing them for 4 seconds of halogen light with power density increasing from 500mW/cm² to 3000 mW/cm². Two additional groups were exposed at 3000 mW/cm² for 6 and 8 seconds to simulate a power density of 4500 and 6000mW/cm². The shear bond strength was significantly different between the groups with a power density of 3000 mW/cm² necessary to achieve a comparable bond strength to a 40 second cure

with a 1000 mW/cm² halogen light. However, bond strengths greater than 10MPa were achieved for all power densities above 1000 mW/cm². The shear bond strength did not increase proportionally with power density but followed an exponential model with no significant increase in bond strength above 4000 mW/cm². A second aspect of this study was to measure the Adhesive Remnant Index (ARI)¹⁸¹, which measures the amount of adhesive remaining on the tooth surface after debonding and is scored from 0 to 3:

0 = No adhesive left on the tooth

1 = Less than half the adhesive left on the tooth

2 = More than half the adhesive left on the tooth.

3 = All of the adhesive left on the tooth, with a distinct impression of the bracket mesh.

There was an increase in the ARI score with an increase in power density, demonstrating that there was enhanced adhesion between the bracket/ composite interface.

Frost *et al.*³⁵¹ used a standard 11 millimetre and an elliptical 19 millimetre light guide to bond brackets to extracted human premolars set up in a maxillary arch and then measured the tensile bond strength. They found that there was no statistically significant difference in the tensile bond strengths (7.98 MPa 11mm guide and 8.18

MPa 19mm guide). They also bonded 30 patients using a split mouth design and found comparable failure rates (10%) and that the larger light guide completed the bonding in a significantly shorter time (30% less). Bishara *et al.*³⁵² compared an 11 millimetre guide and a 4 millimetre guide and found that there was no statistically significant difference in the bond strength and no difference in ARI and therefore the bracket/adhesive/enamel failure site. However Oesterle *et al.*³⁵³, using a pulsed xenon plasma arc light with a 7.1 millimetre round light guide and a 16.5 millimetre elliptical light guide, found that there was no difference in bond strength using Light Bond but the larger tip produced a lower bond strength when using Transbond. However, Transbond had a higher bond strength compared to the Light Bond, which at 30 minutes had a bond strength that was not clinically acceptable (6-8 MPa).

Laser curing systems offer a rapid curing while maintaining and possibly improving the properties of adhesives³⁵⁵. Conventional light sources are polychromatic with a broad bandwidth of 400nm to 520nm with an energy density around 400mW/cm², which decays at a geometric progression with distance (e.g. 40% at 6mm)³⁵⁶. Laser light is monochromatic with the argon laser producing a peak wavelength of 488 nm and operating between a narrow bandwidth of 453nm and 496nm with an intensity that approaches 800mW/cm²³⁵⁷. In addition, the laser beam is collimated, focusing on a specific target resulting in a more consistent power density over distance³⁵⁶. *In vitro* studies by Weinberger *et al.*³⁵⁸ and Kurchak *et al.*³⁵⁹ have showed that an argon laser curing the composite for 10 seconds could produce the same bracket bond strength as a 40 second halogen light cure. Bond strengths after argon laser curing at three

different intensities (200, 230 and 300 mW) were compared to conventional light cure by Talbot *et al.* (2000) and again similar bond strengths were found with a 10 second argon laser cure and 40 seconds conventional light cure, also showing that the energy level did not affect the final bond strength. The energy level did not affect the ARI with the majority of the composite being left on the tooth indicating a strong bond between the enamel and composite. Lalani *et al.*³⁵⁷ demonstrated a 5 second cure gave a comparable bond strength to as a 40 second cure. The ARI value at debond was not associated with the laser curing time. However, enamel fracture occurred twice as much in lingually bonded specimens for both the conventional light cure and the laser cure suggesting undesirable enamel damage may occur more frequently with *in vitro* lingual bonding. Clinically, a 10 second cure has been shown to have superior bonding to a conventional light cure for 40 seconds with a failure rate of 2.4 % compared to 5.7 % over 14 months³⁵⁶.

Plasma arc curing (PAC) lights use a high electrical field to generate plasma energy by transforming the xenon gas into a mixture of ions, electrons and molecules thereby releasing a significant amount of energy as plasma. PAC produces a high intensity light delivering more than 1800mW/cm^2 , which is approximately four times the intensity of a conventional light³⁶⁰ with the light being filtered to a narrow band width of 450-500nm for peak absorbance of camphorquinone. However PAC units are large and reasonably expensive. Oesterle *et al.*³⁶¹ showed that light exposure of 6 to 9 seconds with a PAC light produces equal or greater shear bond strength as a 40

second curing time with a conventional light cure. Pettemerides *et al.*³⁶² calculated that a standard two arch bond up, second premolar to second premolar, with a conventional curing light using 10 seconds cure time per interspace (20 seconds per tooth) would take 220 seconds. Using a plasma arc lamp including the 2 seconds recharge interval would take 88 seconds with a 3 second exposure, 70 seconds with a 2 second exposure and 52 seconds with a 1 second exposure. However, they demonstrated that a 3 second cure was necessary to produce a similar bond strength as a 20 second conventional light cure unit. The locus of the bond failure as determined by the ARI scores, was unaffected by the light source or curing time. Sfondrini *et al.*³⁶³, using a split mouth design, found that there were no statistically significant differences in bond failure over 12 months when curing with a plasma light for 5 seconds (failure rate 4.3%) and a conventional curing light for 20 seconds (failure rate 5.4%). A similar study³⁶⁴ using precoated brackets also found there was no statistically significant difference in failure rates between a halogen curing light (4%) and a plasma arc light (7%). This is not surprising as an *in vitro* study³⁶⁵ found that although clinically acceptable bond strengths were obtained there was a significant reduction in bond strength when curing APC brackets with a high intensity light.

PAC lights are also used to cure resin modified glass ionomer cements, with some studies showing no difference in bond strength compared to halogen lights^{345,362,366}. It has been suggested that the use of a PAC light may reduce the effectiveness of the continued acid-base reaction in resin modified glass polyalkenoate cements and

therefore reduces the effectiveness of the long term bond. However, clinically this has not been shown with failure rates for Fuji Ortho LC when bonded with halogen (11.4%) and PAC lights (10.2%) compared to Transbond XT (3.4% for both groups)³⁶⁷. The reduced bond strength for the halogen curing light may be explained by a curing time of 20 seconds which is only half that recommended by the manufacturer. In another study⁶⁸ where the manufacturer's recommendation of 40 seconds was followed there was no difference in bond failure rate over a 6 month period. Silverman and Cohen³⁶⁸ found that conditioning the enamel first and then curing with a PAC light for 3 seconds produced a failure rate of 0.8% over a test period of 4 months.

LED curing units were introduced in 1995³⁶⁹ after breakthroughs in semi-conductor technology led to higher luminous intensities. They generate light in very narrow wavelengths (440-480nm), with no light in the ultraviolet or infrared spectrum eliminating the need for filters. The efficient energy conversion of the LED's has led to the development of cordless light curing units that operate silently (no fan is needed), are resistant to mechanical shock and vibration and have a very long bulb life (approximately 10,000 hours)³⁷⁰. Several studies have shown that LED curing lights are as effective as halogen curing lights^{349,370-372}. Dunn and Taloumis³⁷¹ found no significant differences in the shear bond strength of metal brackets bonded to extracted third molars with LED curing lights and halogen curing lights. There was no difference in the ARI score between the groups with most of the adhesive

remaining on the teeth. Bishara *et al.*³⁷² found LED curing lights could cure two brackets with the same light exposure without influencing the shear bond strength. Swanson *et al.*³⁷⁰ compared three LED lights and one halogen curing light at 10, 20 and 40 seconds cure time. They found that even at 10 seconds a clinically acceptable bond strength (greater than 8 MPa) was achieved but cautioned that manufacturer's guidelines should be followed. The ARI scores demonstrated that for most teeth there was more than half the adhesive remaining on the tooth surface. Usumez *et al.*³⁴⁹ also compared an LED unit with 10, 20 and 40 seconds cure to a 40 seconds cure with a halogen light. They found that a 10 second cure, although producing a clinically acceptable bond strength (mean 9.1 MPa, sd 3.1), was significantly lower than a 20 and 40 second cure (mean 13.9 MPa sd 4.8 and 12.7 MPa, sd 5.1) and a 40 second halogen cure (mean 13.1 MPa, sd 3.1). The ARI scores showed that most of the adhesive remained on the tooth surface suggesting the weak link is the bracket composite interface. Gronberg *et al.*³⁷³ bonded maxillary incisor brackets to bovine incisors with LED curing at various times (5,10,20 and 40 seconds) and distances (1 and 10 millimetres). They found that the shear bond strength increased with increased duration of cure in a curvilinear fashion, however the rate was much less than previously demonstrated^{361,370}. There were no differences in ARI score with distance but significant differences with time as specimens with the lowest bond strengths (5 second cure) had the highest frequencies of ARI score 3 (all of the composite remaining on the tooth surface). There were no significant differences in shear bond strength with the LED when cured at 1 or 10 millimetres, which is in contrast to

Cacciafesta *et al.*³⁷⁴ who found that the shear bond strength decreased with increased light tip distance (0, 3, and 6 millimetres) for an LED light, stayed the same for a conventional light and actually increased for a PAC light. However, at 0 millimetres there is no difference between a conventional light, a PAC or an LED unit. There were no significant difference in ARI scores among the three lights at the three distances tested.

As higher power LED's were introduced ($>1000\text{mW/cm}^2$) there was some concern that this would produce a higher contraction strain, which would reduce the shear bond strength. To overcome this problem the use of low intensity light followed by a final exposure with high intensity light was introduced and called soft start polymerisation. Turkkahraman and Kucukesmen³⁷⁵ compared fast mode LED, soft start LED and a conventional halogen light. They found that the bond strengths were all clinically acceptable with the soft start mode producing the highest bond strength (23.86MPa, sd 6.20), compared to fast-mode LED (17.14MPa, sd 5.75) and the conventional light (17.38MPa, sd 5.41).

Some concerns have been raised regarding the use of high intensity curing lights as the heat generated may induce a temperature rise that could be detrimental to the pulp. It is known that increasing the pulp temperature by 5.5°C may result in irreversible damage³⁷⁶. The temperature change when curing composite restorations

has been well studied with investigations showing that the heat generation may vary depending on the light source, exposure time, composite resin thickness and the distance between the light source and the pulp. However, there are several factors where orthodontic bonding differs from restorative dentistry. The composite layer is thin (reducing the heat from the exothermic reaction), it is a greater distance from the pulp because there is no cavity and the bracket is between the light source and the tooth³⁷⁷.

Based on anatomy the lower incisors have a higher risk of thermal damage due to thinner dentine and enamel on their labial surface. Uzel *et al.* (2006)³⁷⁷ studied the pulpal temperature increase when bonding a lower incisor and premolar bracket using halogen, PAC and LED lights. They found that all the light curing units produced a higher intra-pulpal temperature increase in the mandibular incisor than the premolar, but the temperature rise did not exceed 5.5° with the greatest rise in temperature being 2.03° in the lower incisor with a halogen light. The halogen light caused a greater rise in temperature than the PAC or LED lights, and a greater rise in temperature was observed when the light guide was in contact with the bracket as opposed to 10mm away. Peutzfeldt³⁷⁸ measured the temperature rise induced by 10 LED units and 3 halogen units when curing a cylinder of composite (height 4mm, inner diameter 4mm and outer diameter 16mm) and correlated the power of the units with the temperature rise. He found that two of the halogen units produced a greater temperature rise than LED units of the same intensity (Optilux 501, 650mW/cm²,

temperature rise 9.3°C sd 0.8, Elipar Highlight, $650\text{mW}/\text{cm}^2$, temperature rise 10.0°C sd 0.4 and Diopower, $600\text{mW}/\text{cm}^2$ (LED) 5.3°C sd 0.3) and that for the LED units the temperature rise was greater with higher light intensities. However it should not be assumed that all LED units produce less temperature rise than halogen units e.g. XL 3000 Halogen unit, $360\text{mW}/\text{cm}^2$ had a temperature rise of 4.8°C sd 0.4 compared to UltraLume LED2, $370\text{mW}/\text{cm}^2$, which had a temperature rise of 5.5°C sd 0.2. Although six units produced a temperature rise greater than the critical 5.5°C recommended³⁷⁶ the test specimen is much greater in size than composite adhesive used in orthodontic bonding. Other factors to consider are the heat conduction within the tooth because of the effect of blood circulation in the pulp chamber and the fluid in the dentine tubules and the surrounding periodontal tissues can, which may promote heat convection limiting the intra pulpal temperature rise³⁷⁷.

In summary, the curing light may affect the bond strength by:

- type of light used
- time of curing
- distance light tip
- type of light guide
- adhesive used (type (composites, reinforced modified glass ionomers), thickness, filler content, initiating agent)

(O) Other methods of accelerating the setting of the adhesive

Voster (1979)³⁷⁹ introduced the concept of electrothermal bonding based on the premise that increasing the temperature of the resin would accelerate the setting reaction. At that time, the most common adhesive was the chemically cured Bis-GMA resin, which had a setting time of 3-8 minutes. Speeding up the setting reaction would increase the accuracy of the bracket position as they would not drift, improve patient comfort by speeding up the bonding process and reduce the likelihood of bond failure when the arch wires were tied in. Basically, a low voltage current is passed through the bracket via a modified tweezer and as stainless steel is a poor conductor it heats up. It usually requires 3-4 pulses (4-8 seconds) to set with the bracket temperature ranging from 43.3°-53.6°C for 5 amps of current and 77.5°-85.9°C for 7.5 amps. The pulp temperature rise depends on the thickness of the enamel but is 2.1°C for 5 amps and 2.8°C for 7.5 amps after 3 pulses^{380,381}. The bond strengths of nine adhesives (3 chemical cure, 3 light cured and 2 glass ionomers) were evaluated³⁸² with increased bond strength for all of the adhesives after 2 minutes but equivalent bond strengths after 14 days, which demonstrated that electrothermal bonding is effective in increasing the initial bond strength and has no longer term detrimental effect.

Algera *et al.* (2005)³⁸³ in an *in vitro* study accelerated the setting of three glass ionomer cements with a 60 second application of ultrasound or 60 seconds of heat.

They found that the mean tensile bond strength increased with both the ultrasound and the heat application for the Fuji Ortho LC and Fuji Plus but only with heat application for the Fuji-IX fast. The rise in pulp temperature was 1.0°C for ultrasound and 2.5°C for heat application.

(Q) Repeated bonding

One of the problems in treatment is bracket failure usually as a consequence of the patient accidentally applying inappropriate force to the bracket or a poor bonding technique. The bracket may also be removed intentionally in order to reposition it to reduce the number of finishing bends and facilitate an easier transition to the treatment goals. Before rebonding a bracket it is important to consider: the use of a new or original bracket; reconditioning of the enamel surface; the bonding system to be used. The literature provides contradictory evidence on the strength of rebonded brackets with some studies indicating lower bond strength³⁰³, no difference³⁸⁴ or even higher bond strength³⁸⁵ compared to first time bonds. Mui *et al.*³⁸⁵ compared different techniques of tooth preparation and either bonding a new bracket or microetching the surface of the debonded bracket. They suggested that the best reconditioning method is to remove residual composite with a tungsten carbide bur, re-etch the surface, and rebond a new bracket with either a light or self-cure resin. If the old bracket is rebonded the bond strength is acceptable but its surface needs to be prepared by microetching. Sonis³⁸⁶ also microetched the surface of debonded brackets and found

that the bond strength (16.8MPa) was not significantly different to the bond strength of new brackets (17.1MPa). Bishara *et al.*³⁸⁷ bonded and rebonded brackets 3 times and compared their bond strengths on each occasion. They found that after the first debond the bond strength was similar but after the second debond the bond strength decreased and was similar after the third debonding. They concluded that this was due to residual adhesive remaining on the surface after preparation of the surface with a carbide bur. This reduction in bond strength is reported by Kinch *et al.*¹¹⁶ who found clinically that 10% of second and third time bonds fail within 4-5 weeks whereas 2% of first time bonds fail in the same time period. Mizrahi³⁸⁸ found only 4% of initial attachments fail, but when they are replaced the failure rate rises to 14% and 25% if they are replaced again. This repeated failure could be due to alterations of the enamel following previous bonding procedures. In contrast Oesterle *et al.*¹⁵⁰ reused bovine permanent incisors up to 5 times showing no statistically significant difference in bond strength, although the first bonding did have a slightly greater bond strength emphasising the difference between bovine and human teeth and *in vitro* and *in vivo* testing.

It is also possible to rebond ceramic brackets with most studies concentrating on chemically retentive ceramic brackets. Lew *et al.*³⁸⁹ heated the bases to remove (burn off) the residual cement, the base was then treated with a silane and the bracket rebonded, however they had 30% less bond strength than a new chemically bonded bracket. Gaffey *et al.*³⁹⁰ treated the thermally debonded surface of ceramic brackets with combinations of heat, hydrofluoric acid and silane and found that the bond

strength when rebonded was best for the silane application (12.7MPa), which was 25% lower than the control brackets. Heat and silane also produced a clinically acceptable rebond strength (8.8MPa) but hydrofluoric acid and silane and heat, hydrofluoric acid and silane produced clinically unacceptable bond strengths. Harris *et al.*(1992)³⁹¹ showed that the shear bond strengths of new and rebonded mechanically retentive ceramic brackets (Transcend 2000) were the same with silane having no benefit. Chung *et al.*(2002)³⁹² found that the bond strength of new mechanical retentive brackets (Clarity) were the greatest (15.66MPa) with an acceptable bond strength if the rebonded bracket is treated with sandblasting and a sealant (7.65MPa). The application of silane does not increase the bond strength (5.94MPa) and hydrofluoric acid reduces the bond strength (0.82MPa).

Although laboratory studies indicate similar or reduced bond strength for rebonded brackets clinical studies indicate that there is an increased chance of failure.

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Chapter 3 Assessment of Bonding Accuracy

The introduction of bonded rather than banded attachments has improved the orthodontist's ability to accurately position the brackets¹. Initially the composite resins were chemically cured, which limited the amount of time available for the orthodontist to position the brackets. However the evolution of composite resins led to light cured materials effectively giving unlimited working time and therefore improved accuracy. Poorly positioned brackets result in poorly positioned teeth and necessitate more archwire adjustments which can lead to an increase in treatment time or a final occlusion that is less than ideal². No matter how well the orthodontist performs during the initial bracket placement, the ideal bracket position may not be possible due to limitations of the malocclusion or operator error. Regardless of whether the brackets are placed directly or indirectly, the question is how accurate is the average orthodontist in positioning the brackets? Several published studies have tried to answer this question and although they provide good information regarding accuracy, their results demonstrate that some operators are performing much worse. These studies and why it was necessary to gather new data for the adjustable bracket design will be discussed.

Aguirre et al 1982³

This study examined the accuracy of direct and indirect bracket placement on eleven patients who had maxillary and mandibular incisors, canines and premolars bonded. Each arch was divided into two hemiarches, one side was bonded directly and the other indirectly, decided randomly by the flip of a coin. Photographic images were taken with a specially constructed jig and the resultant slides were projected, magnified 7.15 times and traced. For each tooth there was one linear measurement to identify the vertical position of the bracket and one angular measurement to identify the brackets variation from the considered ideal of 90 degrees. Overall, 206 brackets were bonded and 189 measured. The measurements taken were compared statistically to each other and to the ideal angular measurement of 90 degrees and the ideal linear measurement using a t test for unpaired data.

Results and Conclusions

- (1) Neither technique proved 100 per cent accurate for the linear or angular measurements.
- (2) When comparing the two techniques in relation to the linear measurements, no statistically significant differences were found in the upper arch except for the canines where the indirect placed brackets were placed closer to the ideal height ($p < 0.05$). In the lower arch the second premolars were closer to the ideal with the

direct technique ($p < 0.01$)

- (3) There was an extreme variation in the angular measurements, with the operator having more difficulty in assessing angulation than height.
- (4) When comparing the two techniques in relation to angulation the upper arch demonstrated no statistically significant differences except for the upper canines, which were closer to the ideal angle of 90 degrees with indirect placement ($p < 0.01$) and again in the lower arch there were no statistically significant differences except for the lower canines, which were closer to the ideal with indirect placement ($p < 0.05$).
- (5) When comparing the direct and indirect techniques for right-left differences there was a trend for left side bonds, direct or indirect, to be more accurate in the upper arch and for right side bonds to be more accurate in the lower arch.
- (6) When comparing the angular bracket placement on the same side for the two techniques there were no statistically significant differences. However there were differences when comparing left-right differences with the upper arch showing direct placement better on the right ($p < 0.05$) and in the lower arch the brackets on the left side were closer to the ideal for the direct ($p < 0.05$) and indirect ($p < 0.01$) techniques.
- (7) Brackets were placed within 0.7mm from ideal and within 1.3 degrees of the ideal angulation of 90 degrees.
- (8) Five typodont teeth and one tooth from six different patients were photographed twice, one day apart to test reproducibility.

- (9) In a busy practice the indirect bonding procedure could provide efficient bracket placement in significantly less chairside time, which outweighs the cost involved in the laboratory procedure.

Critique

- (1) Does not give data on mesiodistal positioning.
- (2) Only one operator is tested in positioning the brackets.
- (3) There is no indication of the severity of the malocclusions or the types of the malocclusions.
- (4) No definition on where the brackets were placed vertically, however as a Boone gauge was used it can be assumed that it was a measured distance from the incisal edge.

Fowler *et al* 1990⁴

Seventy-one clinicians of various levels of experience were asked to mark in pencil the long axis of the clinical crown (LACC) and the LA point with a pin on 3 identical stone models at least one week apart with no reference to any previously marked models. The model represented the upper right quadrant from the first premolar to central incisor. They were given a copy of Andrews' definitions and divided into 3 groups. Group 1 consisted of 25 experienced clinicians with a mean of 6.3 years of

experience, Group 2 consisted of 21 recently graduated clinicians with less than 6 months of experience and Group 3 consisted of 25 final year dental students, who had no training or experience with preadjusted appliances.

The marked LACC and LA point were recorded using a Reflex Microscope and assessed in terms of LACC angulation and LA point height (y-axis) and mesiodistal position (x-axis). The clinical implications of the LACC angulation were assessed trigonometrically using average tooth dimensions⁵ to calculate change in apex position. Changes in torque were assessed using a magnified plot of the labial curvature and using an acetate overlay to calculate the changes in torque for the variations in LA height.

Results and Conclusions

- (1) The variation in perception by the same clinician indicated that the error was greatest for LACC angulation, less for LA height and least for LA mesiodistal position. The greatest variation for angulation occurred on the central incisor (average + 3.18°) and least on the canine (average + 1.96°). The mean variations in LA height were less than + 0.15mm and for the mesiodistal position were less than + 0.22mm).
- (2) The variation in perception between clinicians indicated that the error was greatest for LACC angulation, less for LA height and least for LA mesiodistal

position. The greatest variation in angulation occurred on the central incisor (average + 3.75°) and was least on the canine (average + 2.61°). The mean variations in LA point height were all less than + 0.32mm and LA point mesiodistal position all less than + 0.20mm.

- (3) The variation in perception due to training or experience indicated that recent training reduced the amount of intra- and inter-clinician variability in the perception and marking of the LACC angulation. There was a slight reduction in the intra-clinician variability in LA height with the ability to identify the mesiodistal position similar in all three groups. There was a slight trend for recently trained clinicians to be less variable in the LACC angulation.
- (4) Only the extreme variation in the LA point height would result in changes to crown inclination (torque) and even then the changes are likely to be small.
- (5) The alterations in relative root apex positions appear to be small and would not, for the majority, be sufficient to cause root approximation. However, for the extremes of the LACC angulation poor root apex position would occur.

Critique

- (1) Tested on a model, which does not represent a true clinical simulation. The premolar can be viewed straight on, thereby not producing possible parallax errors that may manifest clinically.

- (2) The test model had well aligned teeth; clinically the brackets are placed on a crowded malocclusion. A crowded malocclusion may pose more problems in identifying the LACC and LA points.
- (3) Lines were drawn to identify the LACC and an indentation for the LA point. This does not represent clinically how a bracket would be placed. The variation in tooth morphology, dexterity of the operator or difficulty in identifying the markings on a bracket could all increase the error in bracket placement.

Balut *et al* 1992⁶

The pre-treatment models of five orthodontic patients representing different malocclusions (one Class I, two Class II Division 1 and two Class II division 2) were duplicated and a diagnostic set up made with the teeth positioned to “ideal” angulation (as per Andrew’s six keys and Roth’s modifications). Acrylic occlusal registration keys (upper and lower) were fabricated for each set up. Then ten faculty members placed preadjusted brackets (“A” company) on each of the five models from first molar to first molar, inclusively. The models were set up in a mannequin to simulate a clinical situation.

The 50 models were then sectioned from the base and transferred to the occlusal keys and secured in place with cyanoacrylate so that five standard photographs could be taken of each set up. The resultant photographs were digitised and the outer edges of each bracket slot was used as a reference. The vertical and angular differences in

bracket positions measured between tooth pairs by digitising the outer edges of each bracket.

Results and Conclusions

- (1) Discrepancies were found in height and angulation. A mean of 0.34mm for the linear measurements (sd 0.29) and 5.54° for the angular measurements (sd 4.32°) between bracket pairs for all faculty members.
- (2) There were statistically significant differences in angular bracket position between 3 faculty members and in linear measurements between 2 faculty members ($p < 0.01$).
- (3) When analysing linear and angular discrepancies between the five models there were no statistically significant differences in the vertical but model 2 showed less angular discrepancy than model 5, both being class II ($p < 0.01$). However, model 5 had a severely malposed lower right first premolar which made it impossible to place the bracket correctly and model 2 had larger crowns and no severely rotated teeth making it easier to place the brackets. There was no correlation between malocclusion type and error in bracket placement.
- (4) The lower anterior teeth showed the least variation in both angular and vertical discrepancy ($p < 0.001$).
- (5) The teeth with the most angular discrepancy were the upper anterior teeth and the

lower canines ($p < 0.001$).

- (6) The upper second premolars demonstrated the most vertical discrepancy in bracket placement.
- (7) The error in bracket placement seems more related to the skill of the operator, tooth structure, size of the clinical crowns and malposition of the tooth in the dental arch.
- (8) The clinical implications in the error of bracket placement in this study are unstable tooth positions, lack of root paralleling, food impaction because of marginal ridge discrepancies and failure to establish the very specific occlusal scheme of canine rise or mutually protected occlusion.
- (9) With proper wire bending or rebonding bracket positions, an excellent result can be achieved. However, increased time and effort must be expended by the orthodontist and the patient to accomplish these goals.

Critique

- (1) The linear measurements were relative to each bracket pair rather than related to either the centre of the clinical crown or a measured difference from the incisal edge.
- (2) The angular discrepancy had a range of 29.1° ; however, this doesn't give the actual angular discrepancy of individual brackets but the discrepancy between

bracket pairs.

- (3) All of the operators were experienced; however, there is no indication of their level of experience.
- (4) The time to position the brackets was not recorded.
- (5) There are no mesiodistal measurements.

Taylor *et al* 1992⁷

Twelve clinicians were asked to place straight-wire brackets at the mid-point of the clinical crown on the six anterior teeth (upper left canine to right canine) on a crowded typodont. The upper left central incisor was fractured to assess whether irregular crown form affects bracket positioning. All of the clinicians had at least one year of experience with straight-wire brackets at Andrew's LA point⁸. The bracket positioning was carried out on three separate occasions a minimum of 4 weeks apart. After the brackets were bonded they were removed from the typodont and placed in a jig, and then the bracket position was measured using an Image Analyser (Joyce Loebel Magiscan). The angulation of the slot, vertical (y) and horizontal (x) position was recorded relative to fixed landmarks. Readings were duplicated to carry out an error analysis. This checked the reliability of the jig and the repositioning of the teeth in the jig.

Results and Conclusions

- (1) Slot angulation showed the largest variation, with vertical bracket placement the least variation.
- (2) There was a wide variation in the slot angulation, with many of the operators unable to consistently angulate the brackets within a 2° limit on the 3 different occasions. The maximum error was 19.03°.
- (3) There was a greater variation in the angulation of the brackets on the fractured upper left incisor when compared to the upper right incisor, which suggests that bracket position is more variable on teeth with fractured crowns or abnormal shapes.
- (4) The variation in horizontal bracket placement for all operators on all occasions was within 0.5mm.
- (5) The variation in vertical bracket position between operators, as demonstrated by the standard deviation, lay within a 0.5mm range. However, analysis of variance demonstrated a significant difference between the ranges for the different teeth.
- (6) There was a large variation in the inclination of the bracket slot, which was surprising as the vertical position was reliable. It may reflect the variation in angulation combined with the thickness of the adhesive causes the bracket base not to fit flush.
- (7) It is suggested that methods be sought to minimise errors in positioning these

attachments on the teeth, with particular attention given to correct bracket angulation.

- (8) Further investigation is required to identify the most reliable technique for bracket placement to allow optimum performance of the preadjusted bracket system.

Critique

- (1) Due to anonymity operator experience was not related to accuracy.
- (2) The study was on a typodont, which was not set up to reflect a clinical simulation.
- (3) The time to position the brackets was not recorded.
- (4) Only one bracket position (LA point) was investigated.

Koo *et al* 1999⁹

Nine faculty members bonded orthodontic brackets directly and indirectly, from second premolar to second premolar on a duplicated stone model of a class II crowded malocclusion mounted on a mannequin to simulate a clinical situation. The heights the brackets were to be positioned was specified and a Boone gauge was provided. The model was sectioned and each tooth was mounted in a jig and photographed, magnified x7.29 and projected where the outline of the crown and the

central vertical line of the bracket were traced on acetate paper. The central horizontal line parallel to the upper and lower margins of the bracket slot was drawn at the midpoint of vertical line. These outlines were superimposed over that of an ideal set up and bracket height, mesiodistal position and angular error was measured.

Results and Conclusions

- (1) There were no statistically significant differences between direct and indirect placement in the vertical positioning for most teeth, except that indirect showed better placement for upper right second premolar and lower left central incisor ($p < 0.05$).
- (2) There were no statistically significant differences between direct and indirect placement in the mesiodistal positioning except that indirect bonding was better for the lower left central incisor ($p < 0.05$).
- (3) There were no statistically significant differences between direct and indirect placement in the angular positioning except that direct placement was better for the upper right lateral incisor ($p < 0.05$).
- (4) Overall, on average, indirect bonding was more accurate in bracket height ($p < 0.05$) with no differences in mesiodistal positioning or angulation.
- (5) Neither technique showed ideal bracket placement.

Critique

- (1) There is no indication of the amount of experience of the faculty members.
- (2) The time to position the brackets was not recorded.
- (3) This study only assesses measured distance from the incisal edge and not the position relative to the centre of the clinical crown.

Hodge *et al* 2004¹⁰

Twenty-six consecutive patients had MBT preadjusted Edgewise appliances fitted directly or indirectly according to split mouth design. A set of working models had the vertical facial axis marked and the brackets were placed on the models with a height gauge. The models were photographed at two-thirds magnification on an acetate locator. The teeth, which were to be bonded directly were removed and a transfer tray constructed. Once the brackets were bonded in the patient (direct and indirect) alginate impressions were taken over the brackets and die stone models were cast. The incisors and canines were then photographed as before. The outline of the crowns of the teeth with the brackets in situ prior to bond up, together with the vertical outline of the tie wings were traced manually at 15 times magnification. The vertical outline of the tie wings and horizontal midlines of the post-bond up images were added to the first to identify vertical, horizontal and angular differences. The linear measurements were calculated knowing the scale of known bracket

dimensions. This was necessary since although the camera angulation and photographic magnification remained constant the teeth were at different angulations.

Results and Conclusions

- (1) There was no significant difference between mean bracket placement errors for direct and indirect bonding methods. However, indirect placement reduces the envelope of error in bracket placement.
- (2) The range of each type of error was greater for direct placement rather than the indirect technique.
- (3) Errors in the vertical plane were significantly greater than those in the horizontal plane, which in turn were greater than the angular errors ($p < 0.05$).
- (4) Errors were greater in the maxillary arch than the mandibular arch ($p < 0.05$).
- (5) Directly bonded brackets tended to be more gingivally positioned than the ideal.
- (6) There were no significant differences between right and left sides of the mouth.
- (7) The magnitude of the findings are of clinical significance.

Critique

- (1) Only incisors and canines were measured.
- (2) Only one operator was examined; therefore, the data do not reflect in general how orthodontists may perform.
- (3) The bracket positions are compared to positions set up manually on a model.

Manual set up on a typodont/ model has been shown to be inaccurate^{6,7} and therefore, the errors could be greater than demonstrated.

Fukuyo *et al* 2004¹¹

Forty subjects (20 male, 20 female) with normal occlusions had their study models digitised using a 3D laser scanner. One operator established bracket positions on the facial surfaces of the images using three methods:

- (1) The FA method, which bisects the clinical crown into gingival and occlusal portions.
- (2) The Height method, which measures from the incisal edge and cusp tips.
- (3) The Marginal Ridge method, which measures from the marginal ridge.

The variability in each bracket position was measured from a constructed plane, which was established as the plane where the sum of the square of the shortest distance between bracket positions established by each method on a given plane reached a minimum.

Results and Conclusions

- (1) This study clarified the characteristics of the three bracket placement methods and provided useful clinical information for bracket positioning.

(2) The FA method:

- In the maxillary arch first molar brackets (mean 0.57 ± 0.25 mm) were positioned most gingival and first (mean -0.44 ± 0.24 mm) and second premolar brackets (-0.46 ± 0.32 mm) were occlusal to the virtual bracket plane.
- In the mandibular arch central (mean 0.15 ± 0.22 mm), lateral incisor (mean 0.12 ± 0.23 mm) and first molar brackets (mean 0.12 ± 0.18 mm) were occlusal and canine (mean -0.19 ± 0.33 mm), first premolar (mean -0.12 ± 0.29) and second premolar brackets (mean -0.08 ± 0.22 mm) were gingival to the virtual bracket plane.

(3) The Height Method:

- In the maxillary arch first premolar brackets (-0.33 ± 0.34 mm) were occlusal to the virtual bracket plane.
- In the mandibular arch canine (mean -0.14 ± 0.27 mm), first premolar (mean -0.25 ± 0.24 mm) and second premolar brackets (-0.45 ± 0.21 mm) were gingival and central incisor (mean 0.19 ± 0.23 mm) and first molar brackets (mean 0.42 ± 0.16 mm) were occlusal to the virtual bracket plane.

(4) The Marginal Ridge Method:

- In the maxillary arch lateral incisor (0.26 ± 0.24 mm) and first molar brackets (mean 0.25 ± 0.27 mm) were gingival and first premolar (mean -0.27 ± 0.29 mm) and second premolar brackets (mean -0.27 ± 0.18 mm) occlusal to the virtual bracket plane.
- In the mandibular arch central incisor (mean 0.15 ± 0.29 mm), lateral incisor

(mean 0.26 ± 0.24 mm) and first molar brackets (mean 0.31 ± 0.23 mm) were occlusal and canine (mean -0.20 ± 0.28 mm), first premolar (mean -0.17 ± 0.27 mm) and second premolar brackets (mean -0.29 ± 0.30 mm) gingival to the virtual bracket plane.

Critique

Does not give information regarding accuracy of actual bracket positioning, but rather if brackets were placed ideally according to each method there would not be perfect alignment and it would require bracket repositioning or arch wire adjustments to fully correct the malalignment.

Eliades et al 2005¹²

Forty adolescent patients were divided into 2 groups. The first group had the bracket slot positioned 4 mm from the incisal edge, with the use of a gauge, using the centre of clinical crown concept (FA point). In the second group the bracket position was determined individually, with the objective of levelling out the difference between the proximal embrasures and transferring the difference between the premolar and adjacent molar to the bracket slot difference.

Measurements were performed clinically with a gauge with 0.5 mm accuracy. The measurements included the distance of the slot from the gingival and incisal edges as

well as the difference in proximal contact height between the first and second premolars. Bite registration with the use of articulating paper was performed with the archwire removed and prior to debonding.

Results and Conclusions

- (1) The 4mm scheme led to significantly higher number of discrepancies of proximal contact between the first and second premolars. In most cases, the distal proximal contact of the second premolar was positioned 1 to 1.5 mm gingival to the mesial marginal ridge of the molar and first premolar.
- (2) The occlusal contact assessment indicated that bonding the bracket at 4mm from the incisal edge (the centre of the crown) led to a reduced number of contacts and a poorer occlusion.

Critique

- Only gives information about premolars bracket positioning.

Therefore, it can be seen that the studies are limited and do not answer all of the questions necessary to design an adjustable bracket. It was decided to perform two studies to determine the accuracy of bracket placement. These two studies would look

at two aspects of accuracy; firstly, whether clinical experience played a role and secondly, whether the technique of placement (i.e. where the clinician aims to position the bracket) affects the accuracy. This would hopefully provide some insight into bracket positioning errors and provide the data necessary to design the prototype bracket and ensure it was able to fulfil the necessary requirement of compensating for bracket positioning errors. The tooth that was consistently positioned with the most error would be selected and a bracket designed to compensate for these errors. It would also have to fulfil the requirements of maintaining satisfactory bond strength after movement and also not pose a significant risk of damage to the pulpal tissue.

This Chapter discusses three studies:

- (1) Measuring the difference in accuracy of direct bonding between experienced clinicians (orthodontists) and inexperienced clinicians (dental students) in positioning the orthodontic brackets at the centre of the clinical crown.
- (2) Measuring the difference in accuracy of direct bonding by experienced clinicians (orthodontists) at the centre of the clinical crown and a measured distance from the incisal edge.
- (3) Measuring the excess adhesive around orthodontic brackets after bonding orthodontic brackets with APC Plus adhesive coated appliance system and Transbond XT applied at the chairside according to manufacturers instructions.

Whilst part 3 would have no direct bearing on the design of the final prototype it was an opportunity to examine an area where recent claims that the colour change feature gives the clinician a visual marker of adhesive placement and is especially convenient in flash clean up. As the methodology could be incorporated into one of the experiment designs without adversely affecting its outcome it was pursued and is therefore presented.

As the studies have been sent for publication the manuscripts are included as part of the chapter. As it is necessary to be brief in publications, additional method details will be presented prior to the papers and additional discussion following the papers.

The Experimental Material

The studies were set up with 20 test subjects in each group with 20 experienced clinicians (orthodontists) bonding at the centre of the clinical crown and a measured distance from the incisal edge and 20 inexperienced clinicians (dental students) bonding at the centre of the clinical crown. This would provide an analysis of accuracy of orthodontic bracket positioning when aiming to place the brackets at the centre of the clinical crown, comparing experienced clinicians and inexperienced clinicians (Study 1), comparing the accuracy of experienced clinicians when aiming to place the brackets at the centre of clinical crown versus measured distance from the incisal edge (Study 2). It would also provide the means and range of errors for vertical, mesiodistal and angular tip errors, allowing the prototype bracket to incorporate the necessary amount of movement into its design. The experienced clinicians would complete the third study when they positioned their brackets at the centre of clinical crown. Half of the group (10 subjects) would bond brackets with APC Plus System on the upper right and lower left and brackets with the Transbond XT on the upper left and lower right and the other half (10 subjects) would bond

brackets with APC Plus System on the upper left and lower right and brackets with the Transbond XT on the upper right and lower left, effectively a split mouth design. In order to perform the three studies, the materials required were:

(1) 60 sets of orthodontic brackets (20 brackets per set, upper and lower second premolar to second premolar)

Ten sets of 0.18 inch slot, Victory series low profile MBT APC Plus System brackets and 50 sets of 0.18 inch slot, Victory series low profile MBT, 1 tube of Transbond XT and one 4-4.5 millimetre height gauge were provided by 3M Unitek, Australia at a reduced cost. The lower premolar brackets were off set and the prescription of all of the brackets is demonstrated in Table 3.1.

Table 3.1 The prescription of the Victory series low profile MBT brackets.

Tooth	Upper		Lower	
	Tip (degrees)	Torque (degrees)	Tip (degrees)	Torque (degrees)
Central Incisor	4	17	0	-6
Lateral Incisor	8	10	0	-6
Canine	8	0	3	0
First Premolar	0	-7	2	-12
Second Premolar	0	-7	2	-17

(2) 60 sets of typodont teeth (manufactured).

(3) 60 crowded malocclusion typodonts (manufactured).

(4) A selection of instruments (mirror, probe, periodontal probe, scaler, $\frac{1}{2}$ Hollenback, flat plastic, ruler and height gauges (4-5.5 millimetres, 3M Unitek)), borrowed from the orthodontic clinic.

(5) Latex lips for the typodont to prevent direct vision of the premolar teeth (manufactured).

(6) An adjustable mount for the typodont (existing adjustable typodont mount was modified).

(7) A custom camera jig to photograph the teeth straight on (buccal) and from the occlusal with custom made jigs for each tooth to enable them to be positioned in a reproducible position (manufactured).

(8) Digital software to measure the bracket positioning errors (AnalysSIS Pro 3.1, Soft Imaging System, Munich, Germany), available at the department of Orthodontics, University of Sydney.

(9) Training and access to a Scanning Electron Microscope (SEM). Dr Ian Kaplan, Electron Microscope Unit, University of Sydney provided the training with the access to the SEM (Phillips XL30) allowed after registering a project with the Electron Microscope Unit.

The Manufacturing of the Experimental material

Unfortunately, due to a lack of funding and the prohibitive cost of typodont teeth it was necessary to manufacture the teeth for these studies. A set of dentoform typodont teeth (Dentaurum, Germany, Figure 3.1) was used and a mould taken with an addition cured vulcanising duplication laboratory silicone impression material (Dublisil-15) (Figure 3.2). The teeth were removed from the mould and a rapid set polyurethane resin (Easy Cast, Barnes, Australia) was prepared by mixing the two liquids in equal proportions, the mixture was injected into the mould with a monoject 412 dispensing syringe. Once the polyurethane resin had set the duplicated teeth were removed and the excess around the apex was removed. Any of the duplicated teeth that had any visible defects were discarded and the process was repeated until 60 sets of teeth were available (Figure 3.3).

Figure 3.1 Dentoform Typodont Teeth (Dentaurum, Germany)

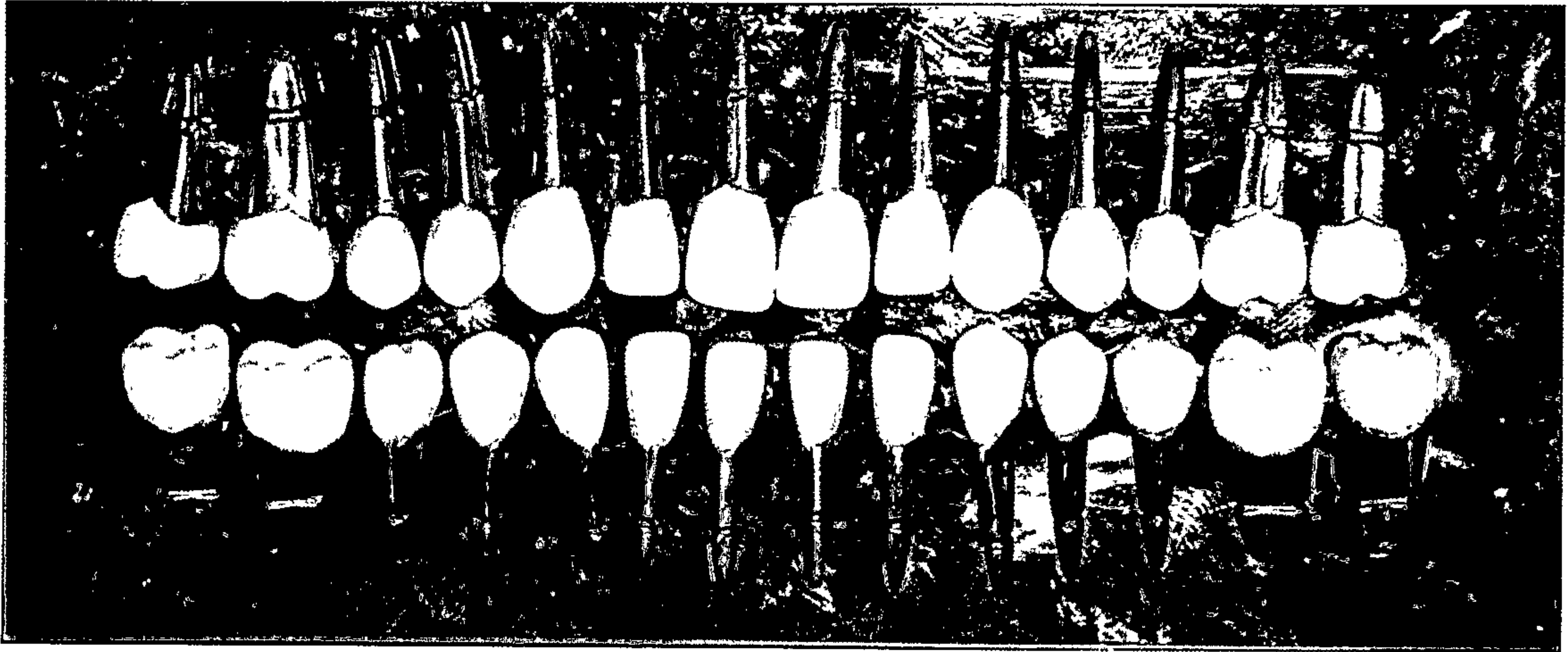


Figure 3.2 A Dublislil-15 mould for construction of the typodont teeth

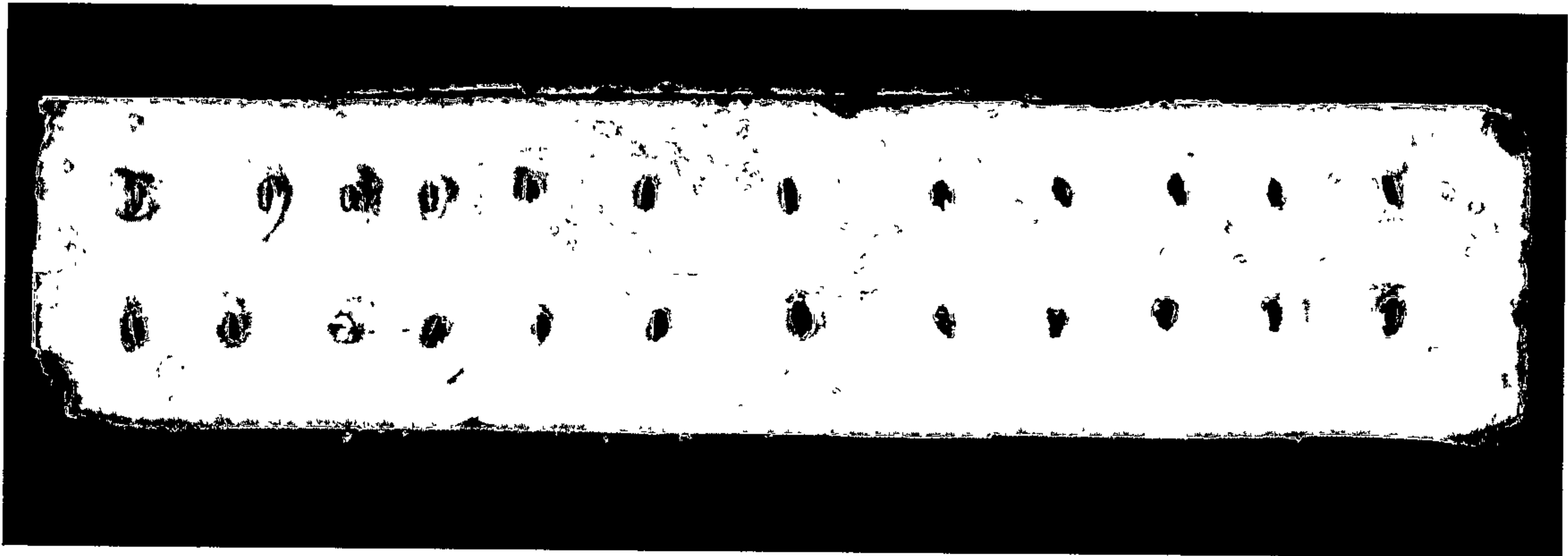


Figure 3.3 A set of manufactured typodont teeth



A standard typodont with well aligned teeth would not provide a realistic worst case scenario and therefore, would under-estimate the amount of error in bracket placement. Therefore, it was necessary to make a custom made crowded typodont for the studies.

The starting point was a typodont (Ormco) with well aligned teeth (Figure 3.4). The teeth were removed and an impression was taken with an addition cured vulcanising duplication laboratory silicone impression material (Dublisil-15) (Figure 3.5) and a rapid set polyurethane resin (Easy Cast, Barnes, Australia) duplicate was made by mixing the two liquids in equal proportions and pouring mixture into the mould. The area that houses the teeth was reshaped, using a straight handpiece with an acrylic

bur, so as to create enough space to facilitate the placement of the previously made typodont teeth (Figure 3.6).

Figure 3.4 Typodont with well aligned teeth (ORMCO, CA, USA)

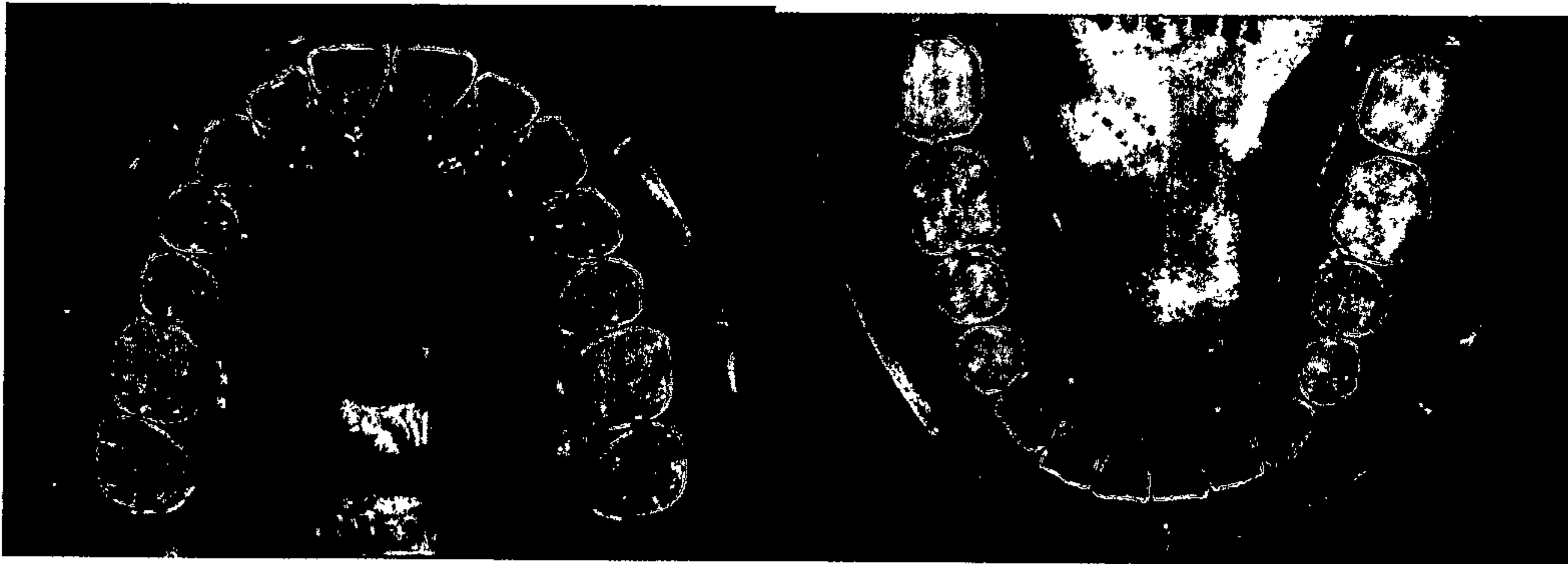


Figure 3.5 Dublislil-15 mould of the Ormco Typodont

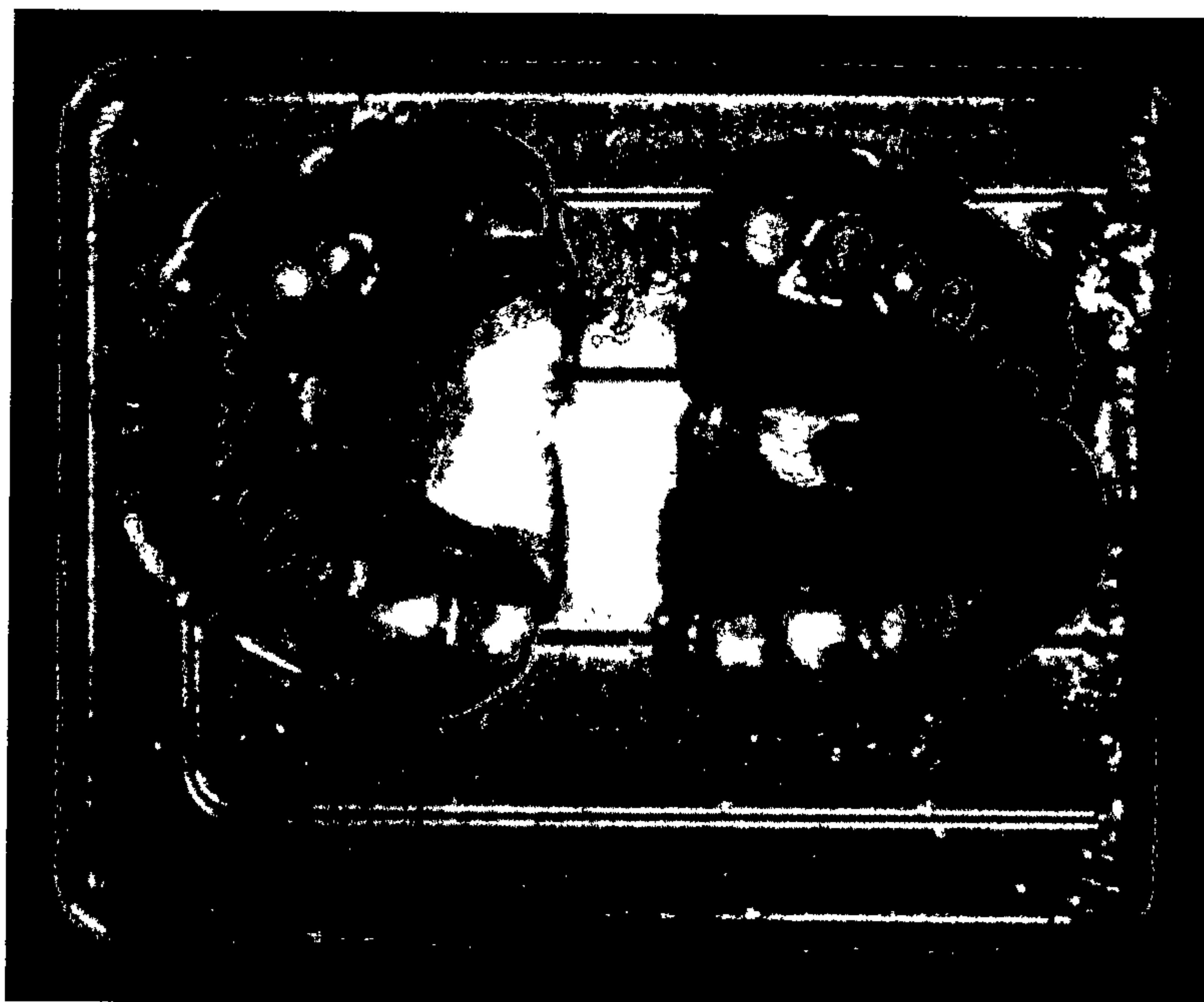
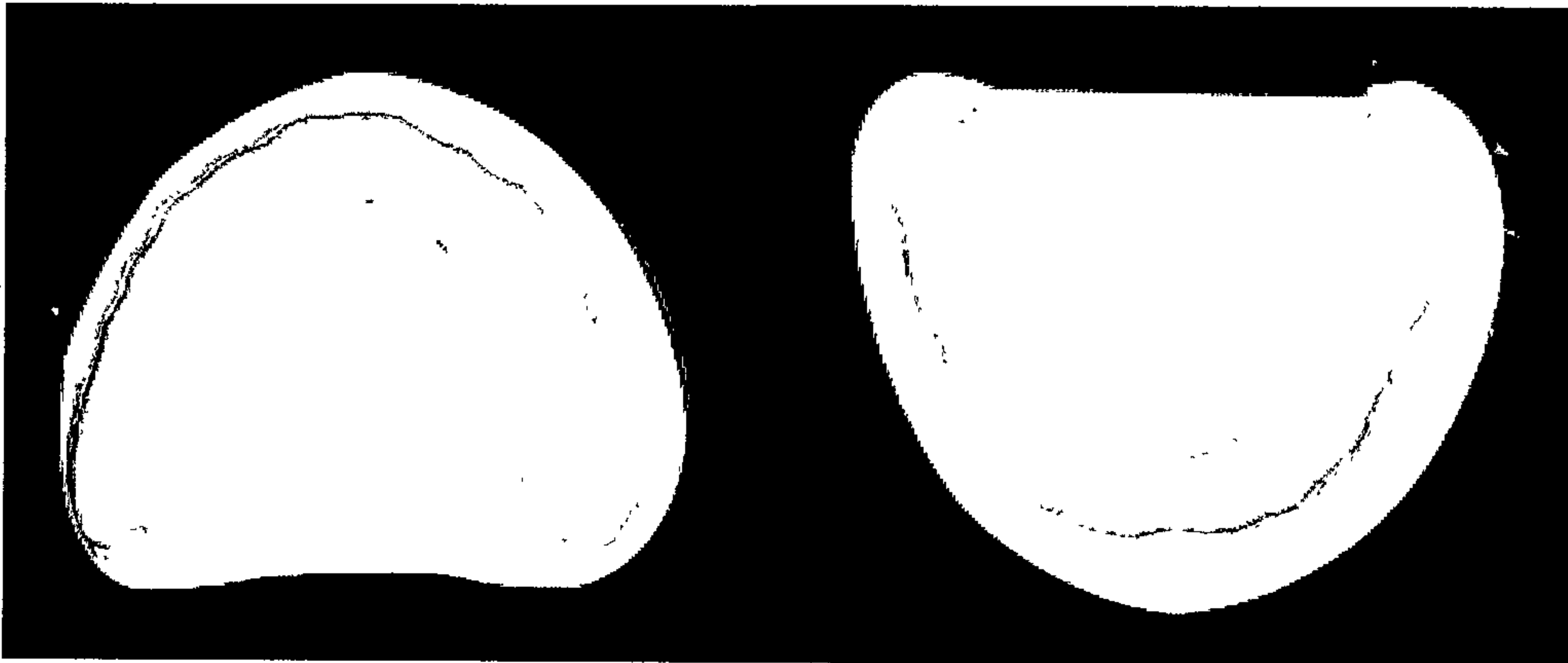
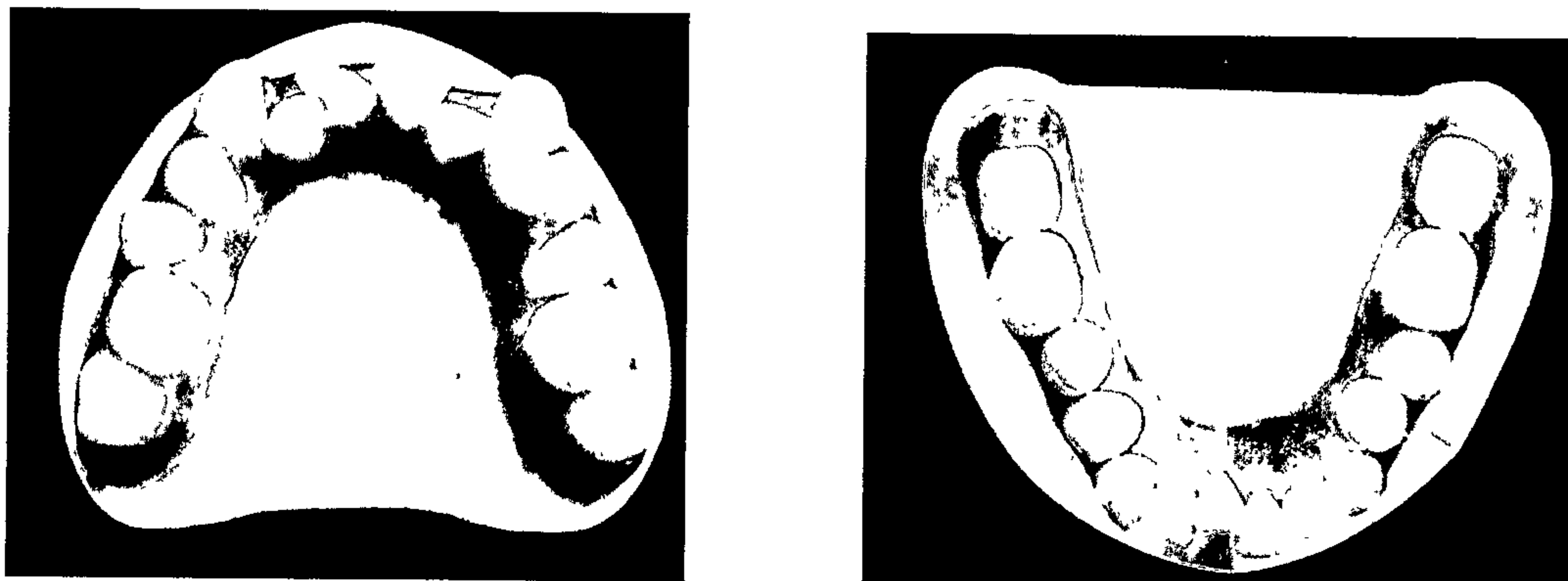


Figure 3.6 The duplicated typodont base with reshaped alveolus.



The typodont teeth were then set up in a class I malocclusion with severe crowding using wax (Investo dental modelling wax, Ainsworth Dental Company Marrickville, Australia). However, no tooth was so severely displaced that it would prevent ideal bracket placement (Figure 3.7).

Figure 3.7 The custom made severely crowded class I malocclusion



An impression was taken with an addition cured vulcanising duplication laboratory silicone impression material (Dublisil-15) (Figure 3.8) thus creating a template for the resetting up of the malocclusion on subsequent typodonts (Figure 3.9).

Figure 3.8 Duplication of the Class I crowded Typodonts

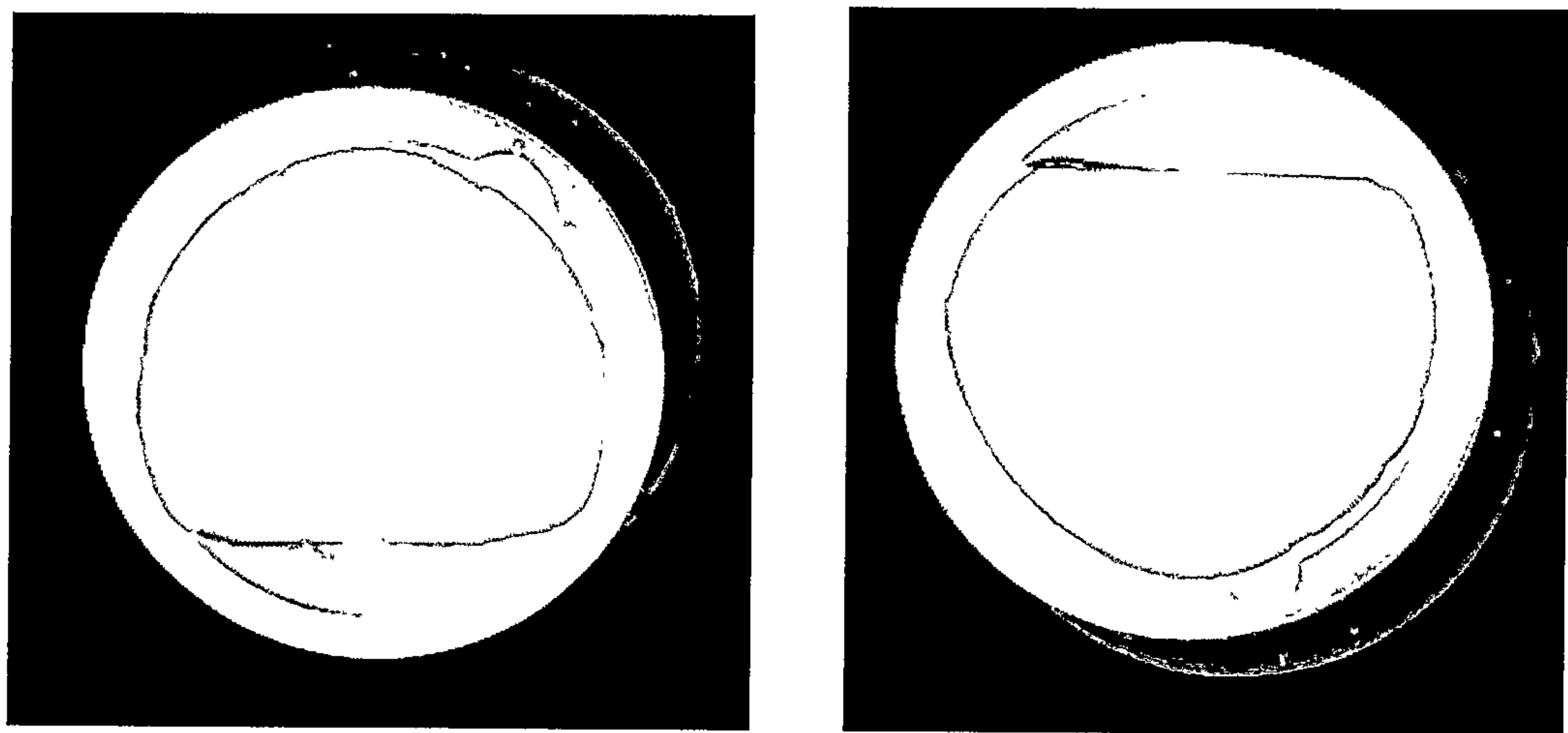
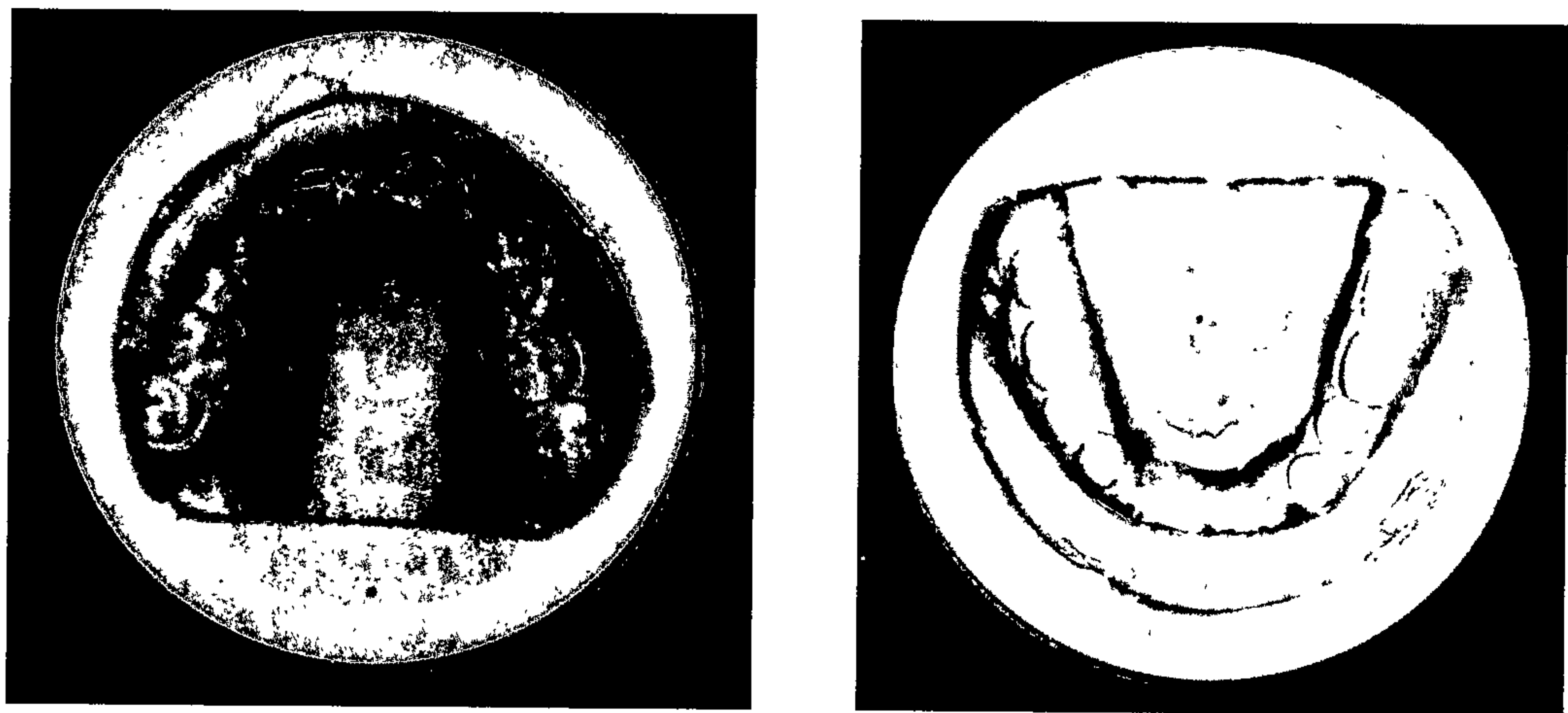


Figure 3.9 The Dublisil-15 Templates (moulds) of the Class I crowded Typodonts



As there were 60 sets of orthodontic brackets to be bonded it was more time efficient to make a number of identical typodont bases. Therefore, the teeth were removed from the base and an impression was taken with an addition cured vulcanising duplication laboratory silicone impression material (Dublisil-15) (Figure 3.10) and 10 sets of bases were made. The bases had 2 holes drilled in the base to enable the heated wax to be poured into the mould (Figure 3.11). However, when setting up the 10 bases with the malocclusion it was more practical to keep the molar teeth in position and only remove the experimental teeth, this necessitated the addition of 2 more anteriorly positioned holes.

Figure 3.10 Dublisil-15 template (mould) of the bases

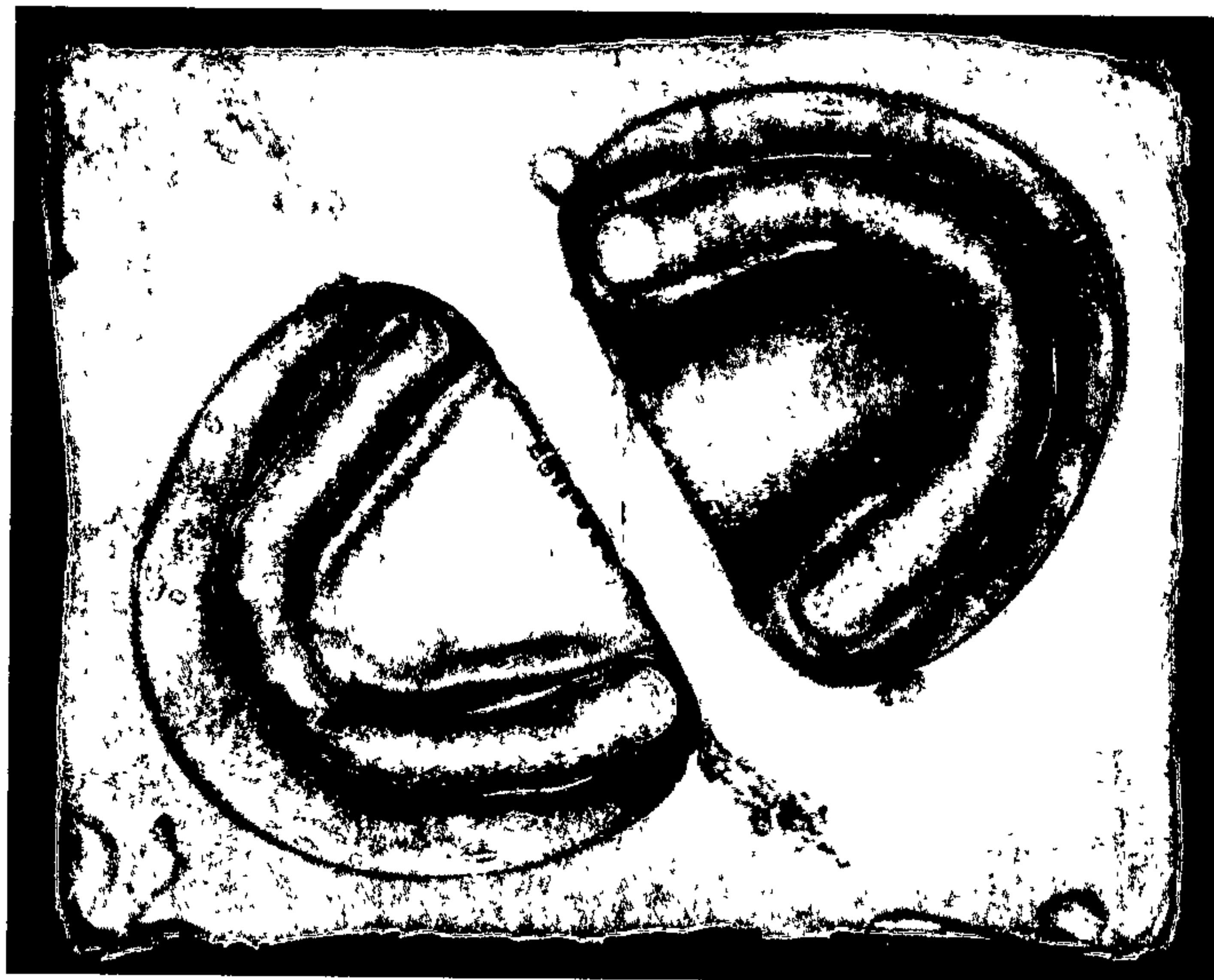
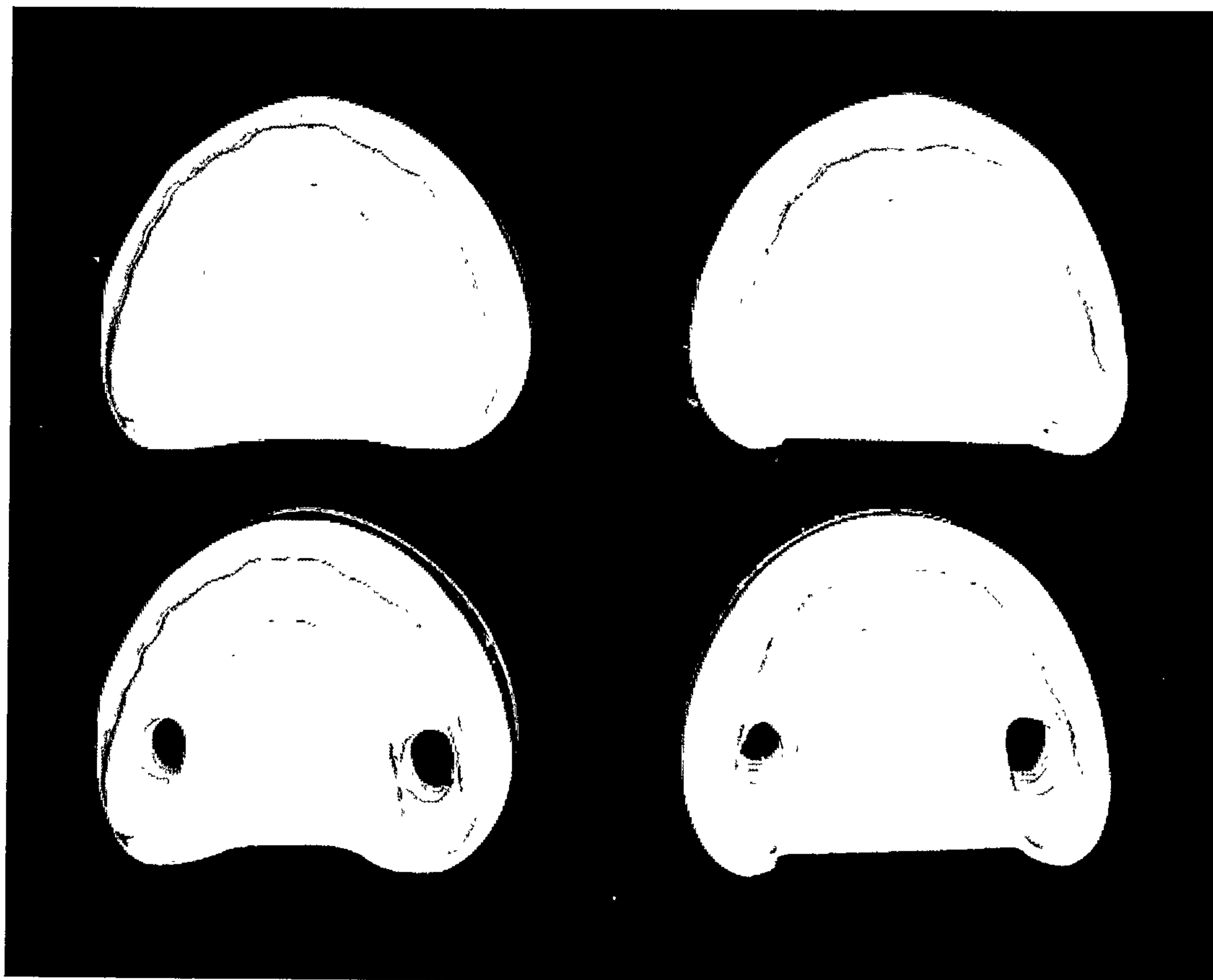


Figure 3.11 Modification of the Custom bases to allow wax to be poured



To make each of the 60 identical class I crowded malocclusions the typodont teeth were positioned in the Dublisil-15 templates (Figure 12). The modified bases were then placed (Figure 3.13) and the heated wax (Ainsworth Dental Company, Australia) poured in. As there was some shrinkage of the wax on cooling additional wax was placed and the excess smoothed once the wax had set. The typodonts were removed from the templates and any wax that was on the crowns of the teeth was removed.

The alveolus and gingival wax was then prepared in a similar way to preparing a denture for investment, it was finely smoothed initially by a flame with a hand held torch and then brought to a fine shine with an alcohol wipe. This made the typodont much more presentable and ensured that each one was carefully assessed, if any of the teeth had moved on placing the bases the teeth were removed and the process was repeated. The final crowded typodont was then created (Figure 3.14)

Figure 3.12 Typodont teeth positioned in the Dublisil-15 Template

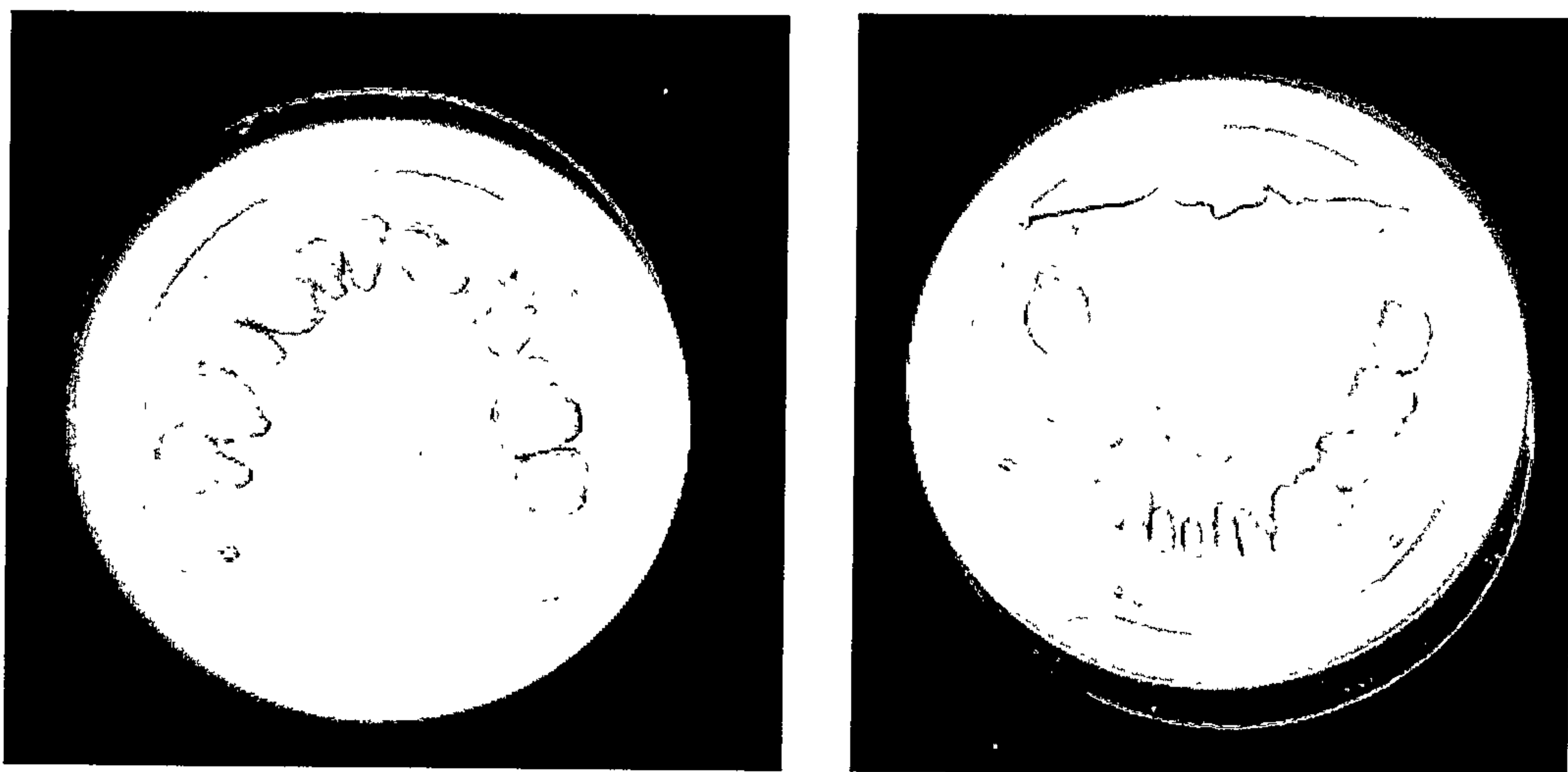


Figure 3.13 Bases positioned and wax poured

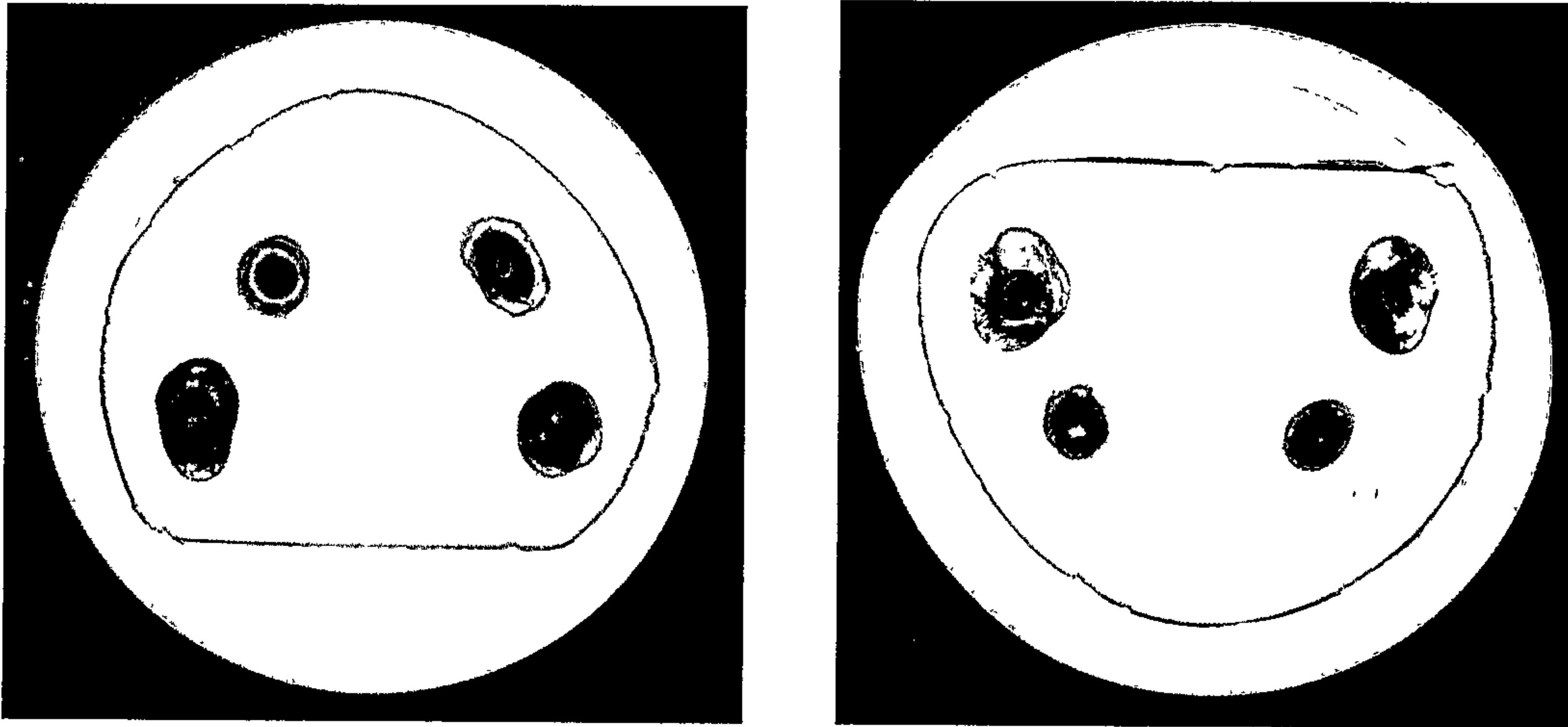
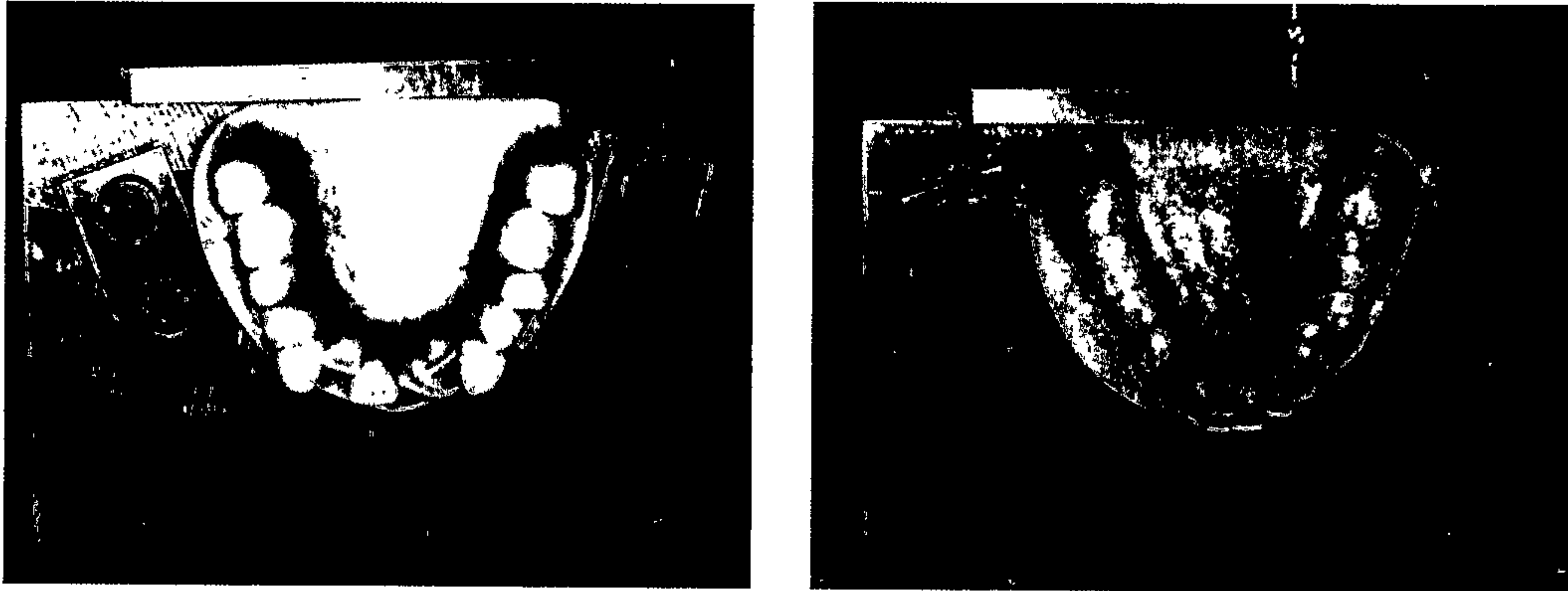


Figure 3.14 Class I crowded Typodont



Each of the 10 sets of typodonts was positioned in a jig (Figure 3.15) and had 2 holes drilled to enable them to be mounted on a standard adjustable typodont mount that had been modified (Ken Tyler, Department of Biomaterials, University of Sydney).

Figure 3.15 The Jig to Reproduce the Mounting holes



The modified rod consisted of the standard adjustable rod with the addition of a brass plate (50mm x 55mm) bent at 140 degrees (22mm from the superior end) with 4 mounting pins attached (Figure 3.16). The mounting pins would allow the each of the custom made typodonts to be mounted simulating a patient with their mouth open ready for the positioning of the orthodontic brackets (Figure 3.17).

Figure 3.16 The modified adjustable mount

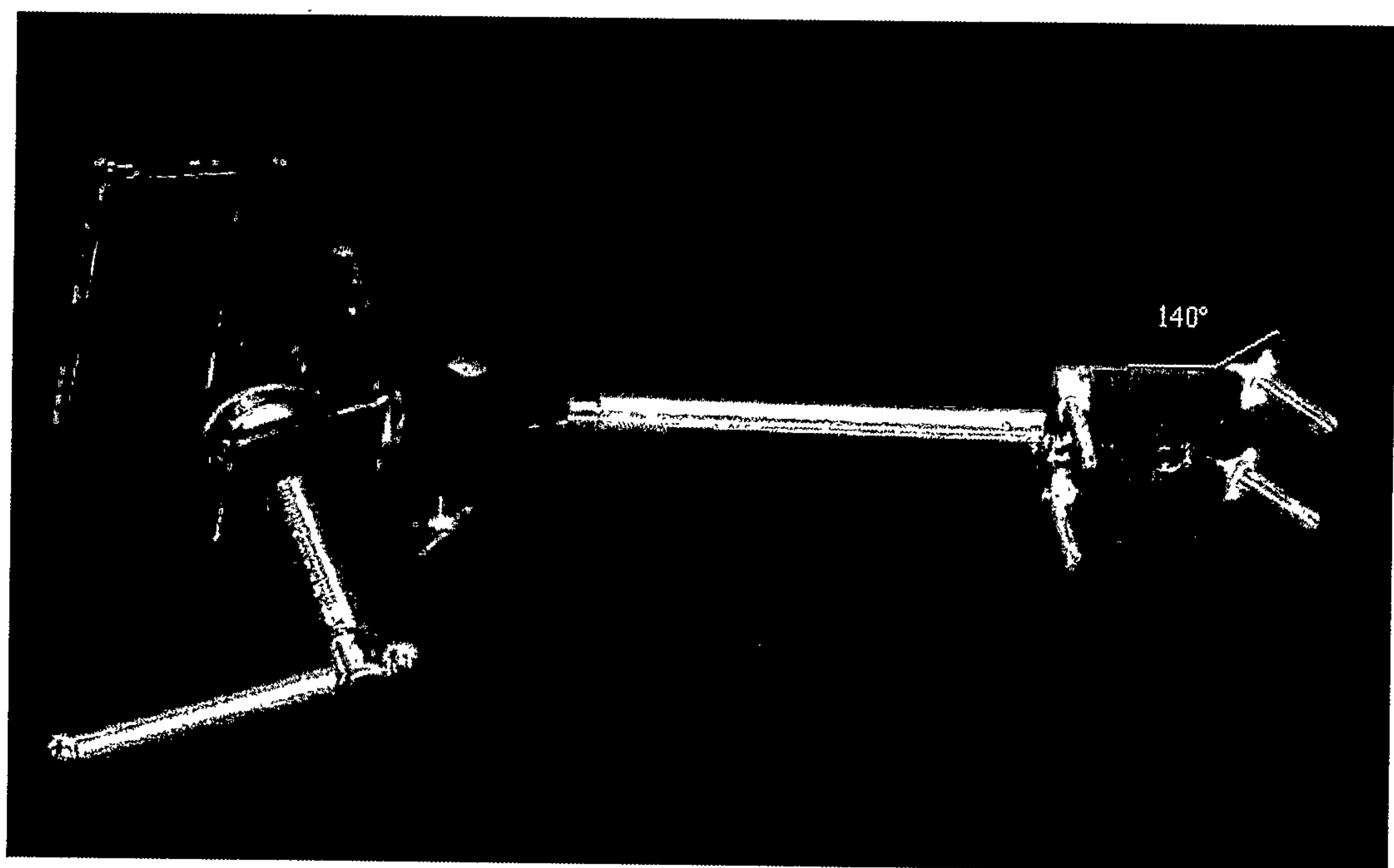
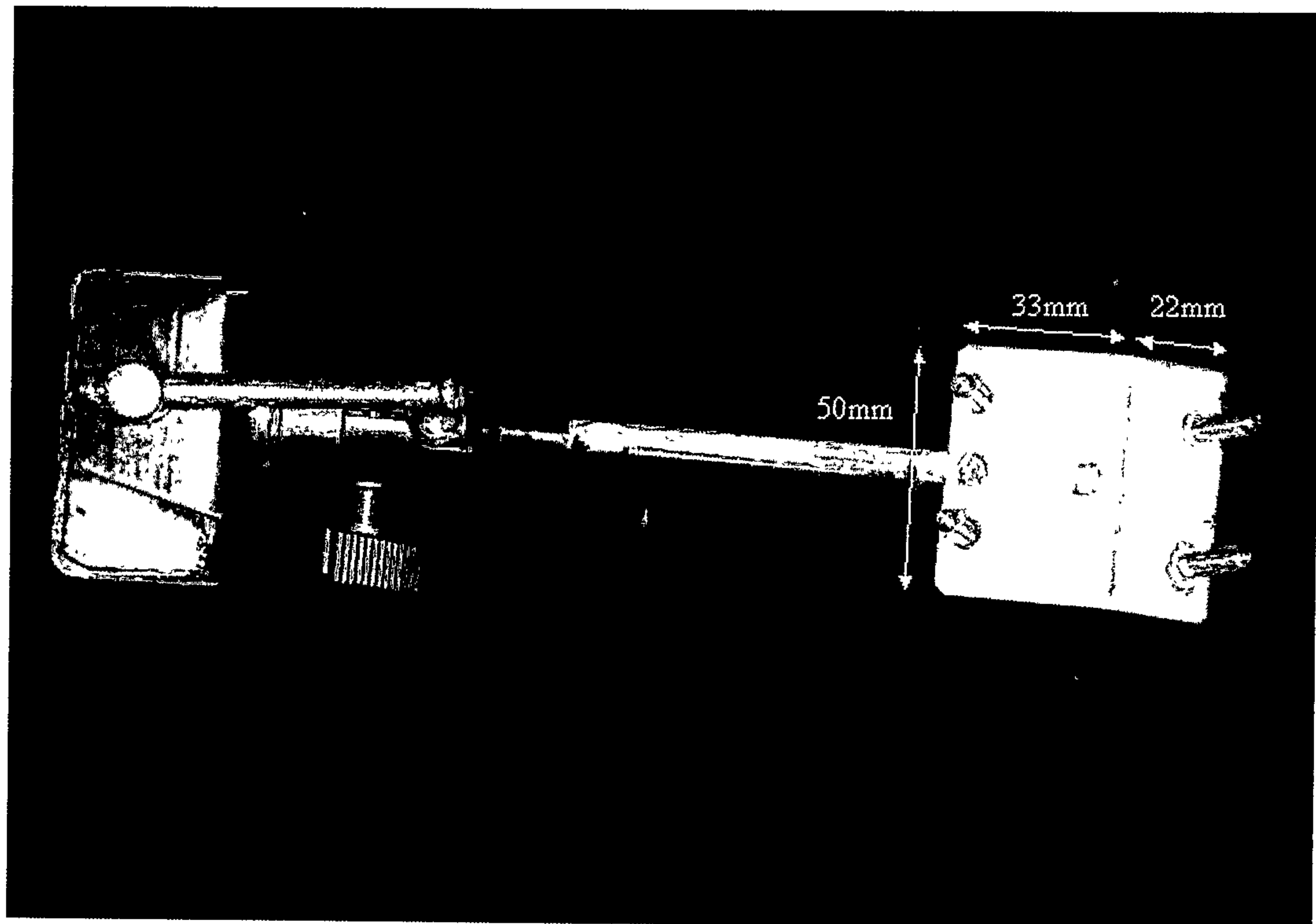
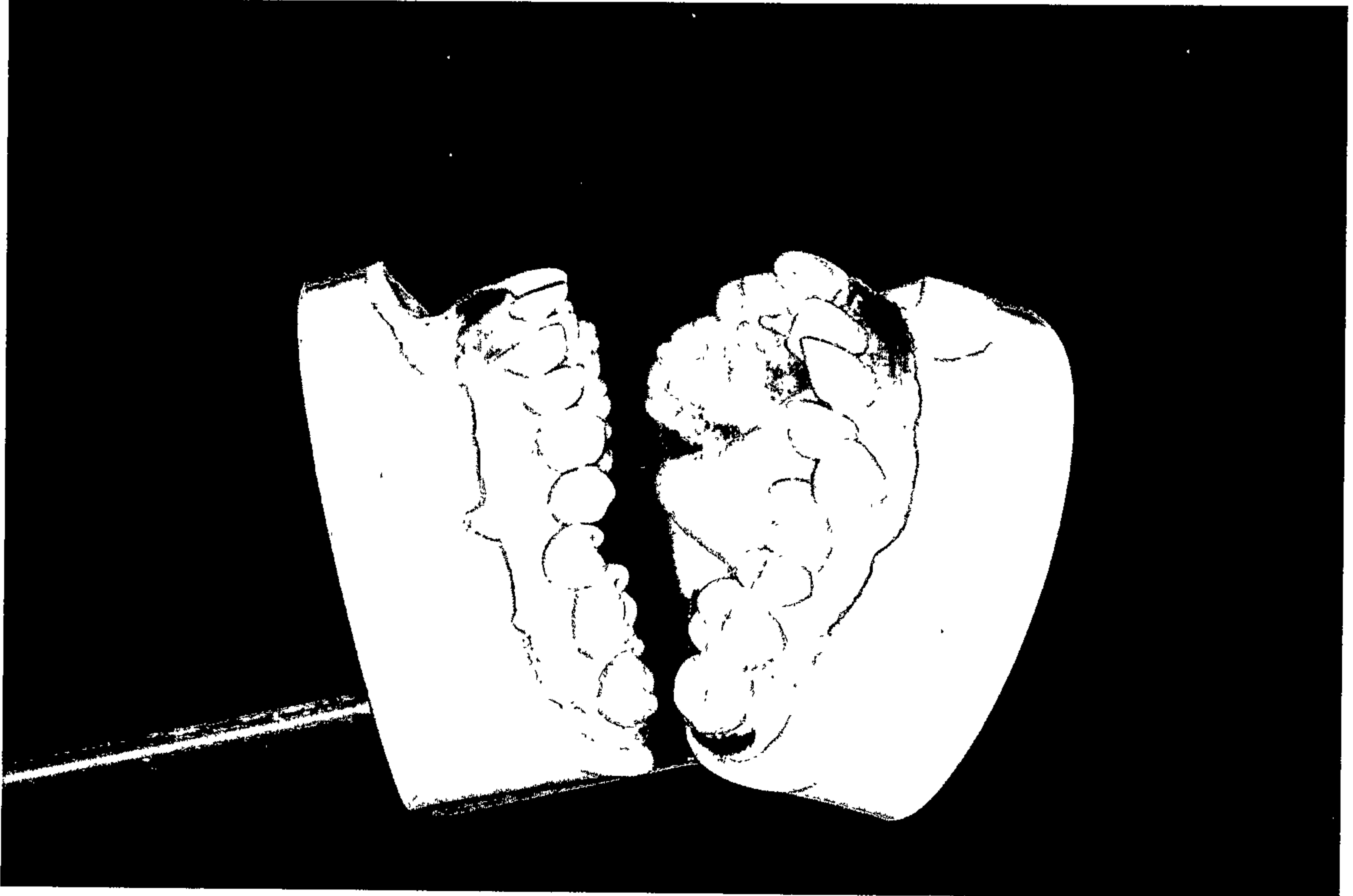


Figure 3.17 A Typodont Mounted on the Rod



To simulate a clinical situation latex lips are used on typodonts and as a custom typodont was made it was necessary to create custom made latex lips to prevent direct visual access of the premolar teeth and to ensure that the operators had to use their mirrors to recreate the difficulties faced clinically in positioning orthodontic brackets on premolar teeth. A mounted typodont was covered in several layers of paper to act as a spacer between the typodont teeth and the latex lips. The paper was held in place with sticky tape. The homogenous mass was then covered in cling wrap and multiple liquid latex layers (Spray/ Dip latex, Barnes products, Australia) were painted, allowing a drying time of at least one hour between layers and 24 hours once the final layer was painted. This created simulation latex lips of a satisfactory thickness. The

excess latex was removed and a mouth opening cut. Initially a smaller opening was cut and then by gradually increasing the opening and reassessing with the cheek retractor (Sasa, Kongivor, Norway) a suitable clinical situation was created (Figure 3.18-3.20).

Figure 3.18 Typodont on mount with latex lips

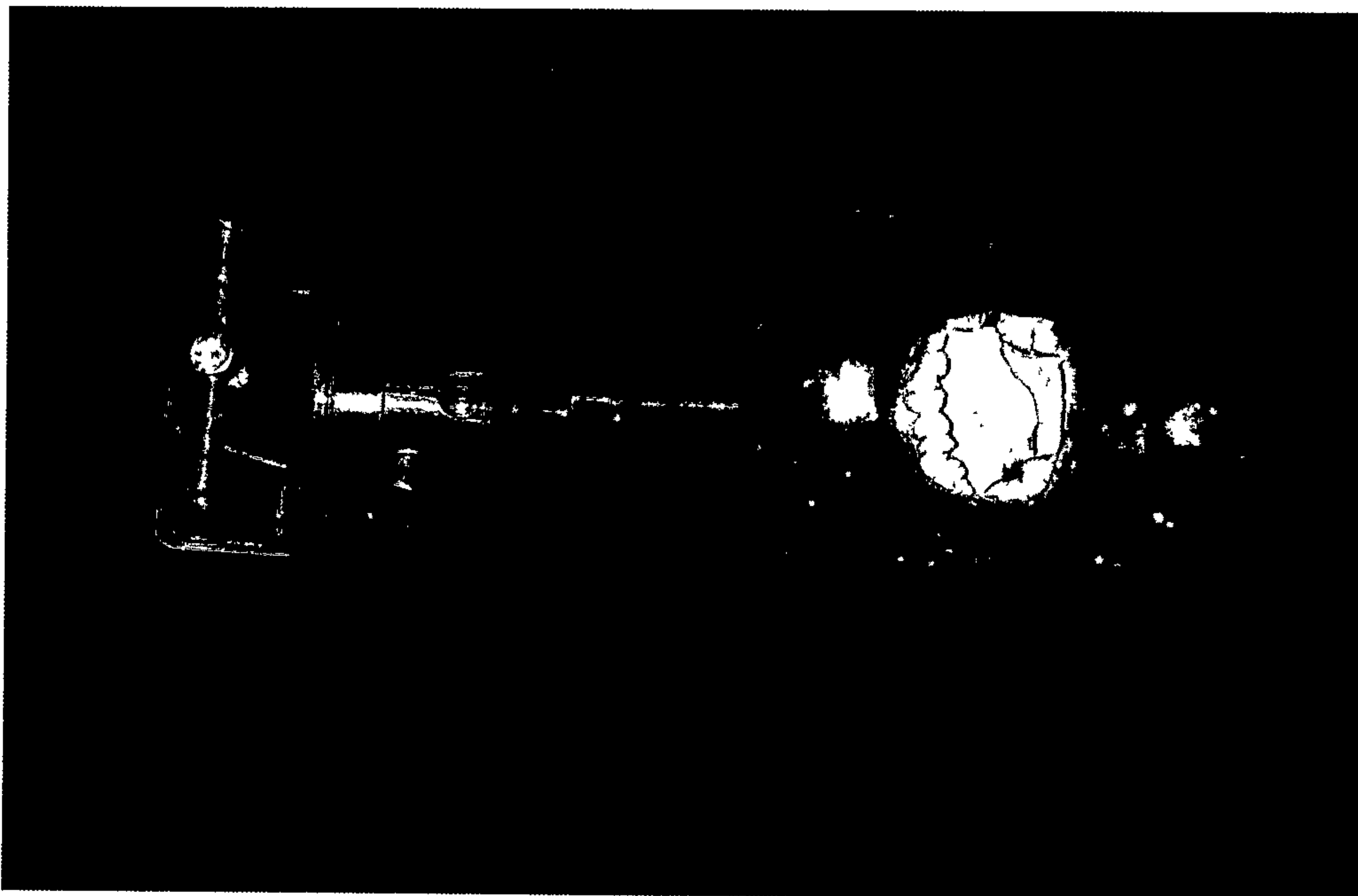


Figure 3.19 The Typodont set up with latex lips and the cheek retractors in place

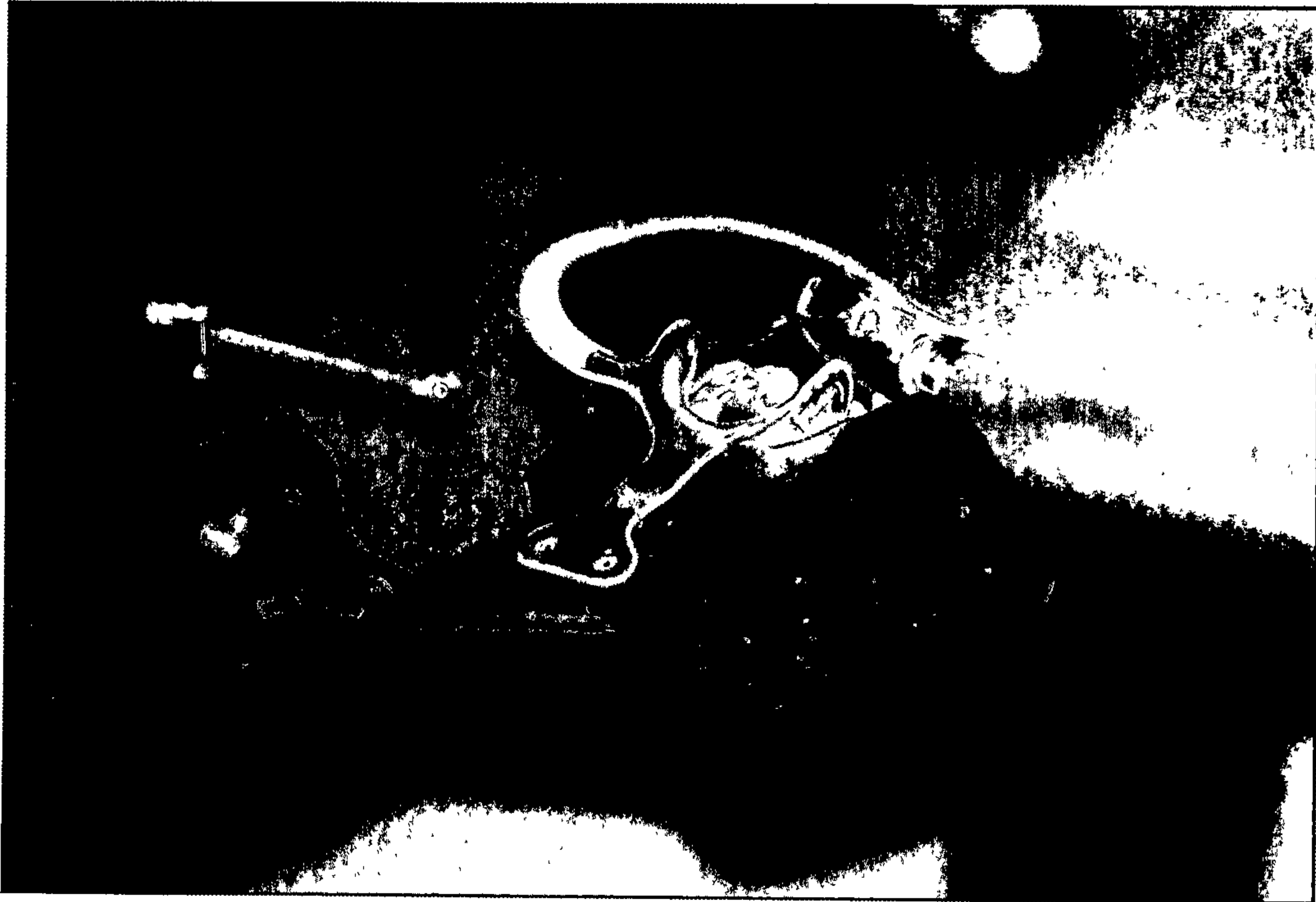
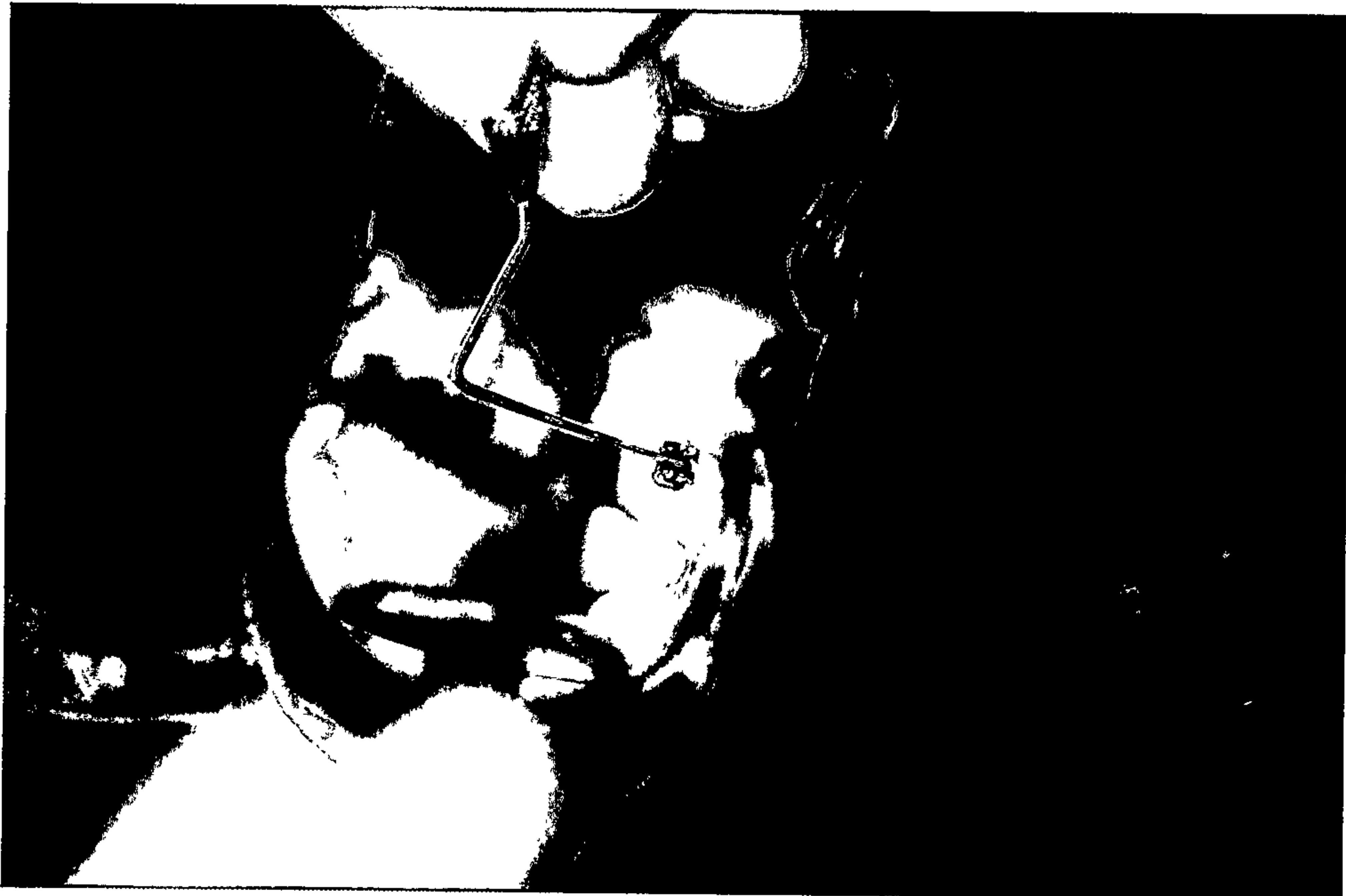


Figure 3.20 Bracket bonding with the latex lips and the cheek retractors in place



In order to photograph the teeth in a reproducible manner two jigs had to be made. The smaller jig would fit into the larger in two positions allowing the teeth to be photographed straight on (buccally) and from the occlusal (Figure 3.21,3.22)

Figure 3.21 Photographic jig with tooth placed for straight on (buccal) image

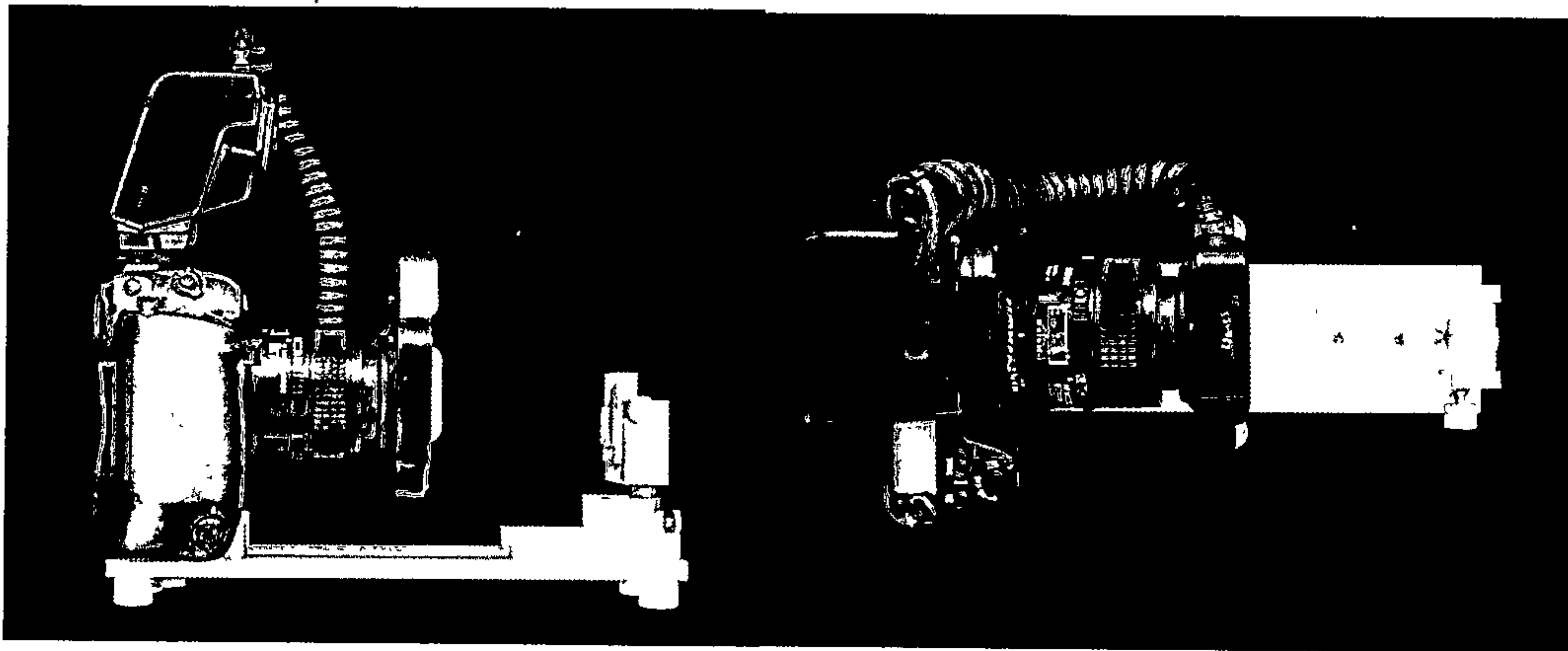
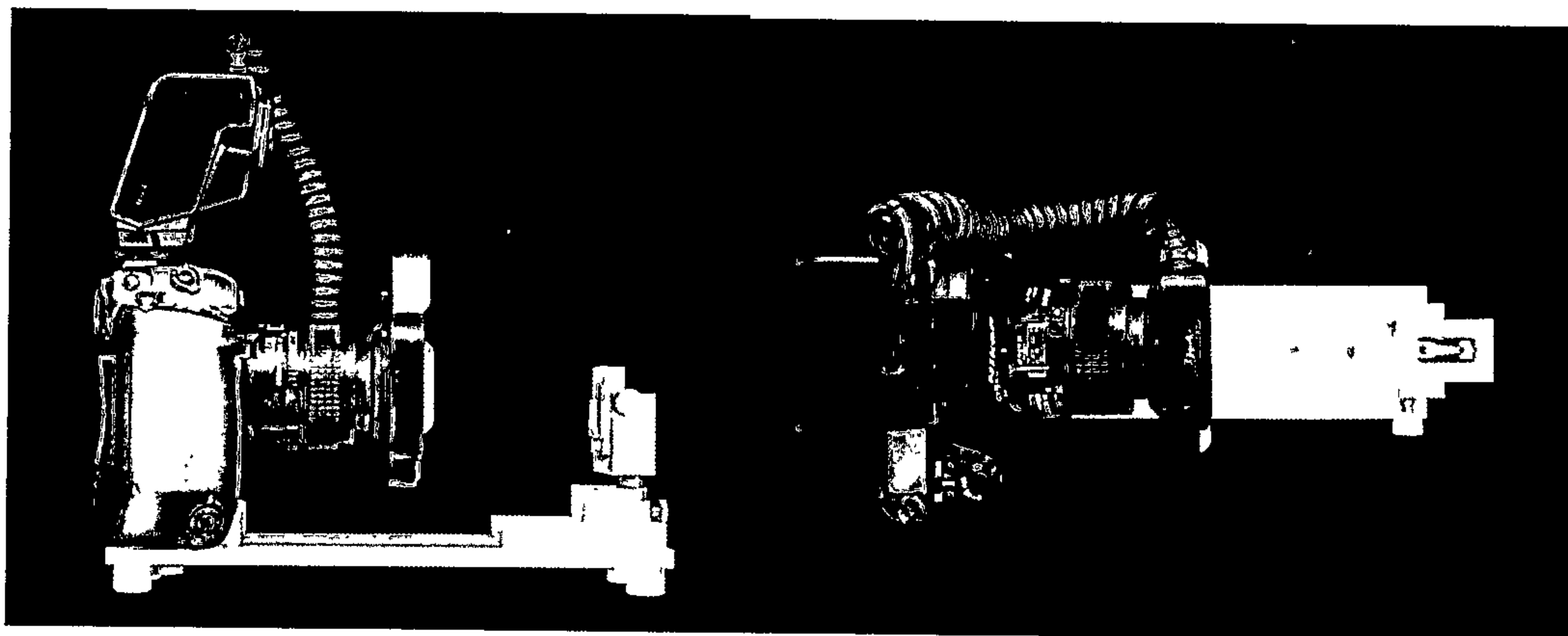


Figure 3.22 Photographic jig with tooth placed for occlusal image



The larger jig would support the camera and the smaller jig would hold the teeth. Ken Tyler (Department of Biomaterials, University of Sydney) constructed the camera jigs, after discussion regarding the requirements. The larger jig consisted of a large steel base (298mm x 79mm x 10mm), which allowed the camera (Nikon D10) with flash unit (Nikon SB 29) to be mounted on one end of the jig in a reproducible position. The camera has an attachment on its base for the attachment of a tripod. This was used with a screw attachment placed from the inferior surface in conjunction with 2 stops on the superior surface to positively seat the camera (Figures 3.22,3.23).

Figure 3.22 The camera jig (Superior view)

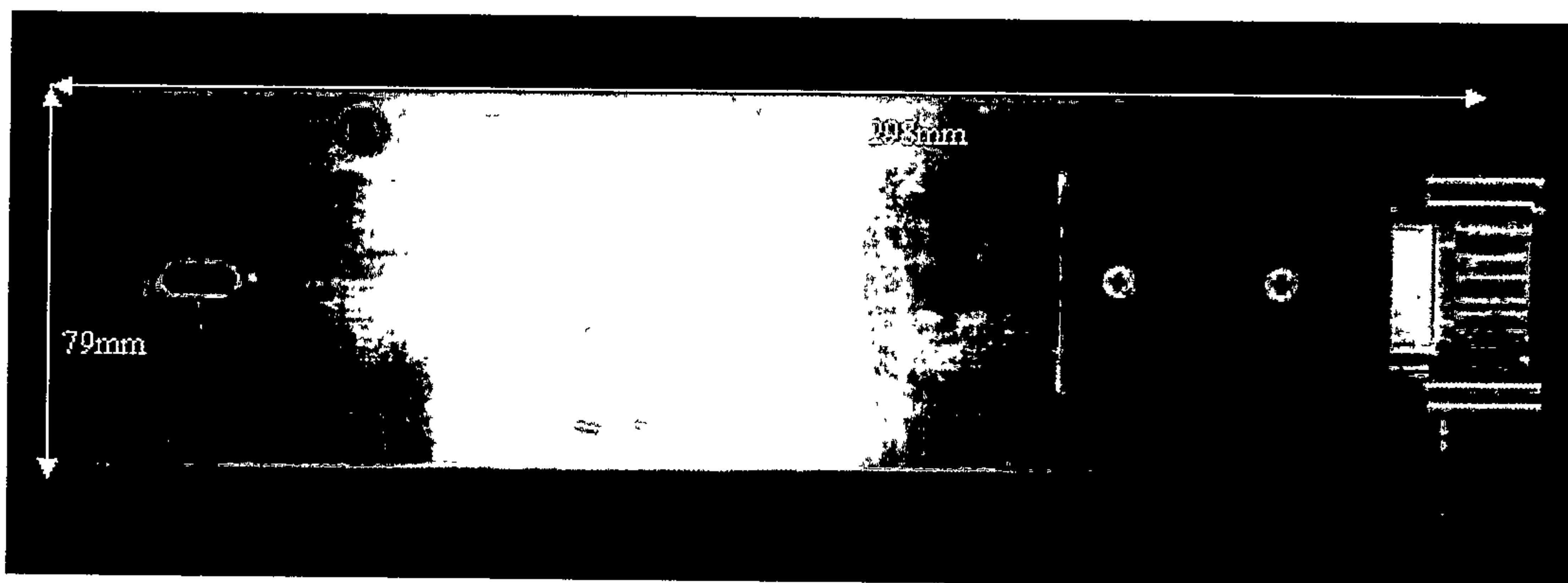
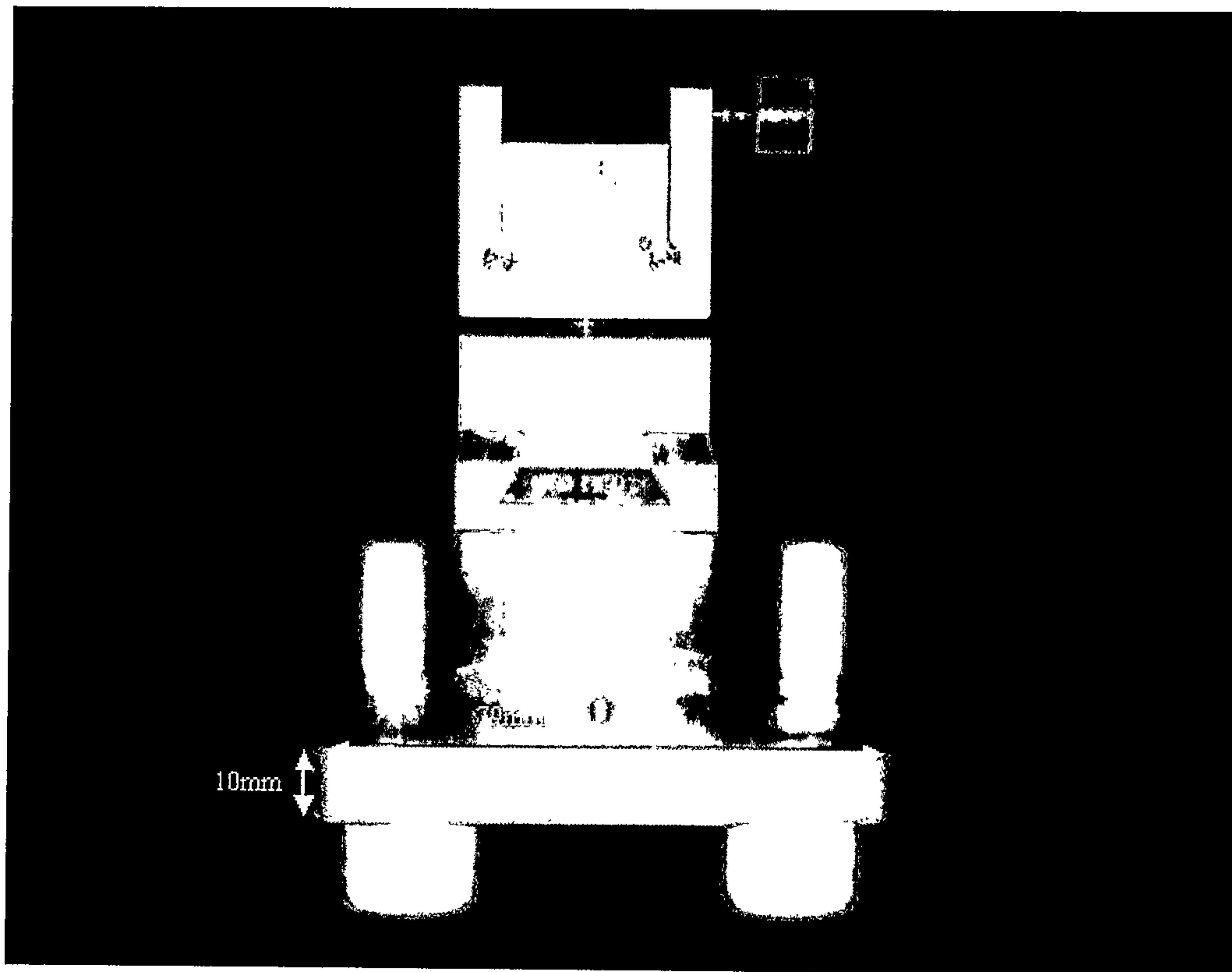


Figure 3.23 The camera jig (Camera end view)



The opposite end of the jig consisted of the removable smaller jig, which fitted in two configurations into a mounting device (one for the straight on image and one for the occlusal image). It was secured with a screw (Figures 3.24, 3.25). The mounting device was adjustable (horizontally and vertically) so that the camera settings could remain constant and the teeth in the jig could be finely adjusted for focus depending on which smaller jig was attached or which position the smaller jig was placed (straight on or occlusal).

Figure 3.24 The mount with smaller jig (buccal view)

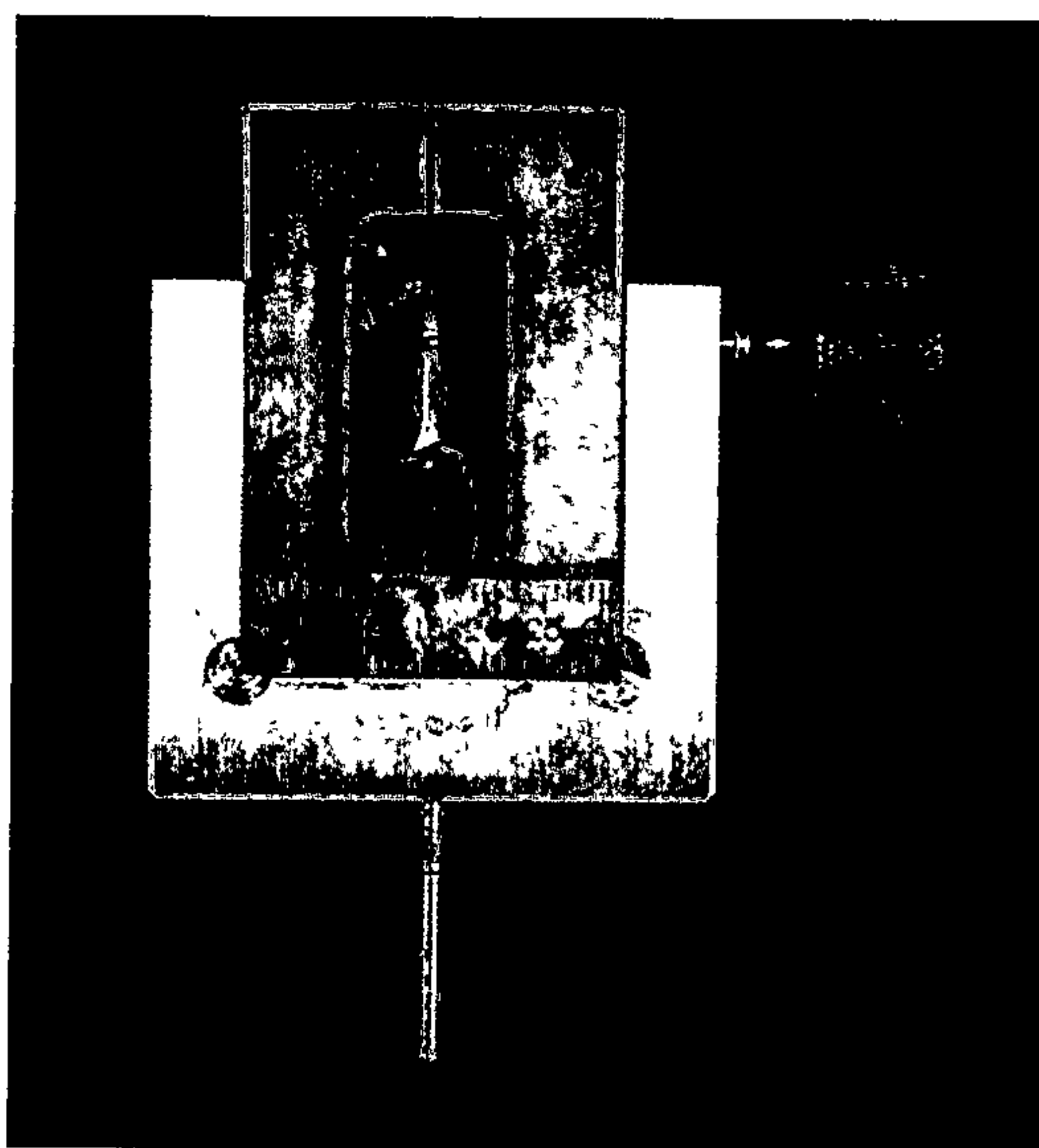
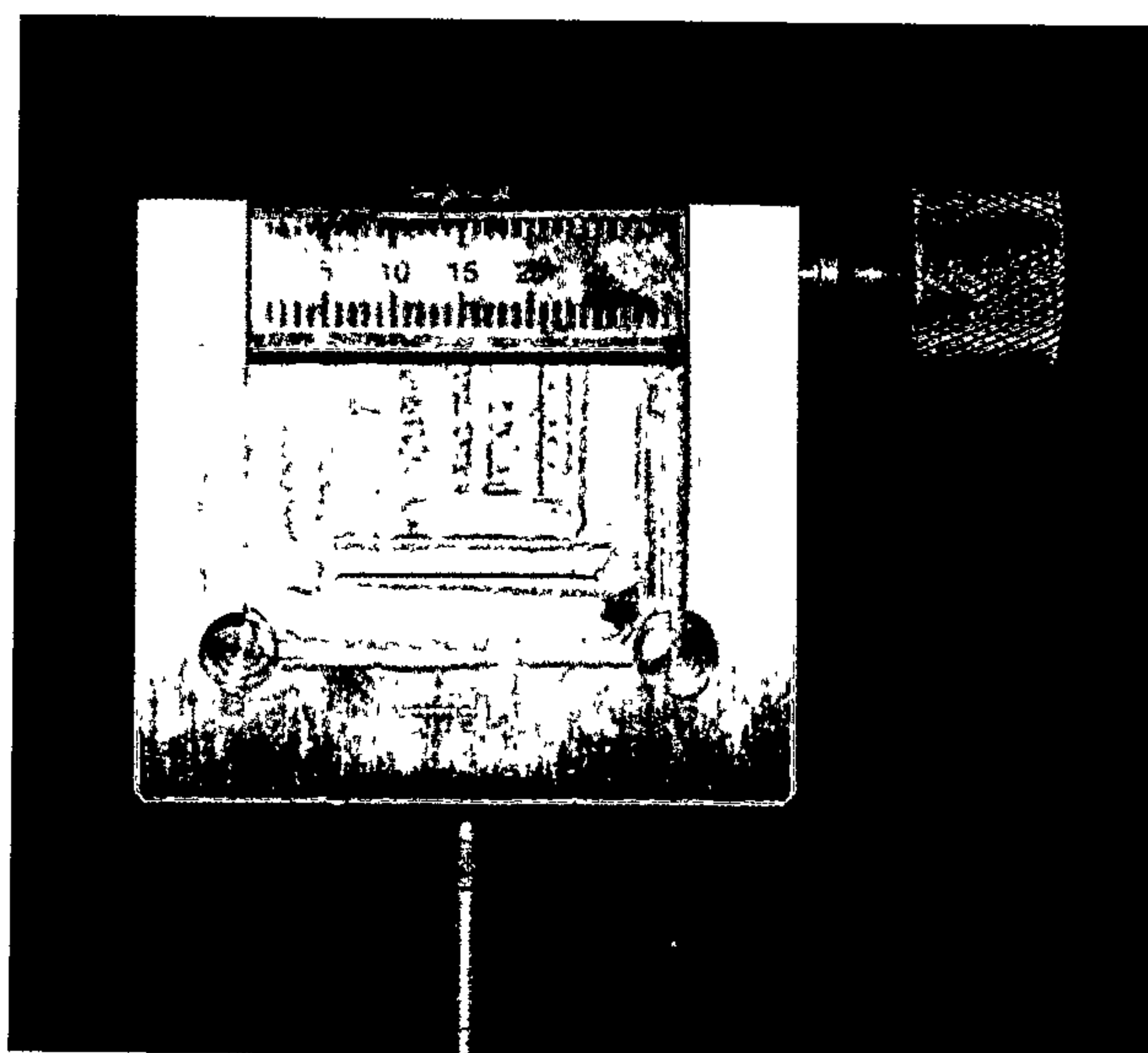


Figure 3.25 The mount with smaller jig (occlusal view)



The smaller jig consisted of a rectangular plastic frame (external dimensions 33mm x 48mm and internal dimensions 13mm x 29mm) with superior and inferior markings in the midline parallel to the sides. A plastic ruler was attached so that it would be present on the photographic image (Figure 3.26). It was to be used to calibrate each image when it was measured with the digitising software (AnalysSIS Pro 3.1, Soft Imaging System, Munich, Germany). Twenty separate silicone inner sections were made (Figure 3.27), one for each tooth (Odontosil, Dreve-Dentamid GMBH, Germany). The long axis of each tooth was drawn and each of the 20 teeth were mounted using 0.20 inch stainless steel wire and wax, using the sides of the jig and the parallel markings as a guide. The odontosil was then injected and the excess removed. It was then set under pressure as per the manufacturers instructions (Palmat practic, Kulzer, Germany).

Figure 3.26 The smaller jig

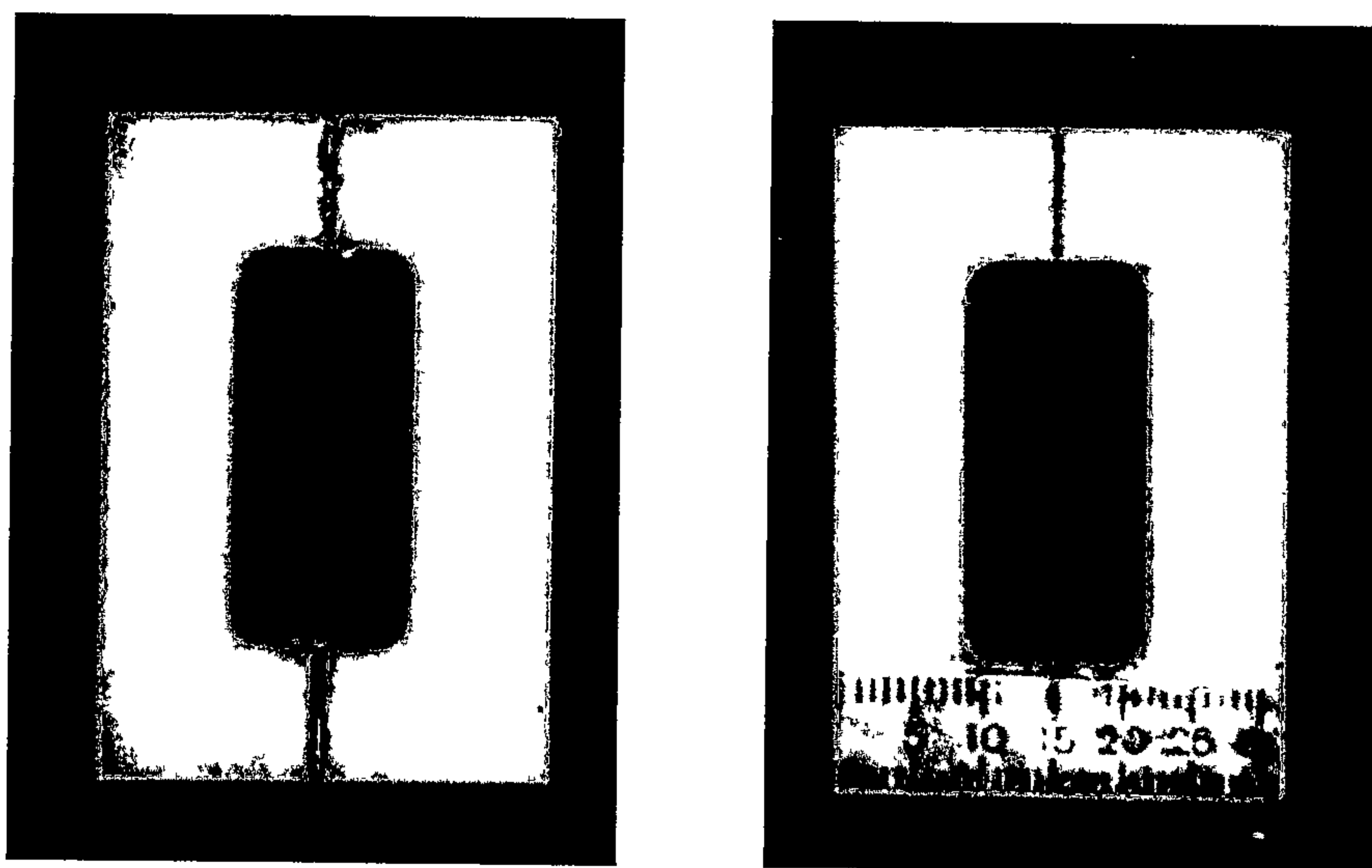
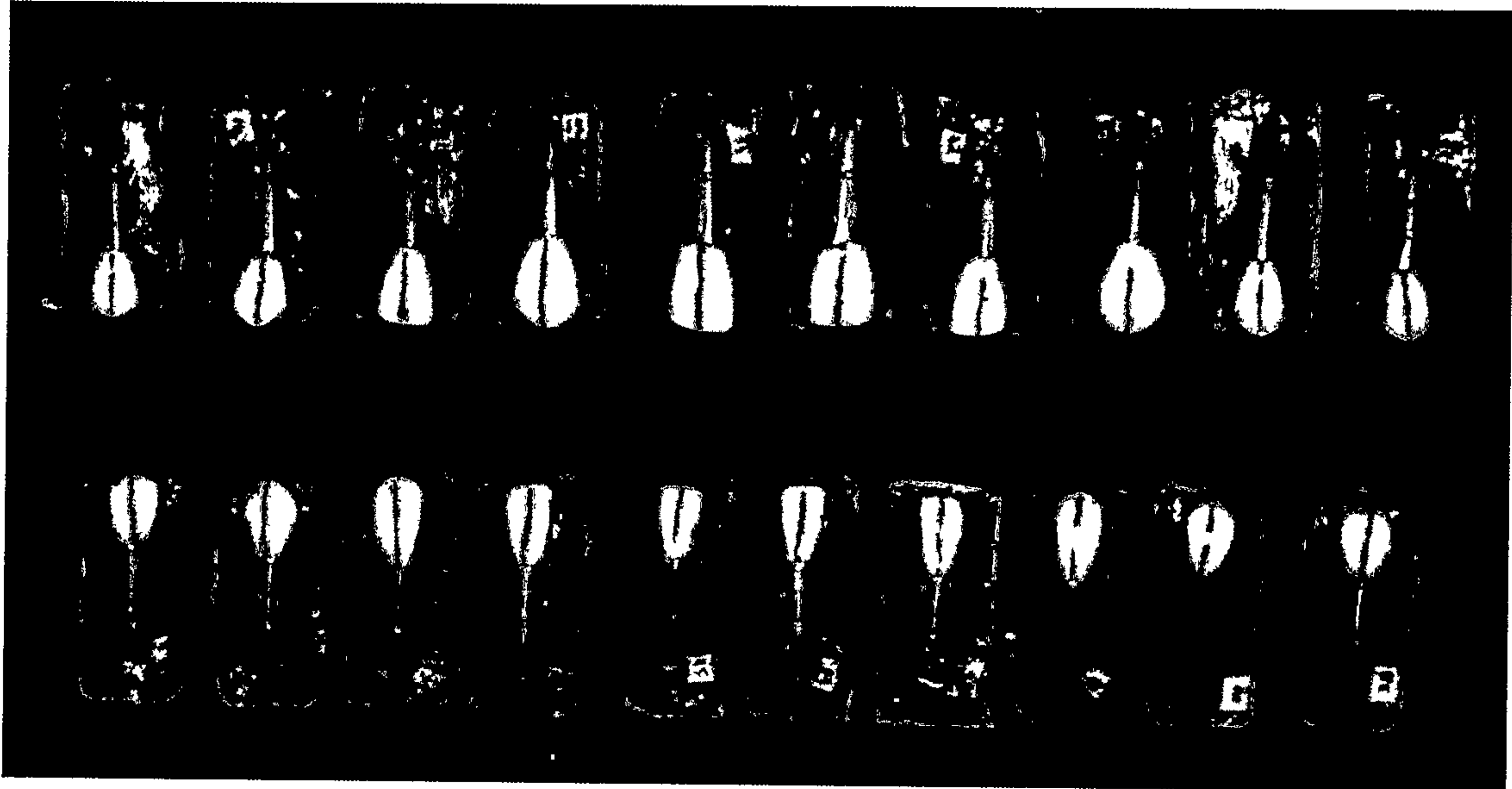


Figure 3.27 The individual silicone (Odontosil) inner sections

(which fit into the smaller jig)



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8. Andrews LF. The Straight-wire appliance. Origin, Controversy, Commentary. *J Clin Orthod* 1976;10:99-114.

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12. Eliades T, Gioka, C, Papaconstantinou, S, Bradley, TG. Premolar bracket position revised: Proximal and occlusal contacts assessment. *World J Orthod* 2005;6:149-155.

Protocol for Bracket Positioning (Orthodontists)

Thank you for agreeing to participate in this study. The basis for this study is to establish parameters for accuracy of bracket placement to facilitate in the modification of the bracket I have designed for my PhD. I would be grateful if you could read the following protocol and although you may find it simplistic it is important to ensure that all the participants in the study (orthodontists and dental students) are attempting to place the brackets in the same position.

The Procedure:

- (1) Read the following definitions and sign the last page to indicate you have read the information sheet and to give your informed consent.
- (2) Bond the class I crowded typodont with Victory low profile brackets (3M, Unitek) and place the brackets at the centre of the clinical crown
- (3) Bond the class I crowded typodont with Victory low profile brackets (3M, Unitek) and place the brackets at the prescribed measured distance from the incisal edge.

The instruments you will be provided with are:

- Mouth mirror
- Probe
- Periodontal probe
- Sickle scaler
- Half Hollenback/ flat plastic
- Height gauge
- Any other instrument you would normally use

Part 1 The Centre of Clinical Crown

Andrews studied the occlusions of 120 Caucasian non-orthodontic normal subjects to establish the ideal position for each individual tooth. This led to the development of the pre-adjusted bracket or straight wire appliance (SWA)^(1,2). Andrews found that measuring from the incisal edge, as had been done with standard edgewise brackets, would not allow consistent expression of the three-dimensional bracket programming. He therefore suggested anatomical landmarks to locate the brackets (the long axis of the clinical crown (LACC)⁽³⁾, and the mid point of this long axis (LA point)).

Definitions:

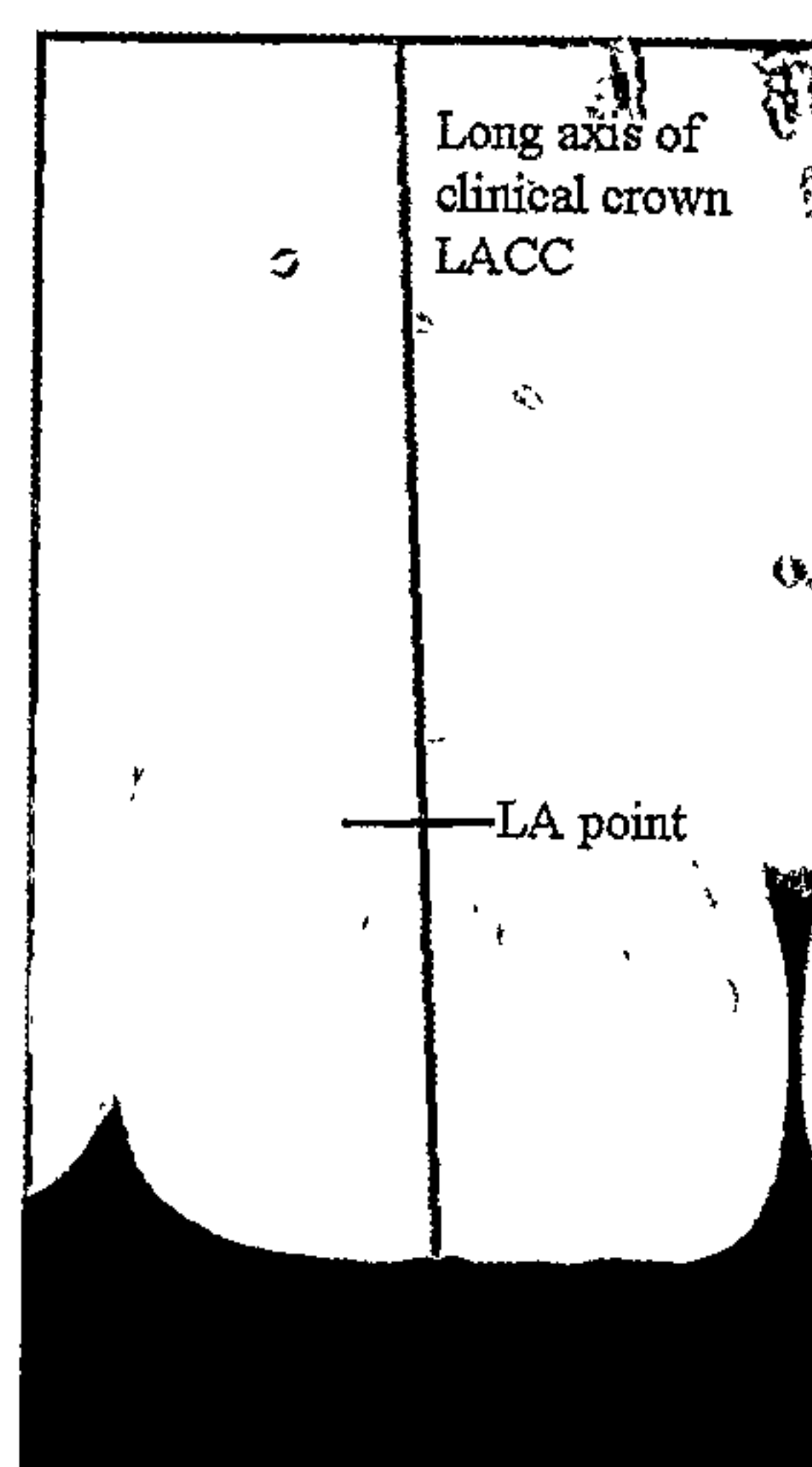
The LACC:

- (a) The vertical mid-developmental ridge, which is the most prominent portion of the central area of the crown when viewed from the bucco-labial aspect.
- (b) The line tangent to the middle of the crown's labial or buccal surface when viewed from the mesio-distal aspect.

LA point:

The LA point is at the mid point of the LACC. The crown has no obvious horizontal axis or equator, so judge the point by estimation or by measuring from the cemento-enamel junction to the incisal edge and dividing by two.

The ideal bracket position for Andrews appliance was with the vertical axis of the bracket parallel to the LACC and the centre of the bracket base corresponding to the LA point.



There are specific bracket positioning errors ⁽⁴⁾, which need to be avoided.

- (a) *Horizontal errors* or placing the bracket too mesial or distal, which leads to a rotation error. Avoid these errors by visualizing the long axis of the tooth either directly or with a mouth mirror.
- (b) *Axial or paralleling errors* which occur if the bracket wings are not parallel to the long axis, and this leads to crown tipping.
- (c) *Thickness errors* are due to leaving too much adhesive under part of the bracket base, or failing to conform the base accurately to the contour of the tooth. This can lead to improper torque or rotation and can be avoided by ensuring all the excessive adhesive is expressed from beneath the bracket during placement and by more accurate contouring.
- (d) *Vertical errors* are due to improper vertical placement and can lead to intrusion or extrusion, torque and in/out errors.

It is also necessary to press the bracket firmly onto tooth:

- to get correct in/out
- prevent rotation error
- maximises bond strength
- minimises bracket drift
- minimise resin excess

Maxillary Central Incisor

- Height:* Position so that the centre of the slot is at the LA point and parallel to the incisal edge.
- Mesio-Distal:* Position so that the scribe line at the mid point of the bracket is centred over the mid-developmental ridge (the mid point mesio-distally).
- Tip:* The scribe line should be placed so it is coincident with the LACC. The bracket is rhomboid in shape with the edge of the base parallel to the scribe line.
- In/Out:* Ensure that excess cement is squeezed out and removed.



Maxillary Lateral Incisor

- Height:* Position so that the centre of the slot is at the LA point and parallel to the incisal edge.
- Mesio-Distal:* Position so that the scribe line at the mid point of the bracket is

centred over the mid-developmental ridge (the mid point mesio-distally).

Tip: The scribe line should be placed so it is coincident with the LACC. The bracket is rhomboid in shape with the mesial and distal edges of the base parallel to the scribe line.

In/Out: Ensure that excess cement is squeezed out and removed.

Maxillary Canine

Height: Position so that the centre of the slot is at the LA point.

Mesio-Distal: Position so that the bracket is centred mesio-distally over the mid-developmental ridge.

Tip: The scribe line should be placed so it is coincident with the LACC. The bracket is rhomboid in shape with the edge of the base parallel to the scribe line.

In/Out: Ensure that excess cement is squeezed out and removed.

Maxillary Premolars

Height: Position so that the centre of the slot is at the LA point and parallel to a horizontal line connecting the mesial and distal marginal ridges.

Mesio-Distal:

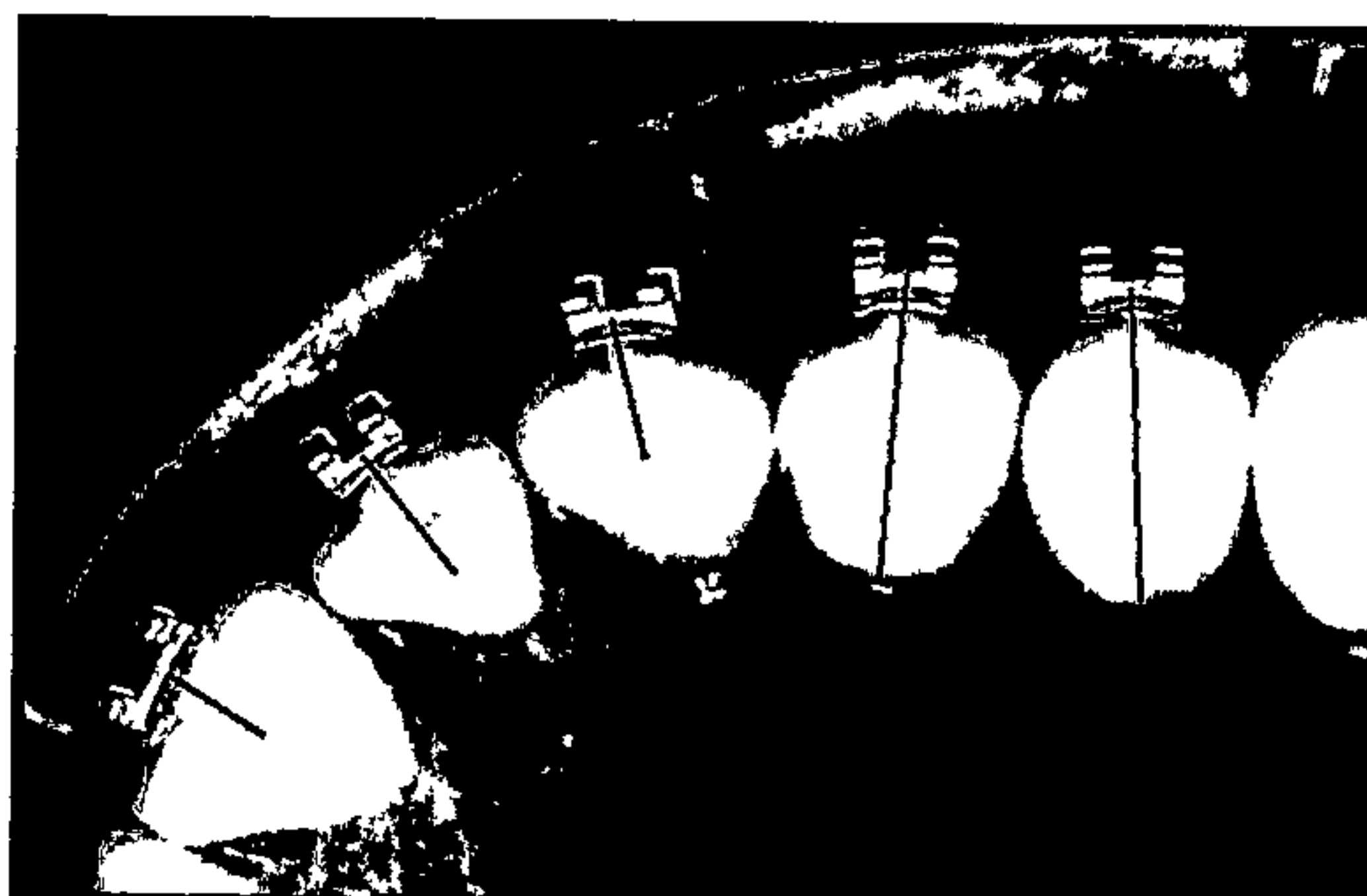
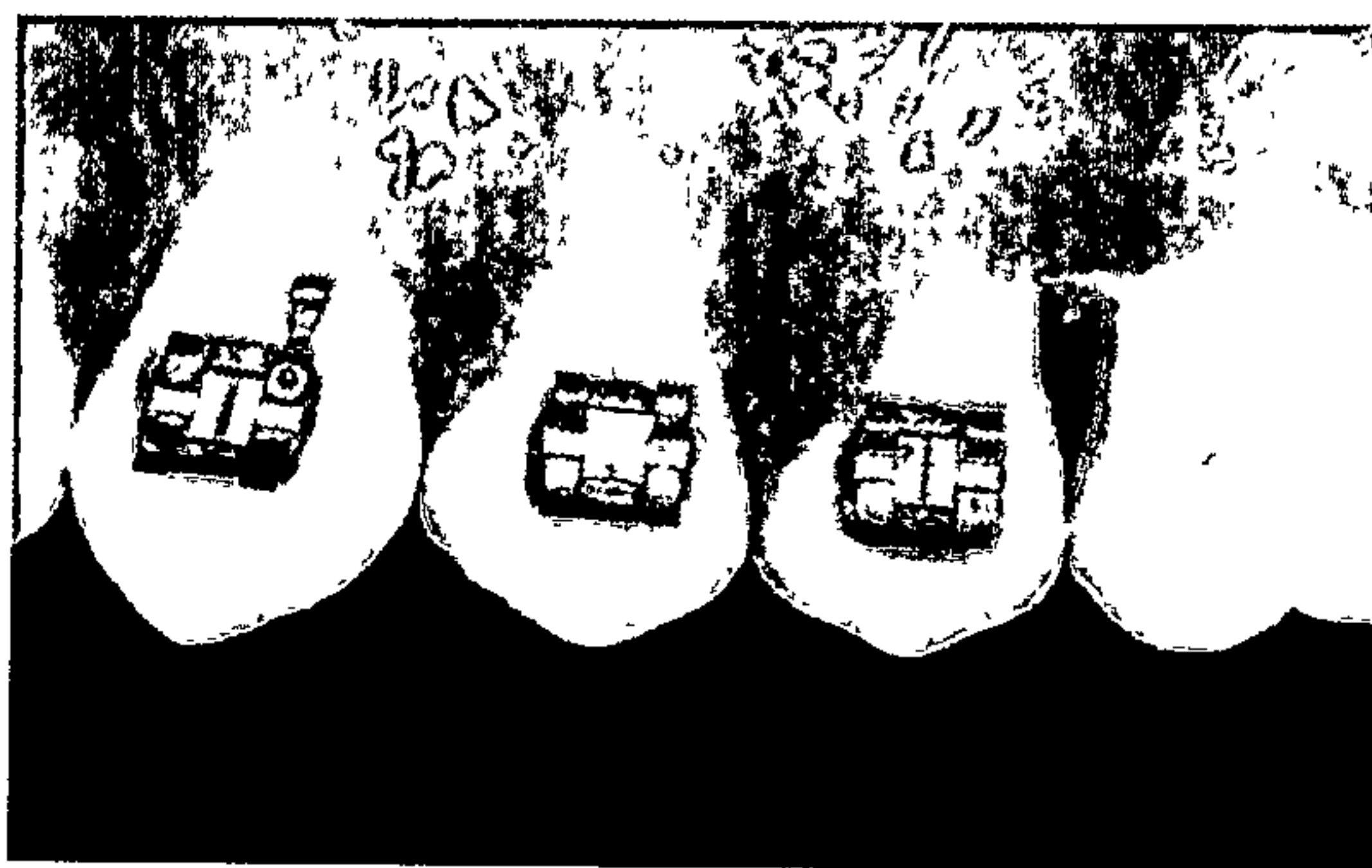
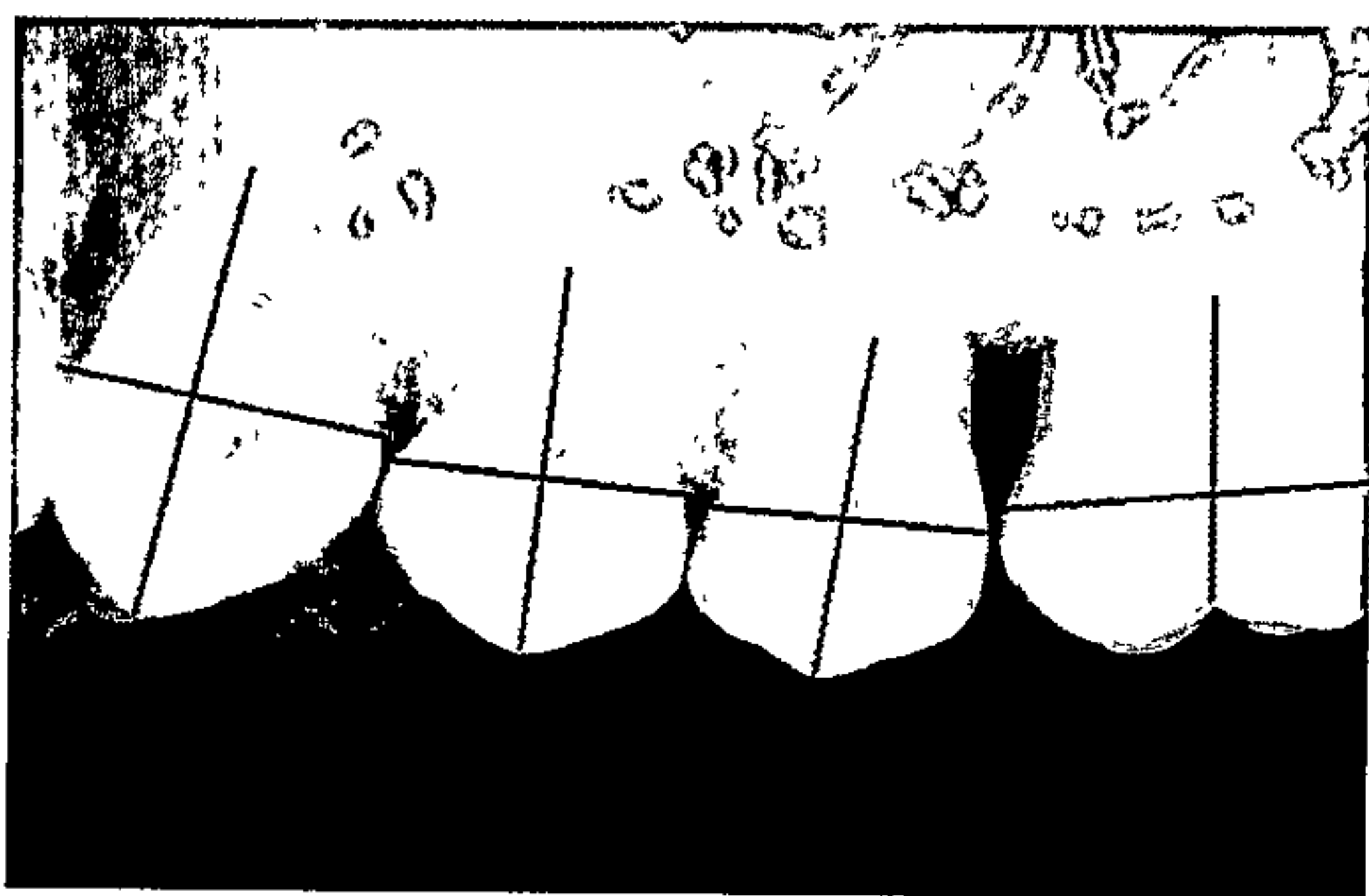
Position so that the scribe line is centred over the mid-developmental ridge (the mid point mesio-distally). Check this by viewing the tooth from the occlusal.

Tip:

The scribe line should be placed so it is coincident with the LACC The bracket is rhomboid in shape with the edge of the base parallel to the scribe line. Use the mirror to view from the buccal.

In/Out:

Ensure that excess cement is squeezed out and removed.



Mandibular Incisors

- Height:* Position so that the centre of the slot is at the LA point and parallel to the incisal edge.
- Mesio-Distal:* Position so that the bracket is centred over the mid-developmental ridge (the mid point mesio-distally).
- Tip:* The vertical tie wings and the mesial and distal edges of the rhomboid shaped base should be parallel to the LACC.
- In/Out:* Ensure that excess cement is squeezed out and removed.



Mandibular Canine

- Height:* Position so that the centre of the slot is at the LA point and parallel to the occlusal plane.
- Mesio-Distal:* Position so that the scribe line at the mid point of the bracket is centred over the mid-developmental ridge (the mid point mesio-distally).
- Tip:* The scribe line should be placed so it is coincident with the LACC. The bracket is rhomboid in shape with the mesial and distal edges of the base parallel to the scribe line.
- In/Out:* Ensure that excess cement is squeezed out and removed.

Mandibular First Premolars

- Height:* Position so that the centre of the slot is at the LA point and parallel to the incisal edge.
- Mesio-Distal:* Position so that the bracket is centred over the mid-developmental ridge (the mid point mesio-distally).
- Tip:* The vertical tie wings and the base marking are referenced to parallel the mid developmental ridge.
- In/Out:* Ensure that excess cement is squeezed out and removed.

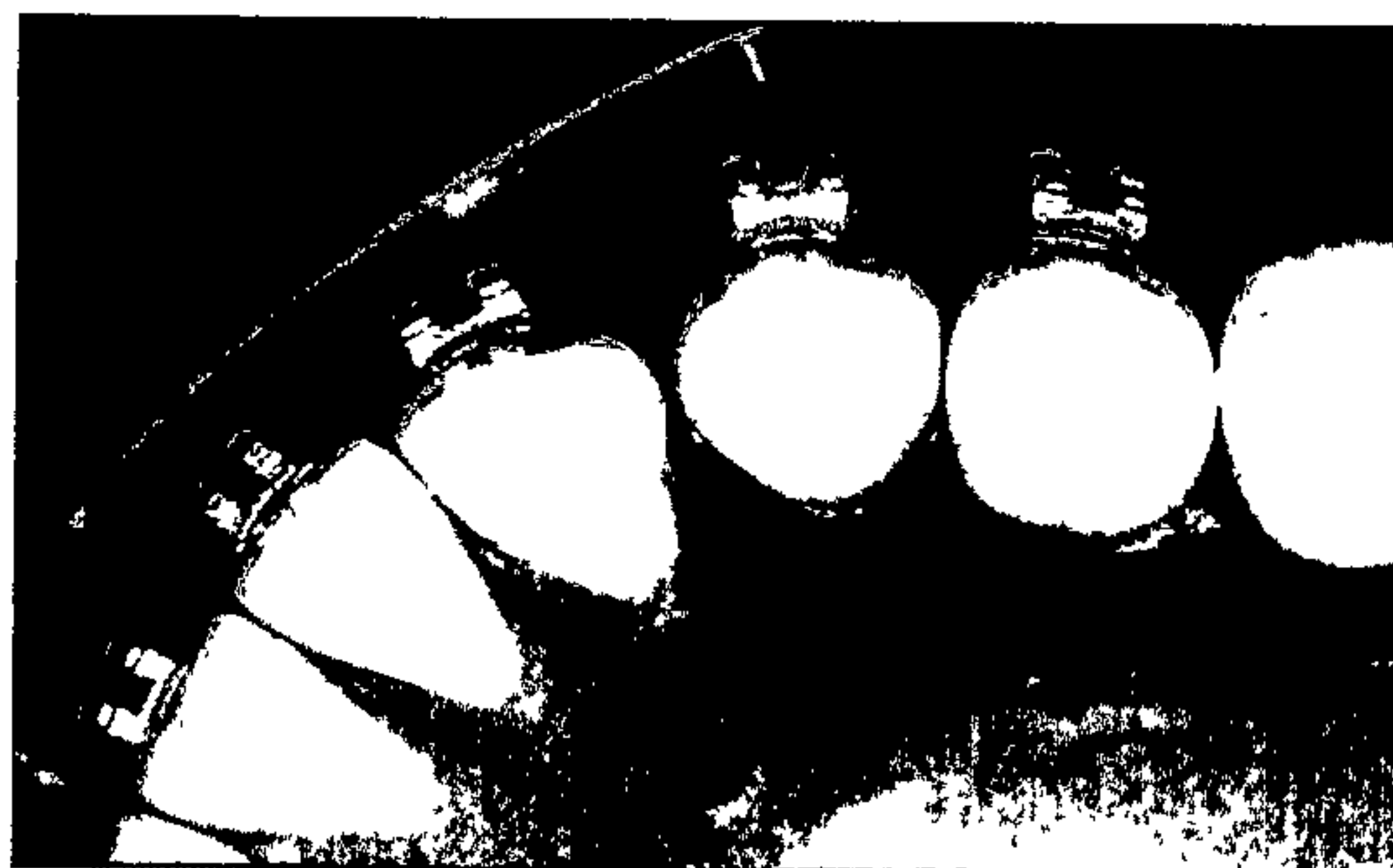
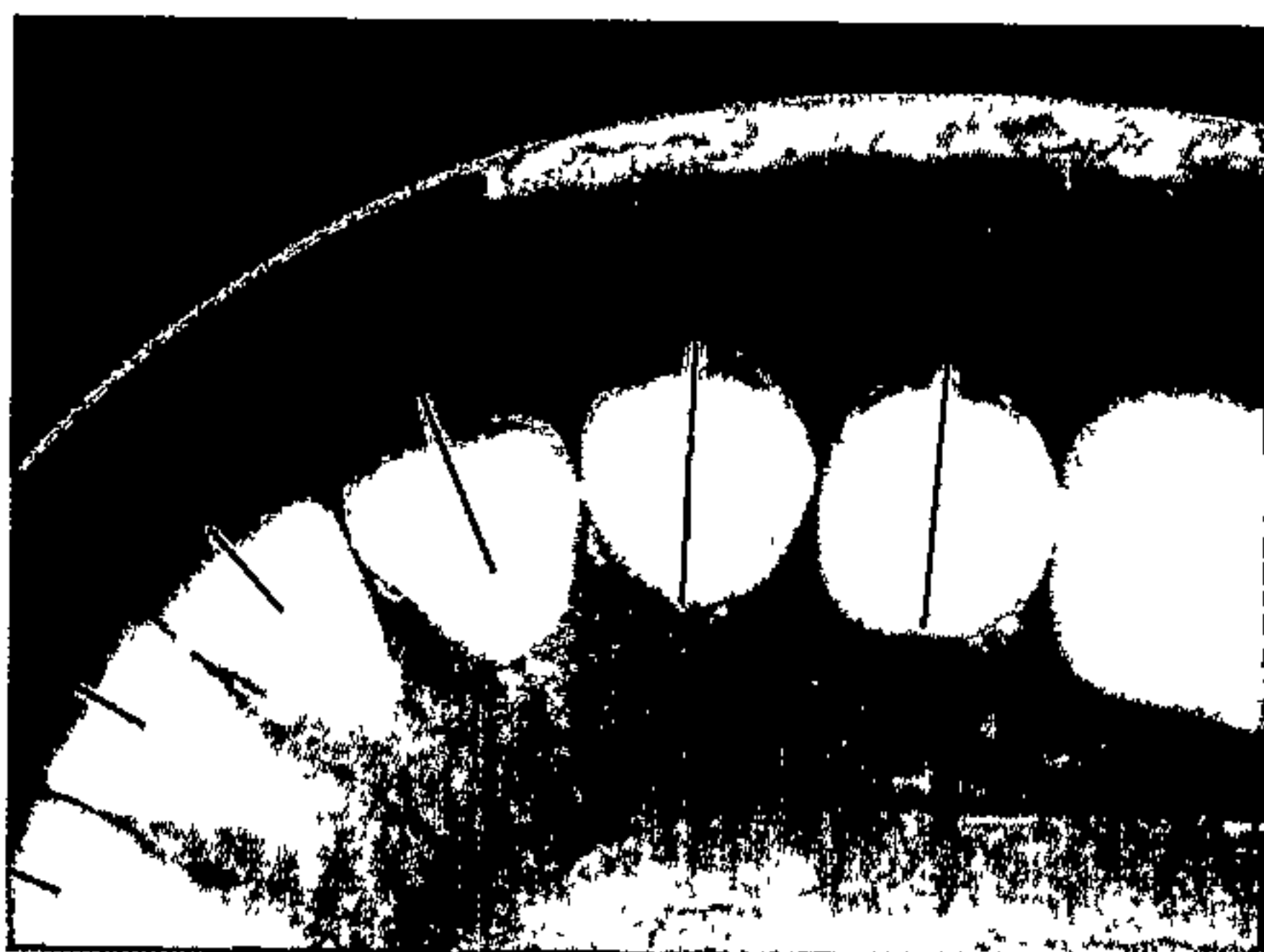
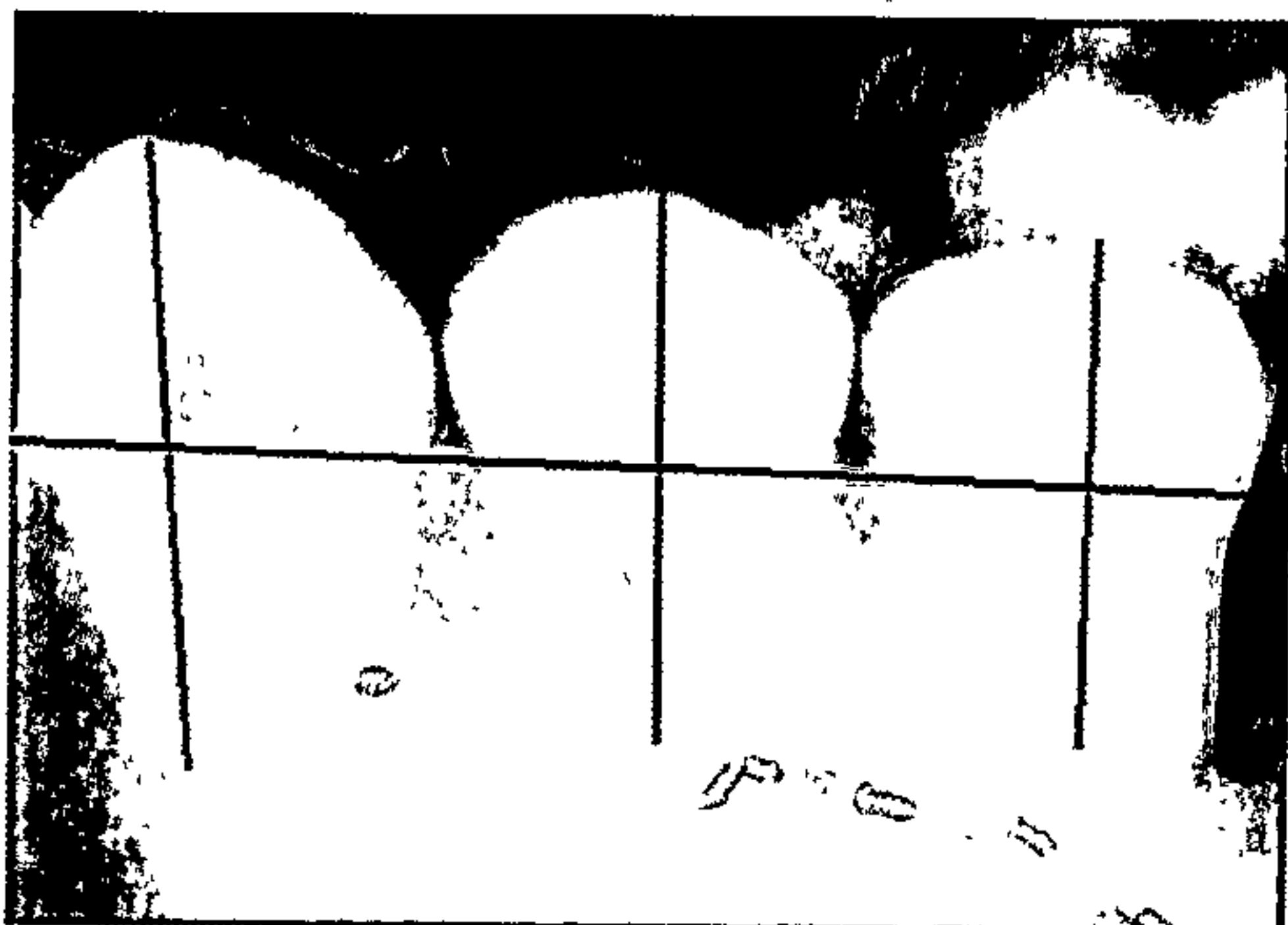
Mandibular Second Premolars

Height: Position so that the centre of the slot is at the LA point and parallel to the incisal edge.

Mesio-Distal: Position so that the bracket is centred over the mid-developmental ridge (the mid point mesio-distally).

Tip: The vertical tie wings and the base marking are referenced to parallel the mid developmental ridge.

In/Out: Ensure that excess cement is squeezed out and removed.



Part 2 Measuring from the Incisal Edge.

Bond the class I crowded typodont with Victory low profile brackets (3M, Unitek) and place the brackets at the specified measured distance as described below.

When placing brackets at the centre of the clinical crown errors can occur in vertical placement. This can be due to a number of factors ⁽⁴⁾:

(a) Gingival Concerns

- partially erupted teeth
- gingival inflammation
- labially and lingually displaced roots

(b) Incisal or occlusal concerns

- Incisal or occlusal crown fractures or tooth wear
- Crowns with long, tapered buccal cusps

(c) Crown length concerns

- Disproportionately long or short clinical crowns

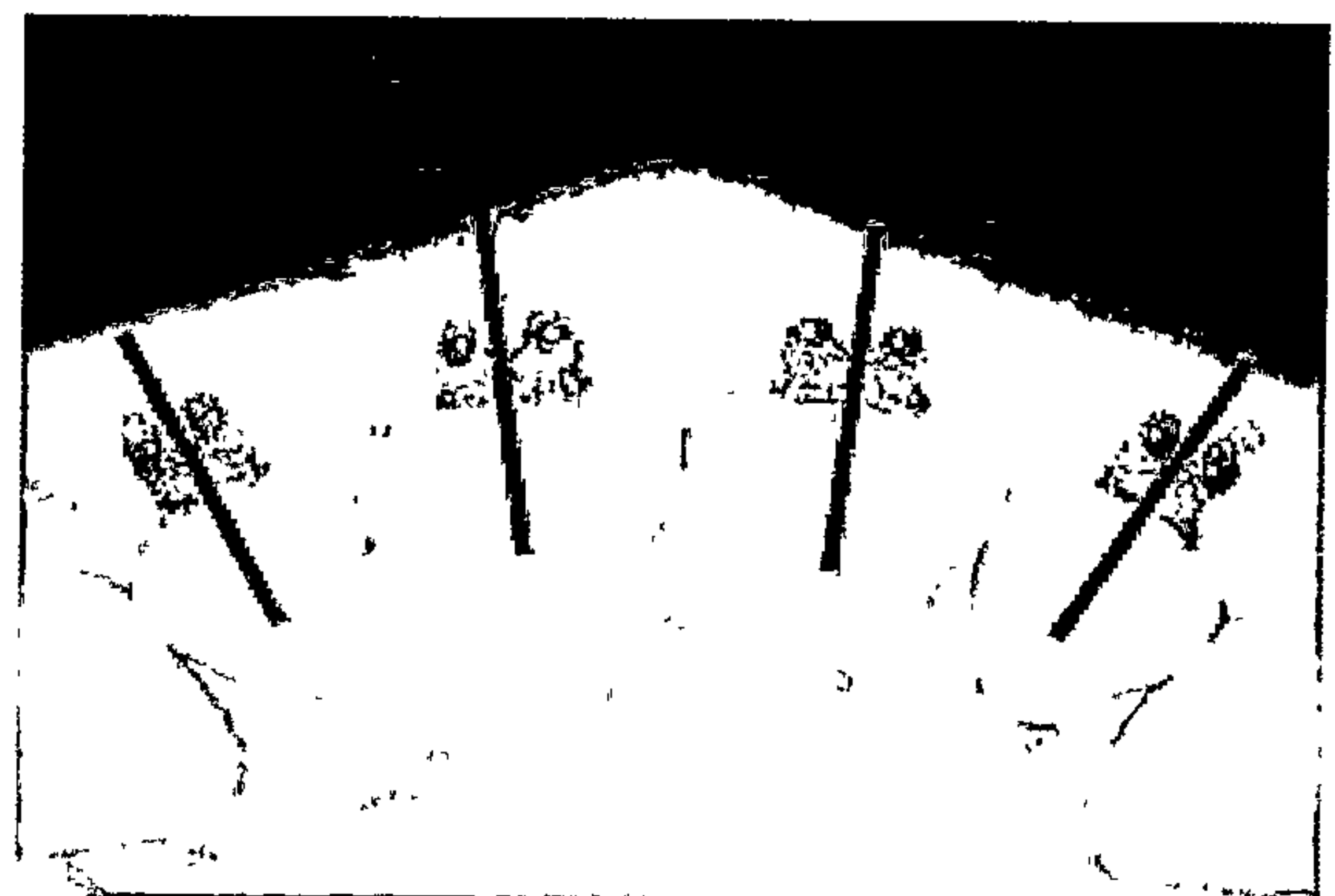
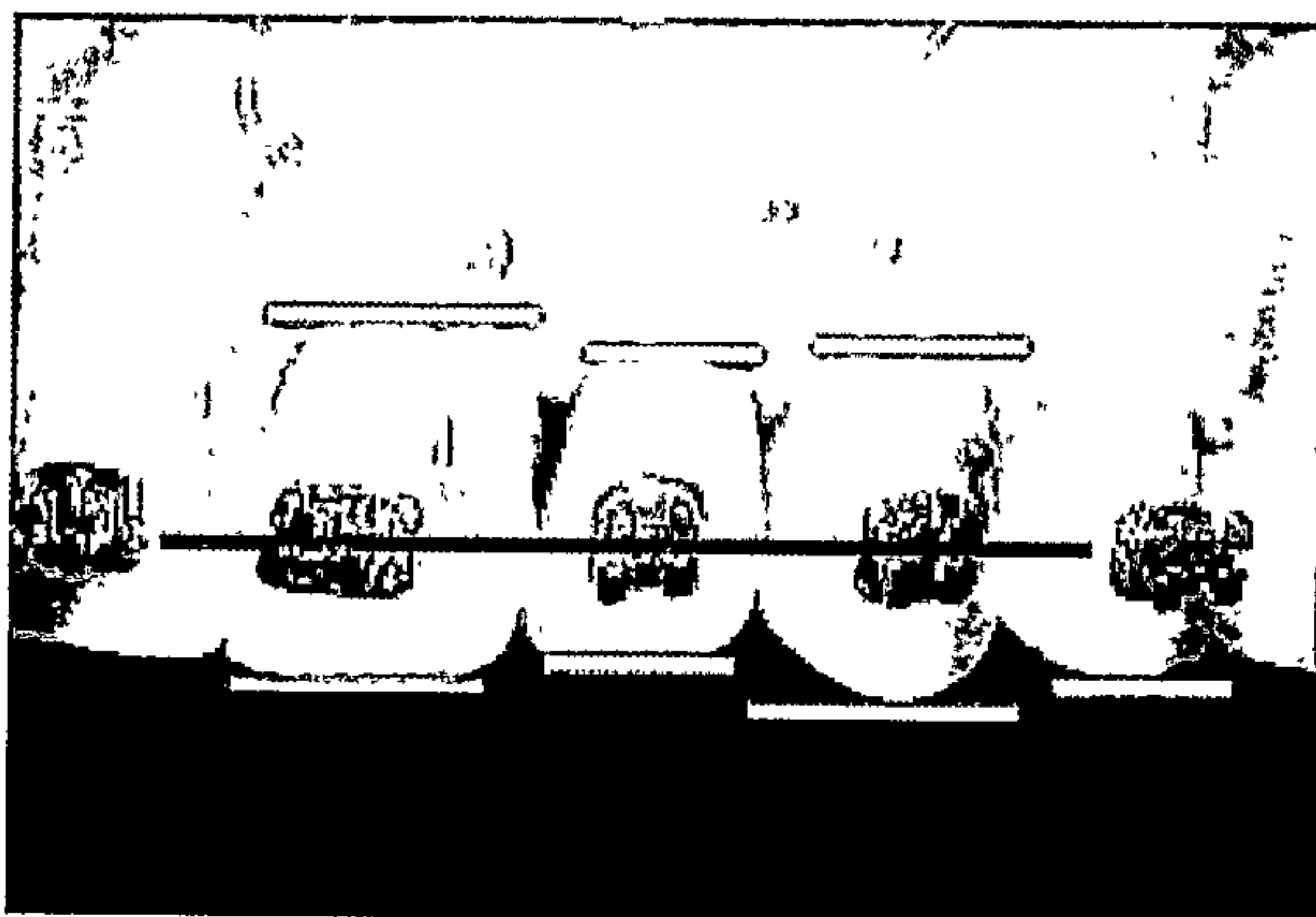
Maxillary Central Incisor

Height: Position so that the centre of the slot is 5.0 millimetres from the incisal edge and parallel to the incisal edge.

Mesio-Distal: Position so that the scribe line at the mid point of the bracket is centred over the mid-developmental ridge (the mid point mesio-distally).

Tip: The scribe line should be placed so it is coincident with the LACC. The bracket is rhomboid in shape with the edge of the base parallel to the scribe line.

In/Out: Ensure that excess cement is squeezed out and removed.



(images taken from reference 5)

Maxillary Lateral Incisor

- Height:* Position so that the centre of the slot is 4.5 millimetres from the incisal edge and parallel to the incisal edge.
- Mesio-Distal:* Position so that the scribe line at the mid point of the bracket is centred over the mid-developmental ridge (the mid point mesio-distally).
- Tip:* The scribe line should be placed so it is coincident with the LACC. The bracket is rhomboid in shape with the mesial and distal edges of the base parallel to the scribe line.
- In/Out:* Ensure that excess cement is squeezed out and removed.

Maxillary Canine

- Height:* Position so that the centre of the slot is 5.0 millimetres from the canine cusp tip.
- Mesio-Distal:* Position so that the bracket is centred mesio-distally over the mid-developmental ridge.
- Tip:* The scribe line should be placed so it is coincident with the LACC. The bracket is rhomboid in shape with the edge of the base parallel to the scribe line.
- In/Out:* Ensure that excess cement is squeezed out and removed.

Maxillary First Premolar

- Height:* Position so that the centre of the slot is 4.5 millimetres from the buccal cusp tip and parallel to the occlusal plane.
- Mesio-Distal:* Position so that the scribe line is centred over the mid-developmental ridge (the mid point mesio-distally). Check this by viewing the tooth from the occlusal.
- Tip:* The scribe line should be placed so it is coincident with the LACC. The bracket is rhomboid in shape with the edge of the base parallel to the scribe line. Use the mirror to view from the buccal.
- In/Out:* Ensure that excess cement is squeezed out and removed.

Maxillary Second Premolar

- Height:* Position so that the centre of the slot is 4.0 millimetres from the buccal cusp tip and parallel to the occlusal plane.
- Mesio-Distal:* Position so that the scribe line is centred over the mid-developmental ridge (the mid point mesio-distally). Check this by viewing the tooth from the occlusal.
- Tip:* The scribe line should be placed so it is coincident with the LACC. The bracket is rhomboid in shape with the edge of the

base parallel to the scribe line. Use the mirror to view from the buccal.

In/Out: Ensure that excess cement is squeezed out and removed.

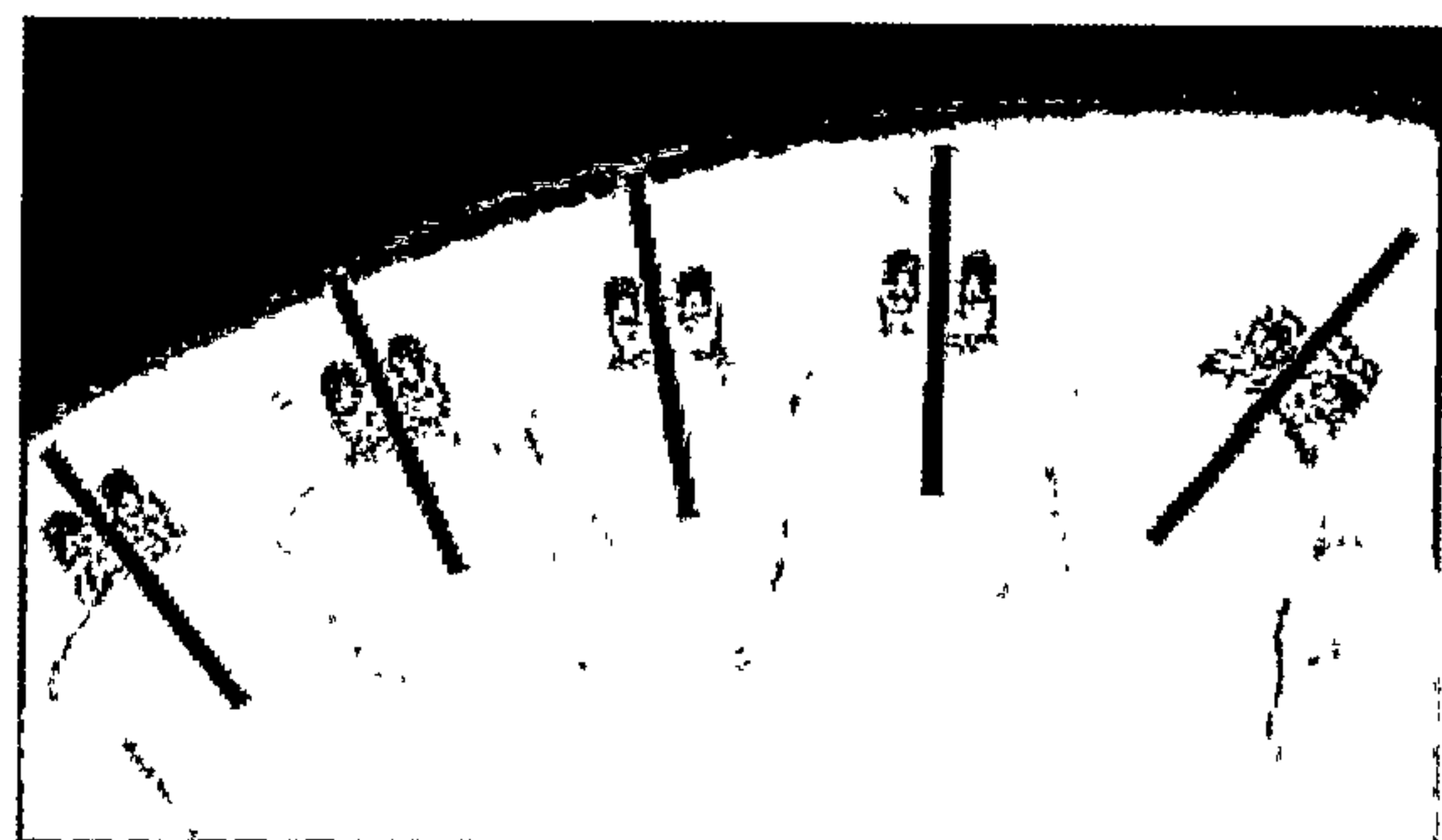
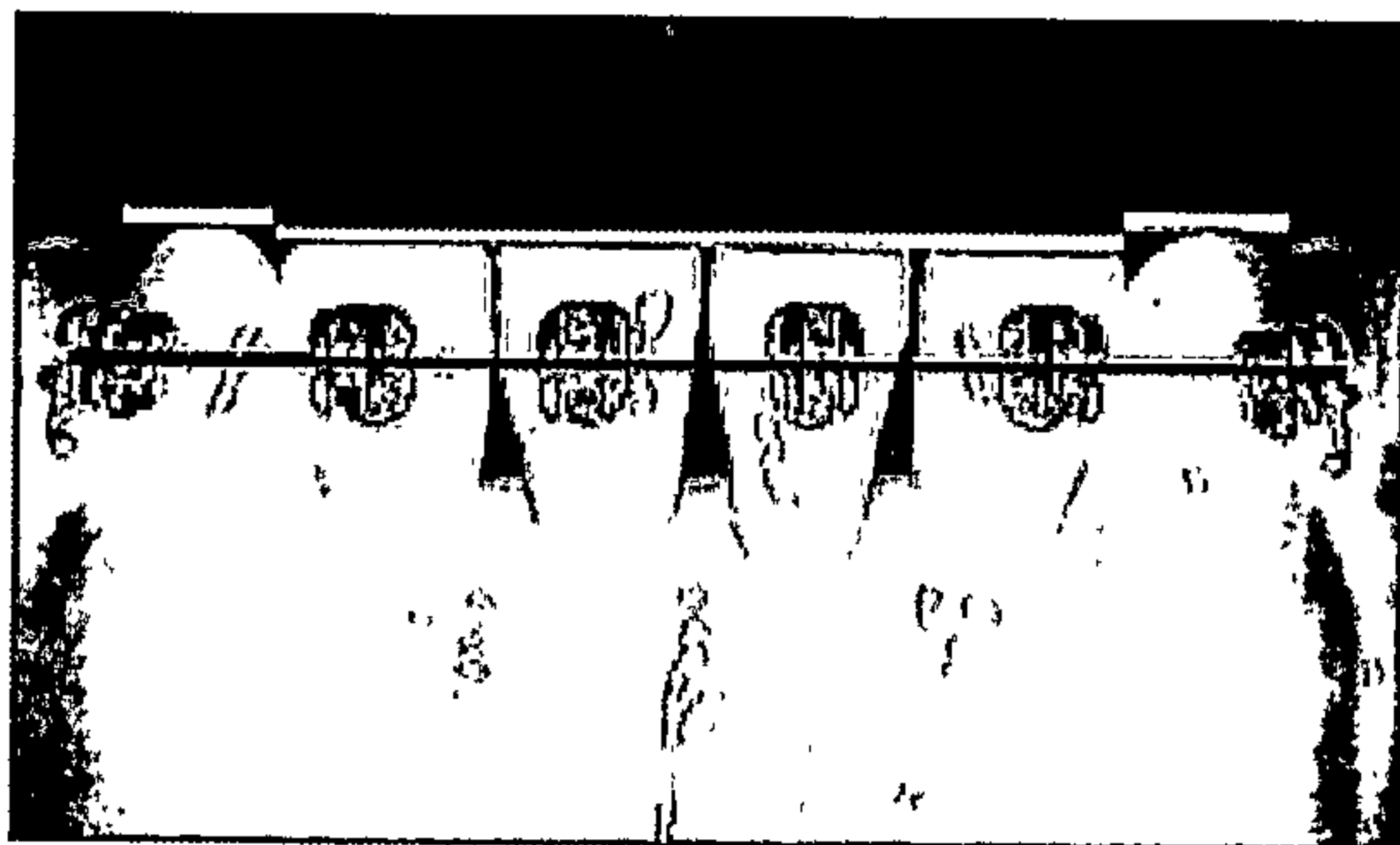
Mandibular Incisors

Height: Position so that the centre of the slot is 4.0 millimetres from the incisal edge and parallel to the incisal edge.

Mesio-Distal: Position so that the bracket is centred over the mid-developmental ridge (the mid point mesio-distally).

Tip: The vertical tie wings and the mesial and distal edges of the rhomboid shaped base should be parallel to the LACC.

In/Out: Ensure that excess cement is squeezed out and removed.



(images taken from reference 5)

Mandibular Canine

- Height:* Position so that the centre of the slot is 4.5 millimetres from the canine cusp tip and parallel to the occlusal plane.
- Mesio-Distal:* Position so that the scribe line at the mid point of the bracket is centred over the mid-developmental ridge (the mid point mesio-distally).
- Tip:* The scribe line should be placed so it is coincident with the LACC. The bracket is rhomboid in shape with the mesial and distal edges of the base parallel to the scribe line.
- In/Out:* Ensure that excess cement is squeezed out and removed.

Mandibular First Premolars

- Height:* Position so that the centre of the slot is 4.0 millimetres from the buccal cusp tip and parallel to the occlusal plane.
- Mesio-Distal:* Position so that the bracket is centred over the mid-developmental ridge (the mid point mesio-distally).
- Tip:* The vertical tie wings and the base marking are referenced to parallel the mid developmental ridge.
- In/Out:* Ensure that excess cement is squeezed out and removed.

Mandibular Second Premolars

Height: Position so that the centre of the slot is 3.5 millimetres from the occlusal plane parallel to the occlusal plane.

Mesio-Distal: Position so that the bracket is centred over the mid-developmental ridge (the mid point mesio-distally).

Tip: The vertical tie wings and the base marking are referenced to parallel the mid developmental ridge.

In/Out: Ensure that excess cement is squeezed out and removed.

Table of vertical heights for Bracket Positioning

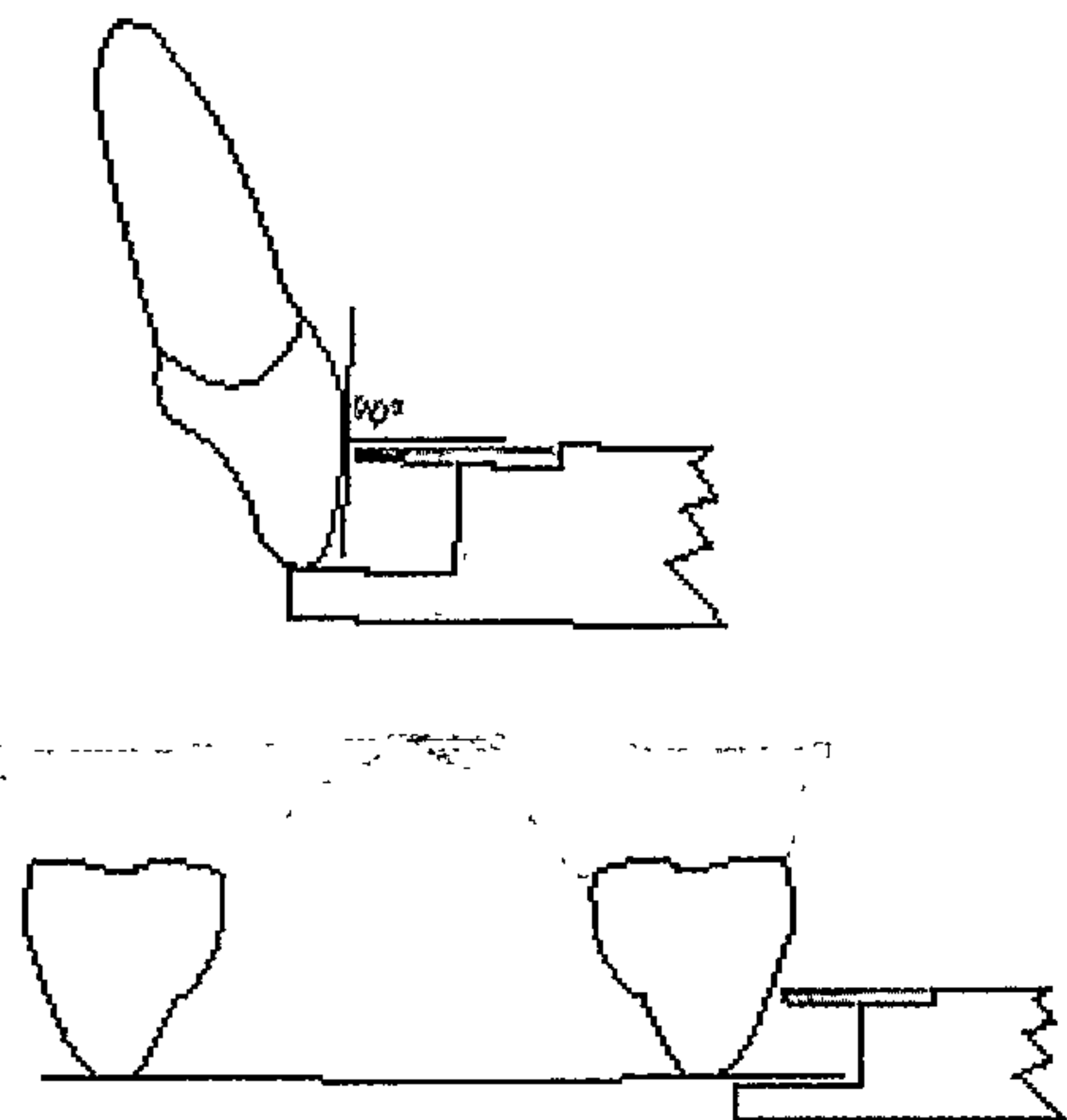
	Central	Lateral	Canine	1 st Premolar	2 nd Premolar
Upper Arch	5.0	4.5	5.0	4.5	4.0
Lower Arch	4.0	4.0	4.5	4.0	3.5

Use of Height Gauges

The vertical accuracy of bracket placement can be improved by the use of height gauges. However, the gauges are used in slightly different ways in different areas of the mouth. When planning where to place the bracket, careful consideration should be taken of the tooth's inclination, eruption status and gingival condition (hyperplasia).

taken of the tooth's inclination, eruption status and gingival condition (hyperplasia).

If the gauge is not used correctly there will be errors in bracket placement.



In the incisal region the gauge is placed at 90° to the labial surface.

For the canine and premolar regions the gauge is placed parallel with the occlusal Plane

Practical Techniques for improved accuracy

I have read the information sheet and give consent to participate in the study.

Name:..... Signature:.....

Year of graduation as a Dentist:/ an Orthodontist:.....

Number of years of Specialist Practice:.....

Do you wear glasses: Yes/ No If yes are you: Long Sighted/ Short Sighted

Do you bond some cases indirect: Yes/ No

Are you left or right handed:

Which bracket did you prefer : Precoat/ Non-Precoat/ No Preference

Where do you normally position the bracket: Centre of Clinical Crown

Measured distance from the incisal edge

Other: Please specify:

References

- (1) Andrews LF. Six keys to normal occlusion. Am J Orthod. 1972; 62:296-309
- (2) Andrews LF. The straight wire appliance: origin, controversy, commentary. J Clin Orthod. 1976; 10:99-114
- (3) Dewel BF. Clinical observations on axial inclinations of teeth. Am J Orthod 1949; 35:98-115
- (4) McLaughlin RP, Bennett JC. Bracket placement with the preadjusted appliance. J Clin Orthod 1995;5:302-311
- (5) Carlson, SK, Johnson, E. Bracket Positioning and resets: Five steps to align crowns and roots consistently. Am J Orthod Dentofac Orthop 2001;119:76-80

Protocol for Bracket Positioning (Dental Students)

The dental students were given essentially the same protocol, minus the information for measurement from the centre of the clinical crown and with a minor modification of the opening statement.