1990

Effect of Infrared Soldering of Fixed Partial Dentures on Marginal Adaptation

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EFFECT OF INFRARED SOLDERING OF FIXED PARTIAL DENTURES ON MARGINAL ADAPTATION

by

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A Thesis Submitted to the Faculty of the Graduate School of Loyola University of Chicago in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

September

1990

DEDICATION

To my deceased father, Yu-Ching Hu; my mother, Yu-Tsung Hsieh; and my brother and sisters for their unselfish support and encouragement.

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Dr. Gerard Byrne for his advice and direction with this research project, to

Dr. Leon W. Laub for his technical guidance and valuable discussion in this study, and to

Dr. Martin F. Land for his advice and serving on his graduation comittee. He also is grateful to

Ms. Fen-Fui Chen for her help in statistical analysis of the data, and to

Drs. James E. Petrie and Xavier Lepe for their guidance during the past two years.

VITA

The author, Jenq-Yong Hu, is the son of Yu-Ching Hu and Yu-Tsung Hsieh. He was born on September 13, 1959, in Hsinchu, Taiwan, R.O.C.

His elementary education was obtained at Pei-Men Elementary School in Hsinchu, Taiwan, R.O.C. His secondary education was completed at Kung-Hwa Middle High School in 1974 and at Provincial Hsinchu Senior High School in 1977 in Hsinchu, Taiwan, R.O.C.

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CHAPTER I

INTRODUCTION

Dental soldering is a traditional technique for joining the components of fixed partial dentures. Several soldering techniques are available; recently an infrared technique was introduced. The alterative to soldering is casting components in one piece. An extra procedure, soldering, is eliminated and the resulting appliance is deemed by many to be satisfactory.

The general desire for improved efficiency and cost effectiveness in the dental service has led to a gradual increase in the number of fixed partial dentures that are cast in one piece, thus bypassing soldering procedures. However, soldering is a valuable technique in the dental armamentarium and is preferred by many operators as the optimal method of joining fixed partial denture units. In addition, it is sometimes a necessary technique for specific procedure, for example, the joining of cast gold units to metal-ceramic units, since this cannot be achieved by casting the appliance in one piece.

The literature contains several studies (1-5) that recommend a one-piece casting technique over soldering. One-piece castings eliminate the soldering step, maximize the strength of the connector (6), and may be more accurate than soldered fixed partial dentures in some instances (3). Other studies (7-11) recommend soldering over one-piece castings. They cite a reduction in interabutment distortion with the former technique, which leads to improved fit. A controversy exists as to which technique results in a better fitting prosthesis.

The purpose of this study is to determine whether an infrared method for soldering fixed partial denture components results in better fitting prothesis than the one-piece casting technique.

CHAPTER II

REVIEW OF THE LITERATURE

Studies (12-14) have been conducted to compare the accuracy of fit of various alloys for single crowns. These studies provide valuable information on casting technique variables and serve as a reference for casting excellence. Likewise, studies have been conducted to assess the accuracy of FPDs joined by various methods. However, conflicting opinions arise as to whether such multiple-units FPDs should be cast in one-piece or components cast individually and then soldered together.

In 1953, Penzer (1) described the technique of FPD fabrication without soldering and concluded that this could be done satisfactorily by casting the entire structure in one piece. This technique cited as advantages, time saving and elimination of soldering difficulties (15-18). However, no details on casting fit were reported in his study.

Fusayama et al. (3) compared the accuracy of multiple-unit FPDs fabricated by one-piece casting technique and various soldering techniques. Wax patterns were invested by Fusayama's improved thermal expansion technique with the use of cristobalite investment (19). The degrees of misfit were determined by measuring the gap between the cervical margins of the abutments and the preparation shoulders of the steel model with a micrometer microscope. They concluded that fewer errors were produced with fewer technical steps and that the one-piece-cast FPDs had the greatest accuracy. However, the average marginal opening reported for a 4-unit FPD was 0.20 mm (200 μm) which is much larger than the 25 μm requirement in ADA Specification No. 8 for acceptable cement film thickness (20); and 120 μm, the maximum clinically acceptable marginal opening reported by McLean et al. (21)

Bruce (4) evaluated multiple-unit castings using a two-abutment expandable die system. He concluded that cast FPDs up to 15.5 mm in length could be cast accurately while FPDs longer than 15.5 mm in length showed slight contraction. Castings produced from plastic patterns were slightly more accurate, but rougher than castings produced from wax patterns. He reported only changes in length but no figures on the accuracy of fit. He reported that, within defined limits, the one-piece casting technique is accurate. Inaccuracy increases as the length of the FPDs increases. (22)

Distortion during wax pattern removal from the die is thought to be one of the problems in one-piece casting fabrication. In 1955, Rubin et al. (5) presented a technique for accurate casting of one piece FPDs. The retainers and pontics were individually waxed and carved on the master cast. After all the individual units were waxed, they were transferred to a refractory cast which was duplicated from the master cast using a reversible hydrocolloid. The wax units were joined together, marginated, and invested for casting. They reported that inaccuracies were reduced because there was no need to withdraw the wax patterns from the refractory cast. However, no data were given to verify the accuracy of the proposed technique.

Garlapo et al. (23) assessed the spatial changes of 4-unit FPDs made as one-piece castings. They measured the distance between the indexing points of five dimensions for wax patterns and completed castings. They concluded that a 4-unit FPD could be cast in one-piece without producing significant vertical warpage which could affect the seating of the FPDs.

One of the factors which leads to the misfit of a one-piece casting is the inadequate retainer-to-retainer expansion (11). The interabutment distortion results in the marginal error that can compromise the simultaneous optimal fit of the retainers.

In 1986, Ziebert et al. (6) compared the accuracy of FPDs of varying lengths fabricated as one-piece castings, or joined by preceramic, or postceramic soldering. They examined the vertical marginal opening only using a travelling microscope. They observed that the fit of all the 3-unit FPDs, whether cast or soldered, was similar. Reported mean marginal gap widths ranged from 32 μm for preceramic soldering to 42 μm for one-piece casting and increased as span length increased. Due to warping phenomenon which occurred during waxing, casting, as well as during soldering stage, distortion was not even across the FPD. The distal margin of the posterior abutment and the mesial margin of the anterior abutment had the largest marginal discrepancy. (6,24) They suggested soldering for FPDs exceeding 4 or more-units.

Schiffeleger et al. (24) compared the marginal discrepancies of 3, 4, and 5-unit one-piece castings and reported mean values for marginal gap width of 54, 92, and 105 μm, respectively. They stated that the longer the prosthesis, the greater the distortion. The castings contracted mesio-distally and expanded facio-lingually. In order to get more uniform expansion, they recommended use of an oval ring which could provide an even thickness of investment around the FPD wax pattern. They reported that the marginal gap width could be reduced by 50 - 70% after sectioning the specimen and seating of the individual components.

Sass and Eames (25) studied the relation between casting fit and the size and shape of a casting ring. Because a greater amount of investment expands against a constant thickness of ring liner when the diameter of the casting ring is larger, larger rings should be more restrictive and decrease the percentage of investment expansion. Hence smaller rings permit overexpansion of investment which could lead to an oversized casting. When FPDs were fabricated in small casting rings, they reported that FPD failed to seat as completely as the casting made using large casting ring. This was attributed to the distorted retainer interrelationship mesio-distally from that formed in the wax pattern by the oversized casting. They measured the gap distance from the cast retainer gingival margin to the die shoulder and reported that through the use of the proper size casting ring satisfactory 3-unit one-piece castings could be produced. FPD fit was affected more by the casting ring size than by its shape.

The position of the wax patterns in the casting ring also affects the accuracy of castings. Due to the thermal zone effect, the cooling rate is slower in the center of the casting ring than in its periphery. When casting multiple-units, the wax pattern should be placed peripherally instead of centrally. (26) Casting shrinkage was more uniform when FPD patterns were invested vertically rather than horizontally. (27)

While distortion occurs by any of the techniques investigated, Hinman et al. (28) found that the most important variable which affected the fit was the amount of resistance that each material offered to uniform expansion of the investment. Investment mold expansion and pattern distortion affected the accuracy of multiple-unit castings, but pattern distortion had a greater influence. Due to its inherent properties such as stiffness and higher glass transition temperature, a plastic runner bar might cause distortion of the invested wax patterns during the setting expansion phase of the investment. Less pattern distortion was reported for the thermal expansion technique than for the hygroscopic technique. They suggested the use of an all-wax spruing system and a bench-set technique which could produce the least distortion and the highest consistency in the fit of multiple-unit FPD castings.

The ratio of special liquid to water influences the expansion of phosphate-bonded investment which ultimately influences the seating of the castings. The liquid contains silica particles that contribute to greater thermal expansion. (29) Also, when the high expansion of the phosphate-bonded investment is reduced through partial substitution of water for the special liquid, surface roughness increases. (30) The ratio of special liquid to water is one of the factors to be varied to compensate for different casting shrinkage requirements for the different alloys used.

Four different soldering techniques have been developed: 1) conventional torch soldering, 2) oven soldering, 3) laser welding, and 4) infrared soldering.

The torch soldering technique is the most popular one and has such advantages as easy approach, good vision, the flexibility to add more solder when needed, and ceasation of heating immediately upon completion of the procedure. However, it is difficult to control the soldering temperature and the oxidization of the joint area. Contrarily, oven soldering can be done with good temperature control and in reduced oxidization circumstances but without accessibility to the joint area with solder once the procedure is started. The laser welding technique was first introduced in 1970 by Gordon et al. (31) It is a rapid and convenient technique which can produce sound welds in dental casting alloys of more uniform strength than soldered connections of the same alloy. (32) Laser welding can be done on the master cast with the assumption that far less distortion is induced than that resulting from transfers and soldering. Relative to infrared soldering, Pirro (33) was probably the first to apply this radiant energy to the joining of dental castings.

Prior to 1950 an attempt was made to bake porcelain on nickel-based alloys. (34) These alloys had the advantage of high yield strength so that thinner castings could be made (15) but units were difficult to solder (15-17). The use of base metal alloys for metal-ceramic restorations became very popular in the late 1970's to reduce the cost of dental services. In 1981, a survey of dental laboratory technicians over a 5-year period showed that only 53% of laboratory owners expressed satisfaction with the solderability of base metal alloys. (16) Other problems associated with these alloys were the potential toxic effects of the elements nickel and beryllium (35-37), and technical difficulties (20,38-40).

In 1972 gold-palladium-silver alloys were developed from high noble metal content alloys by reducing the gold content and eliminating platinum, the palladium and silver contents were increased. In 1974 the gold content was almost eliminated to produce palladium-silver alloys. (41) In 1982 a silver-free high palladium alloy was developed. (42) The casting accuracy of this type of alloy was demonstrated to be equivalent to the gold-platinum-palladium alloys. (12) Since silver-free high palladium alloys were introduced for use in fixed prosthodontics, discoloration of the porcelain and technical difficulties encountered in the fabrication of metal-ceramic prostheses have been solved.

In 1977, Huling and Clark (2) studied the distortion in 3-unit FPDs joined by laser welding, conventional soldering, and one piece casting. They evaluated the accuracy of these techniques by measuring the shifts in the reference markers and concluded that laser welding and one-piece castings of 3-unit partial dentures were significantly superior to those assembled by conventional soldering. Laser welding was the most reliable technique. They compared only the distortion of each surface of the individual abutment crowns. No report was made of actual casting fit.

Dental soldering is also classified as pre- and postsoldering. Presoldering is the technique of joining two or more metal-ceramic crowns before porcelain is fired. Because the fusing temperature of the solder is higher than the firing temperature of the porcelain, modification of the shade is feasible after porcelain firing when needed. It is conventionally done using a torch soldering technique. (43) Postsoldering is needed to form a union between a type III or IV gold alloy and a metal-ceramic alloy. It can also be used to connect crowns after porcelain is fired. Due to the lower fusing temperature of the solder, shade modification is not possible following soldering. Oven soldering is often preferred because it provides a more controlled heating environment. Torch soldering can lead to fracture of porcelain. (44)

Some studies (44-49) have compared the presoldered and postsoldered joints. Results have been inconsistent on account of differences in alloy properties. However, both techniques were found to be equally accurate. (6)

A study (50) by Walters suggested that units to be soldered be either all precious metal or all nonprecious metal. He found the region around the solder and nonprecious metal seemed to lack a chemical or a physical union. If a combination of metals was desired, a dovetail procedure might have been used prior to soldering to provide mechanical locking. It should be used for short-span FPDs as far as strength is concerned.

In order to join the pieces for soldering, an index is needed to maintain them in an exact relationship. Self-curing resin (50-55), zinc oxide eugenol (11), plaster (7,56), and sticky wax (9,18) are commonly used. Clinically, Duralay resin (Reliance Dental Mfg. Co., Worth, IL) is the most popular one because of the cleaniness and ease of use. The accuracy of these materials is affected by their dimensional stability. In 1979, Harper et al. (57) compared the accuracy of seven indexing mediums and found that ZOE bite registration paste was the most accurate. Not only did ZOE demonstrate the least mean vector distortion (0.033 mm), but also the range of the component distortion was the smallest. Moon et al. (58) compared different indexing materials at different duration and/or thickness. They concluded that the most accurate results were obtained with a plaster non-removal technique and that a 3 mm thickness of Duralay was superior to a 6 mm thickness. Because of the continuous polymerization, a soldering index made with Duralay resin should be invested as soon as possible.

The shape of the opposing surfaces to be connected is important to success. Because of capillary action, convex surfaces opposed to each other produce better flow of solder, as reported by Rosen (59). In his study, he concluded that parent alloys and solders with the greatest melting differential produced superior results. Moreover, oven postsoldering results were better because of reduced oxidation in the oven. Conversely, Shillinburg et al. (60) reported that the opposing surfaces on either side of the solder joint should parallel each other and that there was more likelihood of distortion if the space between units was not uniform.

The gap distance between the two pieces to be joined is probably the most controversial parameter in soldering. It affects the distortion or accuracy of the system as well as the strength. (61) The suggested gap distance ranged from tight contact (62), 0.1 mm (52,58), 0.15 mm (43,45,56), 0.2 mm (32), 0.25 mm (48,63), 0.3 mm (46,49,59,64-66), to 0.5 mm (9,17,44). The distance suggested by Pirro to achieve the same result was from 0.05 to 0.13 mm (33). In Rosen's study (59), a gap size of 0.3 mm was selected to allow for thermal expansion of the assembly to be soldered. He thought this gap distance would permit capillary flow of the solder without leading to excessive solder shrinkage and corresponding distortion.

Willis and Nicholls (56) studied the effect of gap distance on dental soldering distortion and found that a soldering gap distance of 0.15 mm was the most desirable. They suggested the use of minimum gap distance without contact. If the parts to be soldered are in contact before heating, warpage will occur. In the investment soldering procedure, the gaps close up to 0.05 to 0.13 mm during preheating to 1100° F, and if the solder gap is narrower than this, warpage occurs. A minimum of 0.13 mm gap is required. (67)

Stade et al. (46) evaluated the gaps at 0.31, 0.51, and 0.76 mm. They suggested the use of a calling card as a guideline for gap space. The thickness of the card is about

0.3 mm. They concluded that the soldering technique was more important than gap distance.

Pirro (33) reported that a space in the range of 0.05 to 0.13 mm would allow the soldering investment to expand without distorting the relationships of the retainers. At the same time, it would facilitate the application of flux and the placement and retention of a variety of solder configurations.

Rasmussen et al. (48) investigated tensile strength of dental solder joints at distances of 0.13, 0.5 and 1.0 mm. The study revealed that high-fusing solders have lower surface tension and flow more easily into narrow gaps, whereas the low-fusing solders tend to be more sluggish and are more difficult to flow into narrow gaps. They concluded that the presolder joints were stronger at narrow gaps and the postsolder joints were stronger at wider gaps. They did not specify the optimal gap distances for either type.

The method of measurement is critical in terms of casting adaptation. Different data could be obtained with different measuring methods for the same specimen. Cooney and Caputo (68) measured vertical marginal discrepancy, Plekavich and Joncas (69) measured absolute marginal discrepancy, and Faull et al. (70) measured the marginal gap. Due to the varying methods of measurement, it is difficult to make direct comparisons between these studies.

Holmes et al. (71) defined internal gap, marginal gap, vertical marginal discrepancy, horizontal marginal discrepancy, and absolute marginal discrepancy. The internal gap is the perpendicular measurement from the internal surface of the casting to the axial wall of the preparation. The same measurement at the margin is called the marginal gap. The vertical marginal discrepancy is the vertical marginal misfit measured parallel to the path of draw of the casting. The horizontal marginal misfit measured perpendicular to the path of draw of the casting is called the horizontal marginal discrepancy. They concluded that the absolute marginal discrepancy, always being greater than or equal to the vertical marginal discrepancy or marginal gap, would always have the largest error at the margin and would reflect the total misfit at that point.

The absolute marginal discrepancy, measured from the casting margin to the cavosurface angle of the tooth, is the angular combination of the vertical marginal discrepancy and the horizontal marginal discrepancy. Even if the internal gap is zero, the margin can still be overextended or underextended. So the absolute marginal discrepancy can best describe the marginal fit.

CHAPTER III

MATERIALS AND METHODS

A silver-free high palladium alloy was used to evaluate the accuracy of 3-unit FPD casts, comparing the infrared soldering technique to a one-piece casting technique. No porcelain firing cycle was simulated. Individual retainers were also cast and sectioned for reference purposes. The study groups were:

Group	Sample Size
I. Individual casting (Reference)	1
II. One-piece casting (Control)	5
III. Infrared soldering (Experimental)	5

All procedures were standardized where possible from die fabrication to final measurements. Castings were fabricated using the optimal technique developed in a pilot study. Samples in the control group were cast in one-piece, while those in the experimental group were cast individually and soldered using the infrared technique. All castings were seated on their respective dies and embedded in a clear epoxy resin. The embedded specimens were sectioned and the axial and marginal gap widths measured using a profile projector. Scanning electron microscope studies were also conducted to assess the marginal fit of representative castings from each group. The procedures are described in detail below:

Fabrication of Die

The Master Die

Nos. 9 and 11 ivorine teeth were prepared for metal-ceramic restorations with No. 10 being the pontic space. The preparations consisted of a 1.0 mm facial shoulder and a 0.3 mm lingual chamfer for both teeth (Figures 1,2). These were attached onto an acrylic base 15 mm x 30 mm x 3 mm, separated by a distance of 6.5 mm (72) to simulate the mesio-distal width of tooth No. 10. Three lines were inscribed on the acrylic base, centering teeth Nos. 9 and 11 mesio-distally and labio-lingually (Figure 3), to ensure sectioning at a definite location for comparison.

Die Mold

An open-ended plastic cup was centered around the master die and base. A silicone material[1] was mixed according to the manufacturer's instructions, placed under vacuum for 15 minutes, and then poured into the plastic cup. The silicone material was allowed to cure 24 hours and the master die was removed. This negative mold of the master die was used to fabricate stone replicas.

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[1] R.T.V. 630, General Electric Co., Waterford, NY

Stone Die

Stone dies were produced by pouring type IV stone[1] into the silicone mold. (Figure 4) The powder to water ratio and mixing time were based on manufacturer's directions. The dies were removed from the mold after 30 minutes. In this way, 22 dies were fabricated (11 master + 11 reserve).

Fabrication of Wax Pattern

In order to standardize the fabrication of the wax pattern, another silicone mold was made on the master die and wax pattern. The duplication of wax patterns was accomplished by using a wax injection technique described by Jean (73).

The Master Wax Pattern

"Ideal" wax patterns for Nos. 9 and 11 metal-ceramic retainers were fabricated on the master die (Figure 5) which was coated with die lubricant[2] and shaken dry several times. A section of round wax, 2.5 mm (10-gauge) in diameter (45,48), was used instead of the pontic. This allowed standardization of the connector. The wax pattern was sprued with 10-gauge wax, and a runner bar 3.0 mm (8-gauge) in diameter was used. Both the pontic bar and runner bar were centered on the master die labio-lingually to facilitate

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[1] Silky-Rock, Whip-Mix Corp., Louisville, KY

[2] Slikdie Lubricant, Slaycris Products., Portland, OR

slicing open the injection mold and wax pattern in two halves.

Injection Mold Construction

A strip of boxing wax was circumferentially attached to the master die base within the confines of its perimeter and divergently extended upward, 5 mm, past the runner bar. This would allow a thickness of approximately 10 mm of rubber mold material around the wax pattern and its sprue. A second sheet of boxing wax was used to surround the inner wax matrix leaving about a 20 mm space between the two layers of boxing wax. Type IV stone was poured into this space. Thirty minutes later the boxing wax was removed and the stone matrix was cut into halves, one of which was discarded. The cut surfaces of the remaining half were arbitrarily indented and lubricated with vaseline. The stone matrix was assembled with the master die and the previous boxing procedure was followed again. The other half of the stone matrix was poured with stone, forming two matching halves.

The inner surface of the stone matrix was arbitrarily indented and assembled with the master die and wax pattern. The nozzle of the wax injection apparatus[1] was luted to the center of the runner bar of the wax pattern. The silicone mold material was mixed, placed under vacuum to remove any air bubbles, poured into the stone matrix around the wax pattern (Figure 6), and allowed to cure for twenty-

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[1] Pro-Craft, GFC., Carlstadt, NJ

four hours.

The master die and nozzle were removed and the silicone mold was carefully sliced into two halves through the runner bar and pontic bar with a No. 11 scalpel blade. This mold was inspected for internal surface defects.

Wax Pattern Fabrication

All the master stone dies were soaked in die lubricant for five minutes. They were numbered from Nos. 1 to 11. Each stone die was then, in turn, fitted in the silicone mold and stone matrix which was secured with an elastic band. Type C hard blue inlay wax[1], used to form the wax pattern, was heated to "medium" hot in the wax injection apparatus until the wax was completely liquefied. The plunger was raised to its upper limit and lowered slightly to bring wax to the nozzle orifice. The mold opening was fitted over the nozzle and, by lowering the plunger, wax was pumped into the silicone mold. Constant pressure was maintained on the plunger for approximately one minute before the mold assembly was removed to prevent wax from flowing back. Five minutes were allowed for the wax to harden. The stone matrix was removed, the silicone mold opened (Figure 7), and the die, wax pattern, and sprue assembly removed. Excessive wax flash was reduced from the margins and the pattern checked for internal adaptation.

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[1] Casting Wax, Whip-Mix Corp., Louisville, KY

A total of 11 patterns were fabricated. Among them, the retainers in Group I (reference), numbered 1, were to be cast individually without the pontic bar; Group II specimens (control), numbered 2-6, were to be cast as one-piece; and Group III specimens (experimental), numbered 7-11, were to be presoldered.

Once deemed acceptable, the patterns were seated on their respective dies. The wax pontic bars of the control and experimental groups were cut as close to the retainers as possible and replaced with the same gauge plastic bars (Figure 8) without disfiguring the retainers. To standardize the location of the joints to be presoldered, a stone jig was fabricated on a surveyor[1] to cut open the plastic bar 0.5 mm distal to tooth No. 9 with a 0.15 mm thick diamond disc[2]. For the reference group, the wax pontic bar was cut flush to the proximal surfaces without replacing it with a plastic bar. To obtain optimal results, the runner bars of the reference and experimental groups were cut and each retainer was invested in a separate ring. The margins of all specimens were then reflowed and carefully carved flush with the die in readiness for investing.

Investing Technique

The "marginated" pattern was removed from its die

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[1] Ney Surveyor, J.M. Ney Co., Bloomfield, CT

[2] Diamond Disc, Brasseler USA Inc., Savannah, GA

and attached to a rubber crucible former. The pattern was sprayed with wax pattern cleaner[1] and blown dry. A casting ring (1 1/4 x 1 3/8 in) was lined with one layer of casting ring liner[2] which was 1/8 inch short of the open end of the ring. The ring was then immersed in water for one minute.

A non-hygroscopic investing technique was used. All wax patterns were invested with a carbon-free phosphate-bonded investment[3] using 60 gm powder, 4.5 ml special liquid[4], and 4 ml water; the optimal powder/liquid/water ratio used by Byrne et al. in a casting accuracy study (12). The mixing was done by 15 seconds of initial hand spatulation followed by 30 seconds of vacuum mechanical spatulation and then held for 15 seconds under vacuum alone. The investment was allowed to set for a minimum of 60 minutes before burnout.

Burnout and Casting

The invested rings were placed in a cold burn-out oven[5]. The pyrometer was set at 1300° F and the rate of climb was set. When the highest temperature was reached, the rings were heat soaked for one hour.

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[1] Wax Pattern Cleaner, J.F. Jelenko & Co., Armonk, NY

[2] Non-Asbestos Ring Liner, Whip-Mix Corp., Louisville, KY

[3] Hi-Temp 2, Whip-Mix Corp., Louisville, KY

[4] Ceramigold Special Liquid, Whip-Mix Corp., Louisville, KY

[5] Accu-Therm 250, Jelrus Technical Products., New Hyde Park, NY

A multiorifice natural gas-oxygen torch[1] was used to melt the alloy. No casting flux was added. The casting was completed in a broken-arm centrifugal casting machine[2], wound four times. Six ingots (6 dwt) of new silver-free high palladium alloy[3] (79 wt % Pd, 10 wt % Cu, 9 wt % Ga, 2 wt % Au) were used for the one-piece specimens and four ingots (4 dwt) for those retainers which were to be cast individually.

Devesting

After casting, the casting rings were bench cooled for five minutes and then quenched in cold water. The investment was removed and the castings were ultrasonically cleaned in a cleaning solution[4] followed by distilled water.

Examination of Castings

The internal surface of each casting was examined with a 20x binocular microscope[5] and all small nodules were carefully removed. The castings (Figures 9,10) were then tried on a reserve die to check for their fit. When the castings were deemed satisfactory, the sprues were cut.

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[1] Harris 88-3FGR, Harris Carolific Co., Cleveland, OH

[2] Centrifico Casting Machine, Sybron/Kerr Manufacturing Co., Romulus, MI

[3] Option, J.M. Ney Co., Bloomfield, CT

[4] No-San, Trio-Dent Inc., Union, NJ

[5] Stereo Star Zoom, American Optical Co., Buffalo, NY

Soldering

For the presoldering operation, each retainer of the experimental group was seated on its die and the die was placed on the surveyor jig. The same diamond disc previously used was passed through the joint area again to ensure a 0.15 mm gap distance (Figure 11). A small V-shaped groove was cut above the joint area with a separating disc for feeding of the solder.

Mounting stone[1] was used to fabricate the occlusal indices (Figure 12) for each of the five samples. Each sample was then invested with soldering investment[2]. After the soldering investment set, the occlusal index was removed. Each soldering assembly was trimmed to a 30 mm x 20 mm x 10 mm size.

A piece of 4 mm long presolder[3] was dipped in soldering flux[4] and then placed on the V-shaped groove of the joint area. An infrared soldering machine[5] (Figure 13) was used to solder the joint. The filter shield was opened and the soldering assembly was placed on the platform of the soldering machine. The rotatable pointer was swung to the

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[1] Mounting Stone, Whip-Mix Corp., Louisville, KY

[2] Hi-Heat, Whip-Mix Corp., Louisville, KY

[3] Option Presolder, J.M. Ney Co., Bloomfield, CT

[4] Flubmittel T, Degussa Dental, Inc., Long Island City, NY

[5] Ney Infrared, J.M. Ney Co., Bloomfield, CT

center lock locating position. The work platform was raised and the soldering assembly was moved until the pointer was centered mesio-distally in the solder joint. The pointer was then moved to the storage position and the work platform was raised slightly to position the tip of the pointer (and ultimately infrared energy) in the occluso-gingival center of the solder joint. The filter shield was then lowered and the soldering procedure was ready to commence.

Before starting to solder, the power level control was turned to the 1st setting and the fine tuning control was turned to the minimal setting. The start button was then pressed. The power level control was kept at the 1st setting and the fine tuning control was slowly adjusted from minimum to maximum. If the solder did not flow, the power level control was turned to the 2nd setting and the fine tuning control was adjusted slowly again from minimum to maximum. This procedure was continued until the solder flowed. During this procedure, the soldering assembly was automatically "preheated". As soon as the solder began to flow, the power was kept at that level until the solder flowed through the whole joint area. After the soldering procedure was completed, the power was released, the filter shield was opened, and the soldering assembly was removed.

Five minutes after soldering, the specimens were recovered from the investment and ultrasonically cleaned in distilled water.

Embedding

A small vent hole was drilled in a proximo-incisal corner of all copings. The castings were seated on their original dies using finger pressure. They were carefully orientated on plastic embedding trays[1] to facilitate aligning and sectioning at the predetermined location on the sectioning machine and then embedded in a clear epoxy resin[2] (Figure 14). The mixing of the clear epoxy resin was done as directed by the manufacturer. The specimens were allowed to set for 24 hours before sectioning.

Sectioning and Polishing

When the epoxy resin had hardened, the plastic trays were discarded. Each resin block was mounted in a sectioning machine[3] (Figure 15) and the cutting blade was carefully aligned with the predetermined lines inscribed on the die. Three cuts were made on each resin block of the control and experimental groups: one in a mesio-distal direction and two in a labio-lingual direction. The mesio-distal cut was made first and the two labio-lingual cuts made subsequently. This resulted in 6 sections for each block (Figure 16). Only two cuts were made on each retainer of the No. 1 samples: one

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[1] Embedding Molds R30, Peel-A-Way Sci., S. El Monte, CA

[2] Buehler Epoxide Resin, Buehler Ltd., Lake Bluff, IL

[3] Vari-Cut VC-50, Leco Corp., St. Joseph, MI

mesio-distally, the other labio-lingually. This resulted in 8 sections for the reference group , 4 sections for each of tooth #9 and tooth #11.

The surfaces to be measured were wet polished by hand with progressively finer grit silicon-carbide abrasive papers from 240, 320, 400, to 600 grit on polishing equipment[1]. A final polish was done on a metallurgical polishing wheel[2] using a polishing cloth[3] with a 5-micron alumina particle suspension.

Measuring

The cavosurface margins were selected as reproducible reference points for measurement. With a profile projector[4] at 100x magnification (Figure 17), marginal adaptation on the labial, mesial, and distal shoulders was evaluated by measuring the vertical gap distance at 150, 300, 450, and 600 microns, respectively, from the reference point (Figure 18); similarly on the lingual chamfer at 50, 100, 150, and 200 microns, respectively, from the reference point (Figure 19). Likewise, the axial adaptation was evaluated by measuring the horizontal gap distance at 500, 1000, 1500, and

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[1] Handimet Grinder, Buehler Ltd., Lake Bluff, IL

[2] Polisher Ecomet III Grinder, Buehler Ltd., Lake Bluff, IL

[3] Microcloth, Buehler Ltd., Lake Bluff, IL

[4] Profile Projector V-12, Nikon, Inc., Instrument Group., Garden City, NY

2000 microns, respectively, from the reference point (Figure 20). Thus, four measurements were taken for each site to avoid magnifying the gap distance resulting from an occasional defect at the margin.

Scanning Electron Microscope

Representative castings were selected from each of the three groups. They were mounted and coated for viewing under a scanning electron microscope[1]. Photomicrographs (Figures 21-24) of the shoulder and chamfer margins and the joint area were taken.

[1] ISI-SX-30E, International Scientific Instruments, Inc., Milpitas, CA

CHAPTER IV

RESULTS

The fit of the castings was analyzed from two aspects: marginal fit and axial fit. The gap measurements of the reference group were considered as mean values. The axial (A) and marginal (M) measurements, in microns, for each specified site for each of the three study groups are recorded in Tables I - III, respectively. The means and standard deviations were calculated for each site (Table IV). The means for any reference group site were smaller than the equivalent sites in the other two groups. The smallest mean for any marginal site in the control and experimental groups was for the labial wall of tooth #11 in the experimental group (15.4 μm). The smallest mean for any axial site in the control and experimental groups was for the labial wall of tooth #11 in the experimental group (12.6 μm). The largest mean for any marginal site in the control and experimental groups was for the mesial wall of tooth #9 in the control group (70.1 μm). The largest mean for any axial site in the control and experimental groups was for the mesial wall of tooth #9 in the control group (35.3 μm).

When values of the relative sites within each group were combined, the reference group had smaller values than the other two groups. The smallest means for axial (12.7 μm) and marginal (15.7 μm) sites in the control and experimental groups were for the labial wall in the experimental group. The largest means for axial (28.2 μm) and marginal (49.0 μm) sites in the control and experimental groups were for the mesial wall in the control group.

Combining all marginal values for each tooth (#9 and #11, respectively) and within each group (#9 + #11) (Table V) showed that the smallest values for the reference group (13.5 μm for #9, 13.3 μm for #11, and 13.4 μm for #9 + #11). The largest mean values were in the control group (34.8 μm for #9, 33.3 μm for 11, and 34.0 μm for #9 + #11).

Results of the statistical analysis of the control vs. experimental groups (Table VI) revealed that there were significant differences on the mesio-axial, mesio-marginal, labio-axial, labio-marginal sites of tooth #9, and on the mesio-axial, mesio-marginal, disto-axial, disto-marginal, and labio-marginal sites of tooth #11 at the $p= 0.05$ level. For the analysis of teeth #9 vs. #11 for the control and experimental groups (Table VII), significant differences were found on the mesio-axial, mesio-marginal, disto-axial, disto-marginal, and linguo-marginal sites of the control group, and on the linguo-axial and linguo-marginal sites of the experimental group at the $p= 0.05$ level.

One way analysis of variance of the marginal values among three study groups (Table VIII) showed significant differences at the p= 0.05 level. Further analysis using Tukey's Studentized Range Test revealed differences between the reference and control groups and between the control and experimental groups.

The values of the mesial site of tooth #9 combined with the values of the distal site of tooth #11 were classified as "external" sites. The values of the distal site of tooth #9 combined with the values of the mesial site of tooth #11 were classified as "internal" sites. The mean and standard deviation for the external and internal sites for each of the three groups were listed in Table IX. Relatively higher mean values were found on the external-axial site (32.4 μm) and on the external-marginal site (65.2 μm) of the control group.

One way analysis of variance of the axial values of the external and internal sites among three groups (Table X) showed no significant difference at the internal sites but significant differences at the external sites at the p= 0.05 level. Tukey's Test pointed out significant differences between the reference and control groups and between the control and experimental groups.

One way analysis of variance of the marginal values of the external and internal sites among three groups (Table XI) revealed significant differences at both the external and the internal sites at the p= 0.05 level. For the external sites, Tukey's Test indicated differences between the reference and control groups and between the control and experimental groups. For the internal sites, Tukey's Test showed differences between the reference and control groups.

Paired t test of the external vs. internal sites within each group (Table XII) revealed significant differences at the axial and marginal sites of the control group only.

TABLE I

Gap Measurements
Group I: Individual Casting (Reference)
(μm)

	#9								#11							
	Mesial		Distal		Labial		Lingual		Mesial		Distal		Labial		Lingual	
	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
Sample																
1	15.0	12.0	13.0	17.0	6.0	12.0	13.0	13.0	9.0	10.0	16.0	14.0	5.0	5.0	20.0	14.0
	13.0	13.0	18.0	13.0	9.0	11.0	15.0	19.0	15.0	15.0	12.0	16.0	4.0	8.0	15.0	19.0
	10.0	14.0	12.0	14.0	7.0	8.0	11.0	16.0	15.0	16.0	11.0	17.0	4.0	7.0	15.0	18.0
	8.0	15.0	13.0	14.0	9.0	11.0	16.0	14.0	9.0	13.0	10.0	17.0	4.0	6.0	15.0	18.0

A: Axial
M: Marginal

TABLE II

Gap Measurements
Group II: One-Piece Casting (Control)
(μm)

	#9								#11							
	Mesial		Distal		Labial		Lingual		Mesial		Distal		Labial		Lingual	
	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
Sample																
2	21.0	72.0	20.0	21.0	15.0	18.0	10.0	21.0	48.0	56.0	31.0	66.0	19.0	21.0	5.0	13.0
	18.0	80.0	33.0	22.0	13.0	19.0	7.0	21.0	34.0	56.0	31.0	80.0	15.0	38.0	5.0	10.0
	18.0	74.0	34.0	21.0	13.0	19.0	6.0	18.0	40.0	57.0	29.0	88.0	17.0	40.0	4.0	11.0
	16.0	78.0	24.0	20.0	13.0	21.0	5.0	17.0	35.0	55.0	31.0	83.0	16.0	42.0	3.0	10.0
3	32.0	57.0	13.0	8.0	16.0	20.0	17.0	26.0	9.0	12.0	30.0	34.0	16.0	30.0	20.0	34.0
	19.0	59.0	10.0	6.0	15.0	18.0	19.0	24.0	4.0	10.0	21.0	38.0	21.0	10.0	8.0	29.0
	27.0	57.0	10.0	18.0	15.0	14.0	18.0	25.0	8.0	10.0	21.0	37.0	21.0	28.0	14.0	30.0
	24.0	59.0	8.0	24.0	15.0	17.0	17.0	25.0	9.0	8.0	20.0	41.0	20.0	31.0	19.0	33.0
4	31.0	60.0	24.0	29.0	15.0	24.0	37.0	37.0	27.0	24.0	40.0	65.0	12.0	16.0	26.0	26.0
	35.0	55.0	26.0	32.0	17.0	19.0	28.0	39.0	26.0	31.0	41.0	73.0	11.0	16.0	24.0	23.0
	32.0	63.0	25.0	26.0	21.0	21.0	28.0	39.0	23.0	27.0	37.0	75.0	11.0	24.0	26.0	22.0
	32.0	68.0	22.0	29.0	20.0	21.0	29.0	40.0	29.0	33.0	35.0	71.0	11.0	17.0	21.0	22.0
5	39.0	61.0	3.0	8.0	14.0	15.0	25.0	28.0	14.0	17.0	30.0	37.0	15.0	20.0	18.0	22.0
	42.0	66.0	2.0	8.0	11.0	19.0	24.0	26.0	13.0	19.0	33.0	42.0	14.0	17.0	18.0	22.0
	46.0	63.0	2.0	7.0	10.0	15.0	22.0	28.0	14.0	21.0	22.0	36.0	12.0	16.0	14.0	22.0
	49.0	66.0	2.0	6.0	12.0	15.0	21.0	28.0	12.0	18.0	27.0	39.0	12.0	16.0	13.0	22.0
6	65.0	80.0	15.0	32.0	19.0	24.0	29.0	44.0	17.0	29.0	29.0	72.0	5.0	5.0	17.0	27.0
	50.0	103.0	20.0	38.0	24.0	23.0	35.0	40.0	21.0	26.0	28.0	77.0	8.0	17.0	24.0	28.0
	53.0	84.0	26.0	25.0	17.0	22.0	30.0	35.0	21.0	24.0	28.0	76.0	8.0	18.0	25.0	29.0
	57.0	97.0	27.0	26.0	17.0	19.0	29.0	34.0	16.0	23.0	24.0	74.0	11.0	17.0	24.0	26.0

A: Axial
M: Marginal

TABLE III

Gap Measurements
Group III: Infrared Soldering (Experimental)
(μm)

	#9								#11							
	Mesial		Distal		Labial		Lingual		Mesial		Distal		Labial		Lingual	
Sample	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
7	14.0	13.0	23.0	28.0	18.0	17.0	18.0	22.0	14.0	13.0	18.0	22.0	16.0	16.0	22.0	24.0
	7.0	9.0	25.0	25.0	18.0	23.0	25.0	26.0	9.0	9.0	17.0	23.0	16.0	23.0	21.0	19.0
	7.0	11.0	23.0	27.0	14.0	20.0	27.0	25.0	10.0	12.0	17.0	19.0	17.0	25.0	20.0	23.0
	11.0	7.0	21.0	26.0	15.0	22.0	22.0	23.0	8.0	10.0	14.0	17.0	21.0	25.0	13.0	20.0
8	17.0	22.0	16.0	20.0	12.0	16.0	16.0	28.0	8.0	25.0	14.0	18.0	13.0	12.0	13.0	12.0
	14.0	22.0	20.0	14.0	11.0	12.0	17.0	26.0	11.0	15.0	10.0	18.0	10.0	19.0	10.0	12.0
	14.0	19.0	17.0	16.0	11.0	14.0	19.0	23.0	17.0	18.0	10.0	11.0	12.0	23.0	9.0	8.0
	13.0	18.0	16.0	15.0	11.0	15.0	17.0	25.0	8.0	11.0	8.0	10.0	8.0	20.0	13.0	12.0
9	9.0	23.0	15.0	16.0	16.0	19.0	19.0	30.0	21.0	21.0	21.0	25.0	14.0	14.0	19.0	30.0
	17.0	21.0	7.0	12.0	15.0	23.0	19.0	23.0	19.0	19.0	25.0	24.0	11.0	12.0	24.0	23.0
	14.0	22.0	7.0	9.0	15.0	17.0	19.0	23.0	15.0	19.0	20.0	24.0	11.0	13.0	25.0	25.0
	15.0	16.0	8.0	11.0	16.0	16.0	19.0	21.0	14.0	17.0	19.0	24.0	12.0	11.0	20.0	23.0
10	22.0	23.0	28.0	32.0	15.0	18.0	40.0	43.0	19.0	23.0	20.0	25.0	14.0	20.0	9.0	15.0
	20.0	22.0	22.0	31.0	13.0	14.0	32.0	40.0	17.0	16.0	17.0	24.0	13.0	18.0	9.0	14.0
	18.0	22.0	22.0	30.0	13.0	16.0	34.0	37.0	20.0	19.0	19.0	21.0	15.0	17.0	7.0	14.0
	22.0	21.0	23.0	30.0	12.0	15.0	32.0	39.0	18.0	18.0	16.0	22.0	15.0	18.0	11.0	12.0
11	17.0	16.0	16.0	23.0	9.0	10.0	22.0	20.0	17.0	15.0	17.0	26.0	8.0	8.0	24.0	29.0
	15.0	13.0	22.0	18.0	9.0	9.0	20.0	24.0	13.0	16.0	20.0	21.0	7.0	4.0	27.0	25.0
	8.0	10.0	13.0	23.0	5.0	14.0	21.0	21.0	16.0	15.0	19.0	17.0	7.0	2.0	23.0	17.0
	12.0	14.0	15.0	21.0	6.0	9.0	23.0	23.0	15.0	15.0	23.0	20.0	12.0	7.0	23.0	22.0

A: Axial
M: Marginal

TABLE IV

Mean and Standard Deviation for Each Site for Each Study Group (μm)

Group	N*		Mesial A	Mesial M	Distal A	Distal M	Labial A	Labial M	Lingual A	Lingual M
I: Individual Castings (Reference)										
#9	4	Mean	11.5	13.5	14.0	14.5	7.8	10.5	13.8	15.5
		S.D.	3.1	1.3	2.7	1.7	1.5	1.7	2.2	2.6
#11	4	Mean	12.0	13.5	12.3	16.0	4.3	6.5	16.3	17.3
		S.D.	3.5	2.6	2.6	1.4	0.5	1.3	2.5	2.2
#9 +	8	Mean	11.8	13.5	13.1	15.3	6.0	8.5	15.0	16.4
#11		S.D.	3.1	1.9	2.6	1.7	2.1	2.6	2.6	2.4
II: One-Piece Castings (Control)										
#9	20	Mean	35.3	70.1	17.3	20.3	15.6	19.2	21.8	29.8
		S.D.	14.4	13.4	10.5	10.0	3.5	3.0	9.4	8.1
#11	20	Mean	21.0	27.8	29.4	60.2	13.8	22.0	16.4	23.1
		S.D.	11.7	16.0	6.0	19.3	4.5	9.9	7.8	7.2
#9 +	40	Mean	28.2	49.0	23.4	40.3	14.7	20.6	19.1	26.4
#11		S.D.	14.8	25.9	10.4	25.3	4.0	7.4	9.0	8.3
III: Infrared Solderings (Experimental)										
#9	20	Mean	14.3	17.2	18.0	21.4	12.7	16.0	23.0	27.1
		S.D.	4.5	5.3	6.0	7.2	3.6	4.2	6.6	7.0
#11	20	Mean	14.5	16.3	17.2	20.6	12.6	15.4	17.1	19.0
		S.D.	4.2	4.2	4.3	4.4	3.6	6.7	6.6	6.3
#9 +	40	Mean	14.4	16.8	17.6	21.0	12.7	15.7	20.0	23.0
#11		S.D.	4.3	4.7	5.2	5.9	3.5	5.5	7.2	7.8

"*" indicates the number of measurements.

TABLE V

Mean and Standard Deviation for Combined Marginal Sites for Each Group

(μm)

Group	N*	Mean	S.D.
I: Individual Castings (Reference)			
#9	16	13.5	2.6
#11	16	13.3	4.6
#9 + #11	32	13.4	3.7
II: One-Piece Castings (Control)			
#9	80	34.8	22.9
#11	80	33.3	20.9
#9 + #11	160	34.0	21.9
III: Infrared Solderings (Experimental)			
#9	80	20.4	7.4
#11	80	17.8	5.8
#9 + #11	160	19.1	6.7

"*" indicates the number of measurements.

TABLE VI

Statistical Analysis of the Control vs. Experimental Groups

Location	Tooth	Mean† (μm) Control	Experim	t Value	Prob>|t|
Mesio-axial	9	35.3	14.3	6.23	0.000*
	11	21.0	14.5	2.35	0.024*
Mesio-marginal	9	70.1	17.2	16.42	0.000*
	11	27.8	16.3	3.10	0.004*
Disto-axial	9	17.3	18.0	-0.24	0.811
	11	29.4	17.2	7.40	0.000*
Disto-marginal	9	20.3	21.4	-0.38	0.705
	11	60.2	20.6	8.95	0.000*
Labio-axial	9	15.6	12.7	2.61	0.013*
	11	13.8	12.6	0.90	0.375
Labio-marginal	9	19.2	16.0	2.80	0.008*
	11	22.0	15.4	2.47	0.018*
Linguo-axial	9	21.8	23.0	-0.45	0.658
	11	16.4	17.1	-0.31	0.761
Linguo-marginal	9	29.8	27.1	1.11	0.275
	11	23.1	19.0	1.91	0.064

"*" indicates significant difference at the p=0.05 level.

"†" Each value is the mean of 20 measurements.

TABLE VII

Statistical Analysis of Teeth #9 vs. #11 for the Control and Experimental Groups

Location	Group	Mean† (μm) # 9	#11	t Value	Prob>|t|
Mesio-axial	Ctrl	35.3	21.0	3.45	0.001*
	Expt	14.3	14.5	-0.11	0.914
Mesio-marginal	Ctrl	70.1	27.8	9.05	0.000*
	Expt	17.2	16.3	0.60	0.552
Disto-axial	Ctrl	17.3	29.4	-4.49	0.000*
	Expt	18.0	17.2	0.45	0.652
Disto-marginal	Ctrl	20.3	60.2	-8.21	0.000*
	Expt	21.4	20.6	0.42	0.674
Labio-axial	Ctrl	15.6	13.8	1.47	0.151
	Expt	12.7	12.6	0.09	0.930
Labio-marginal	Ctrl	19.2	22.0	-1.21	0.233
	Expt	16.0	15.4	0.34	0.736
Linguo-axial	Ctrl	21.8	16.4	1.97	0.056
	Expt	23.0	17.1	2.80	0.008*
Linguo-marginal	Ctrl	29.8	23.1	2.76	0.009*
	Expt	27.1	19.0	3.87	0.000*

"*" indicates significant difference at the p=0.05 level.

"†" Each value is the mean of 20 measurements.

TABLE VIII

Statistical Analysis of the Marginal Values Among Three Groups

One way analysis of variance:

F value = 47.81

Critical F value at 5% = 3.329 (2,349)

Therefore, significant difference at 0.05 Level.

Tukey's Studentized Range (HSD) Test for variable:

Group Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
Ref - Ctr	-27.685	-20.631	-13.577***
Ref - Exp	-12.742	-5.687	1.367
Ctr - Exp	10.871	14.944	19.016***

Comparisons significant at 0.05 level are indicated by "***".

TABLE IX

Mean and Standard Deviation for the External* and Internal† Sites for Each of the Three Groups

Group	Location		N§	Mean	S.D.
I: Individual Castings (Reference)					
	External	Axial	8	11.9	2.7
	External	Marginal	8	14.8	1.8
	Internal	Axial	8	13.0	3.1
	Internal	Marginal	8	14.0	2.1
II: One-Piece Castings (Control)					
	External	Axial	40	32.4	11.3
	External	Marginal	40	65.2	17.2
	Internal	Axial	40	19.2	11.1
	Internal	Marginal	40	24.1	13.7
III: Infrared Solderings (Experimental)					
	External	Axial	40	15.8	4.6
	External	Marginal	40	18.9	5.1
	Internal	Axial	40	16.2	5.4
	Internal	marginal	40	18.8	6.3

* Mesial of #9 + distal of #11.

† Distal of #9 + mesial of #11.

§ Number of measurements.

TABLE X

Statistical Analysis of the Axial Values of the External* and Internal† Sites Among Three Groups

One way analysis of variance:

F value of the external site= 48.04

F value of the internal site= 2.34

Critical F value at 5% = 3.374 (2,85)

Therefore, significant difference at 0.05 level for the external site.

Tukey's Studentized Range (HSD) Test for variable:

Group Comparison			Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
External					
Ref	-	Ctr	-28.126	-20.475	-12.824***
Ref	-	Exp	-11.526	-3.875	3.776
Ctr	-	Exp	12.183	16.600	21.017***
Internal					
Ref	-	Ctr	-13.939	-6.150	1.639
Ref	-	Exp	-10.989	-3.200	4.589
Ctr	-	Exp	-1.547	2.950	7.447

Comparisons significant at 0.05 level are indicated by "***".

* Mesial of #9 + distal of #11.

† Distal of #9 + mesial of #11.

TABLE XI

Statistical Analysis of the Marginal Values of the External* and Internal† Sites Among Three Groups

One way analysis of variance:

F value of the external site= 163.69

F value of the internal site= 4.51

Critical F value at 5% = 3.37 (2,85)

Therefore, significant difference at 0.05 level for both sites.

Tukey's Studentized Range (HSD) Test for variable:

Group Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
External			
Ref - Ctr	-61.614	-50.400	-39.186***
Ref - Exp	-15.339	-4.125	7.089
Ctr - Exp	39.801	46.275	52.749***
Internal			
Ref - Ctr	-19.525	-10.050	-0.575***
Ref - Exp	-14.300	-4.825	4.650
Ctr - Exp	-0.245	5.225	10.695

Comparisons significant at 0.05 level are indicated by "***".

* Mesial of #9 + distal of #11.

† Distal of #9 + mesial of #11.

TABLE XII

Statistical Analysis of the External* vs. Internal† Sites within Each of the Three Groups

Group	External Mean§ (μm)	Internal Mean§ (μm)	t Value	Prob>|t|
I: Individual Castings (Reference)				
Axial	11.9	13.0	-0.78	0.449
Marginal	14.8	14.0	0.75	0.464
II: One-Piece Castings (Control)				
Axial	32.4	19.2	5.27	0.000***
Marginal	65.2	24.1	11.83	0.000***
III: Infrared Solderings (Experimental)				
Axial	15.8	16.2	-0.40	0.689
Marginal	18.9	18.8	0.04	0.969

"***" indicates significant difference at the p= 0.05 level.

* Mesial of #9 + distal of #11.

† Distal of #9 + mesial of #11.

§ Each value is the mean of 8 measurements for the reference group and 40 measurements for the control and experimental groups.

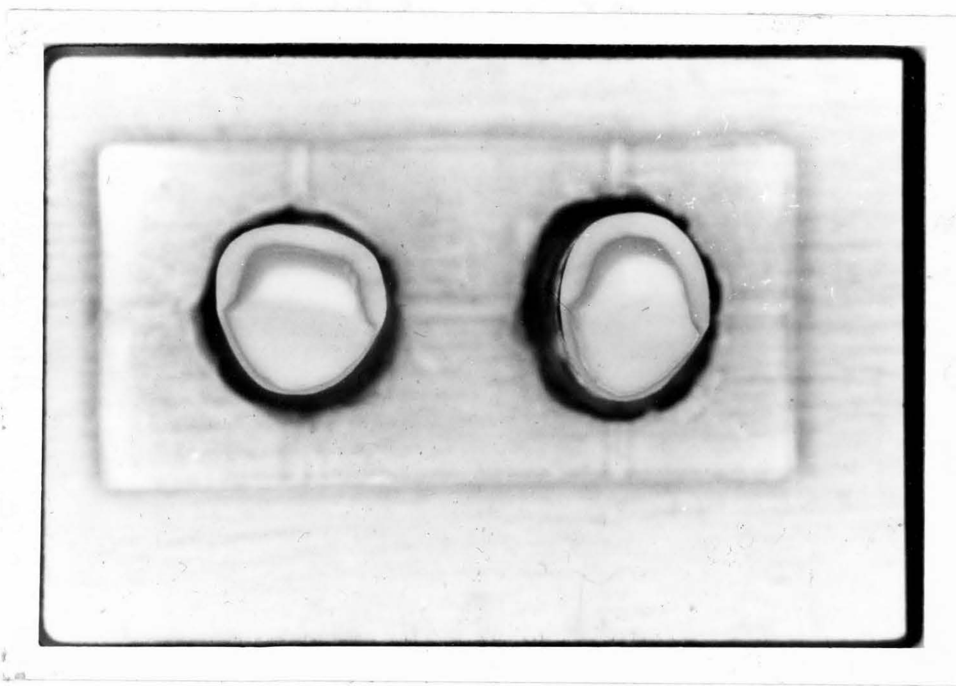

Figure 1. Sample preparation, occlusal view.

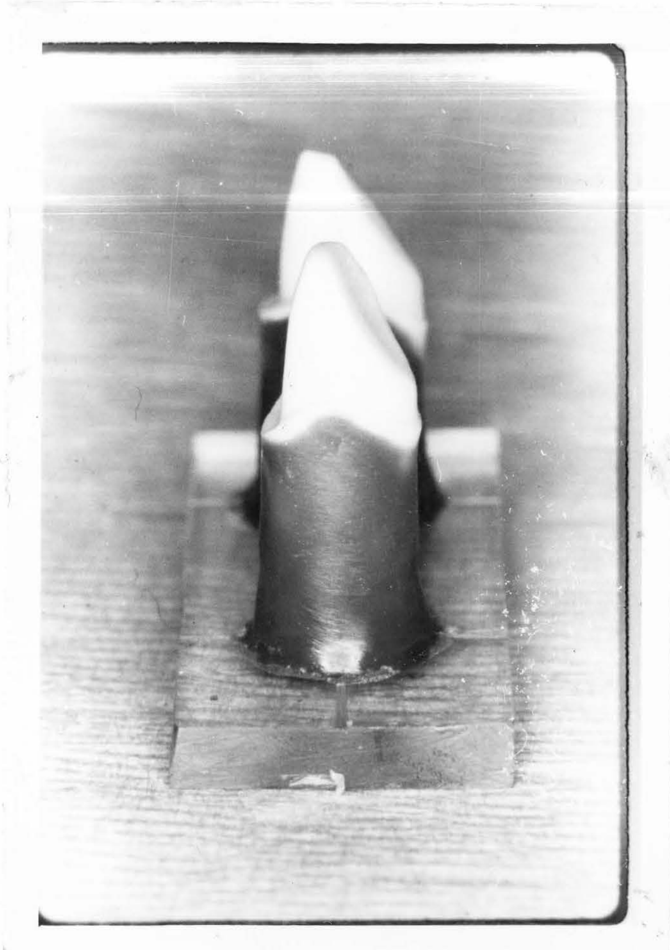

Figure 2. Sample preparation, mesial view.

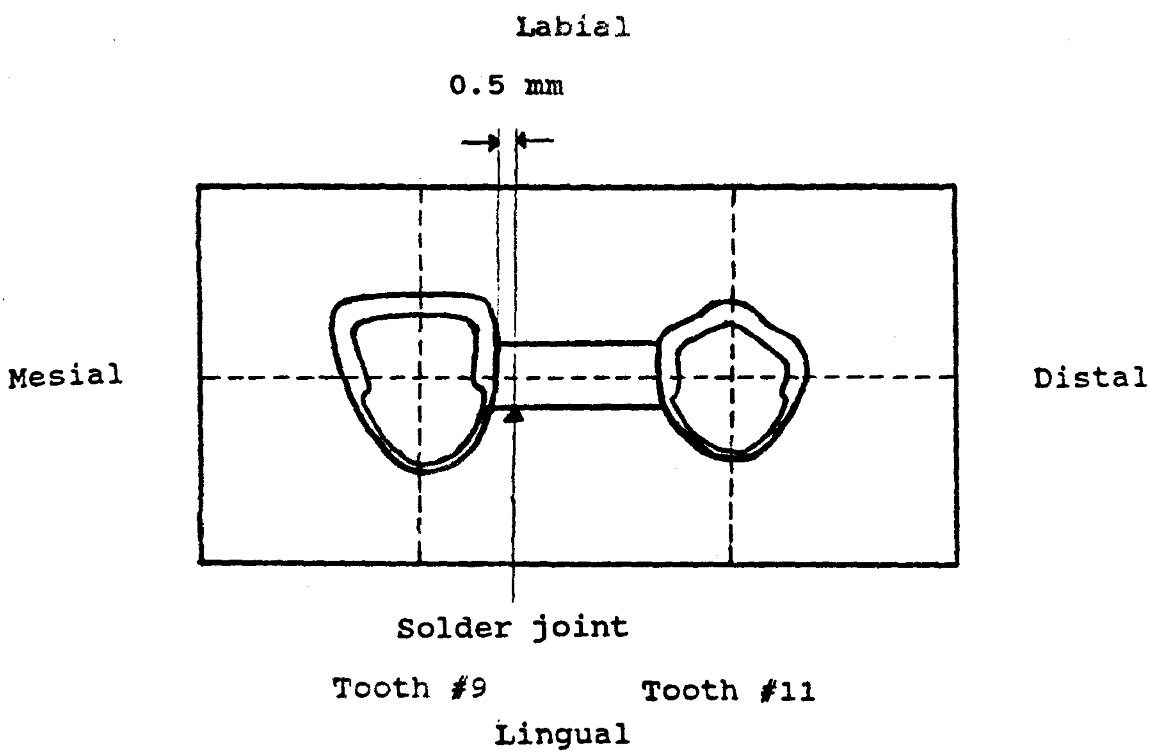

Figure 3. Three lines inscribed on the acrylic base and the joint area to be cut 0.5 mm distal to tooth #9 are shown.

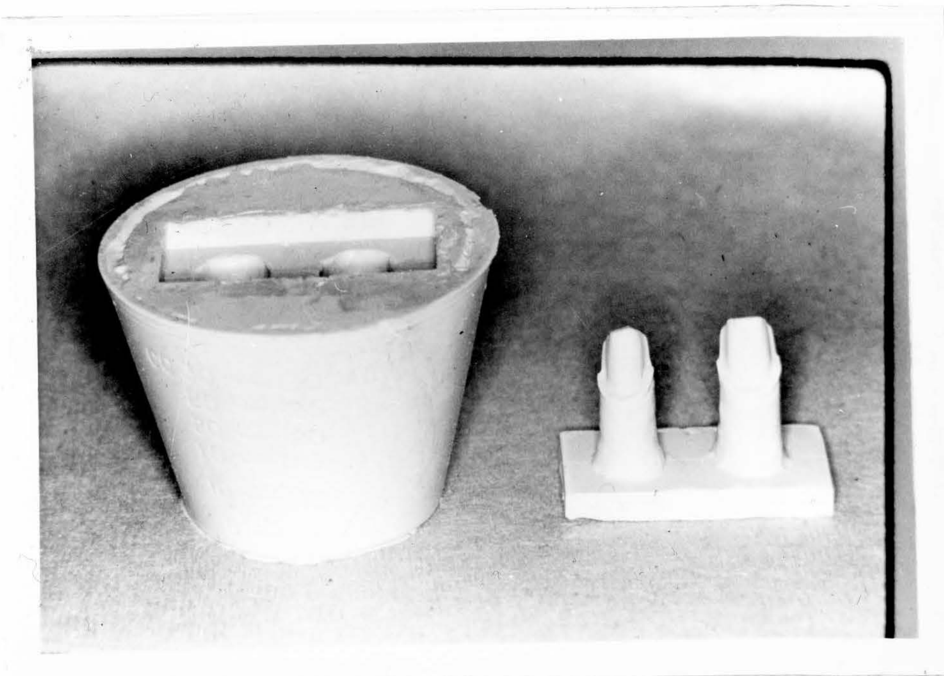

Figure 4. Silicone mold and poured stone die.

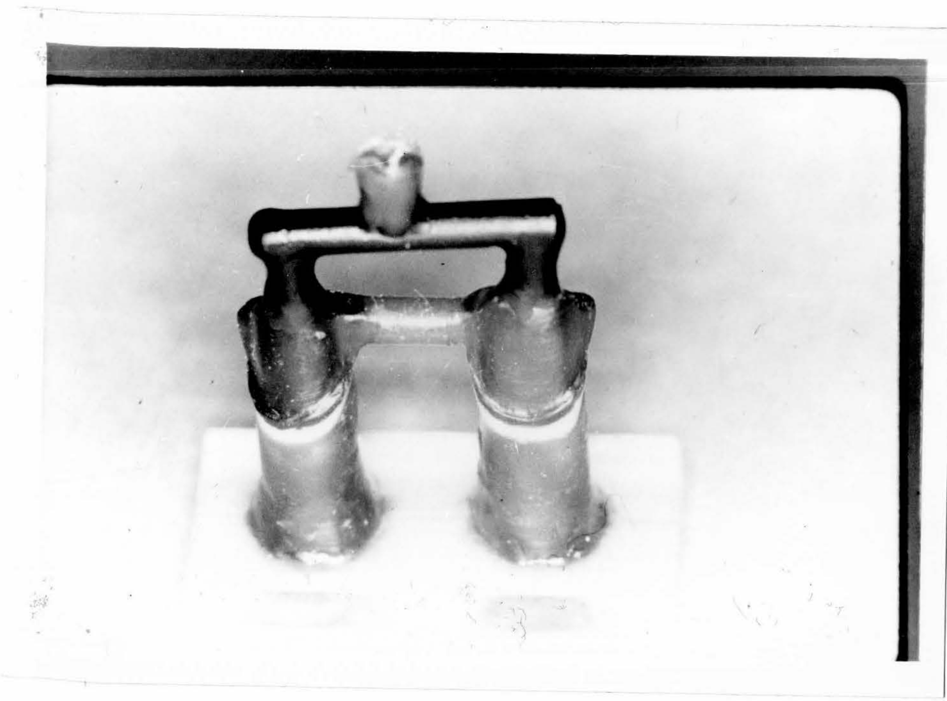

Figure 5. Wax pattern on the master die.

Figure 6. Fabrication of silicone mold for duplicating wax patterns.

Figure 7. Wax pattern in its mold.

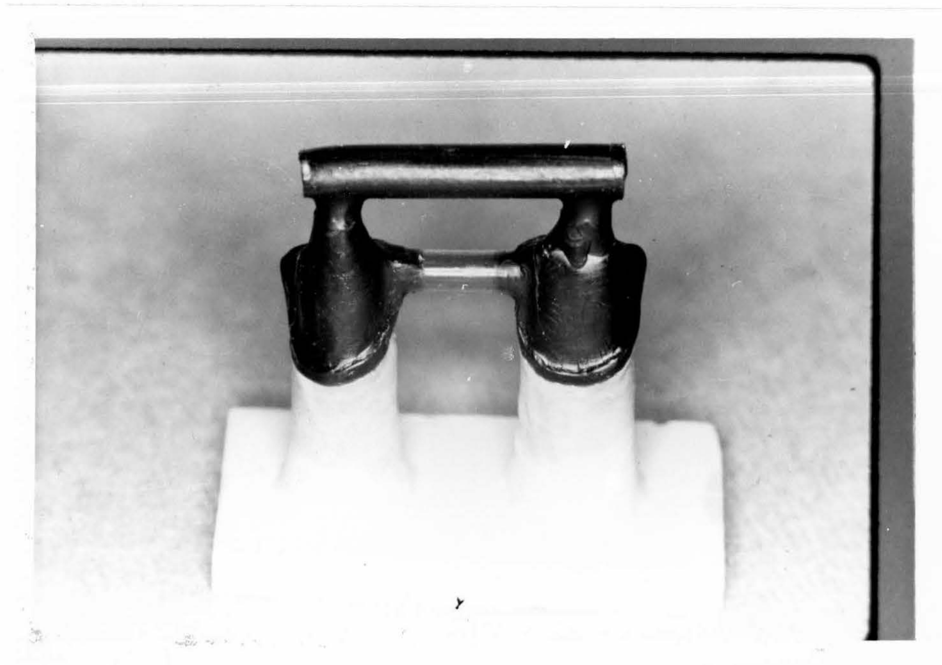

Figure 8. Wax pontic replaced with plastic bar.

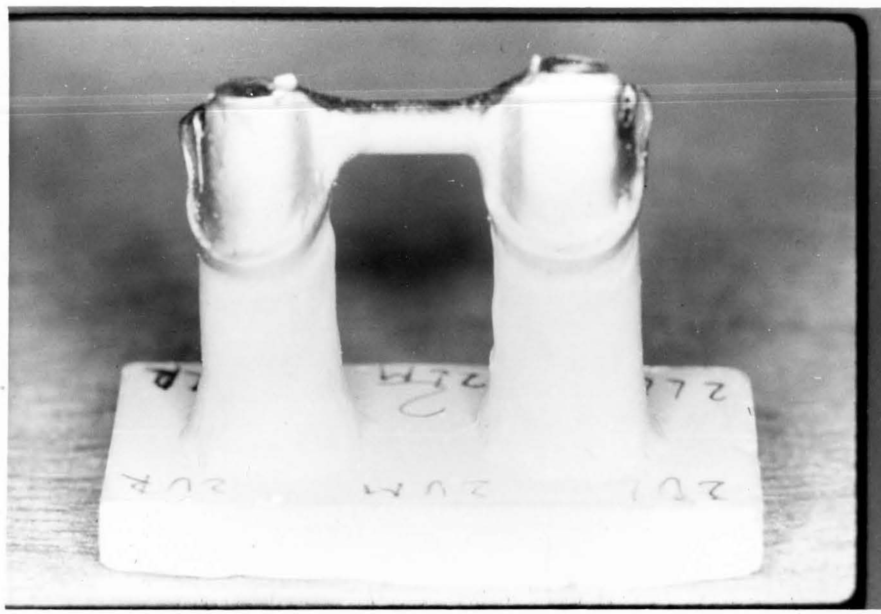

Figure 9. One-piece casting seated on its die.

'igure 10. Castings in the soldering group seated on its die.

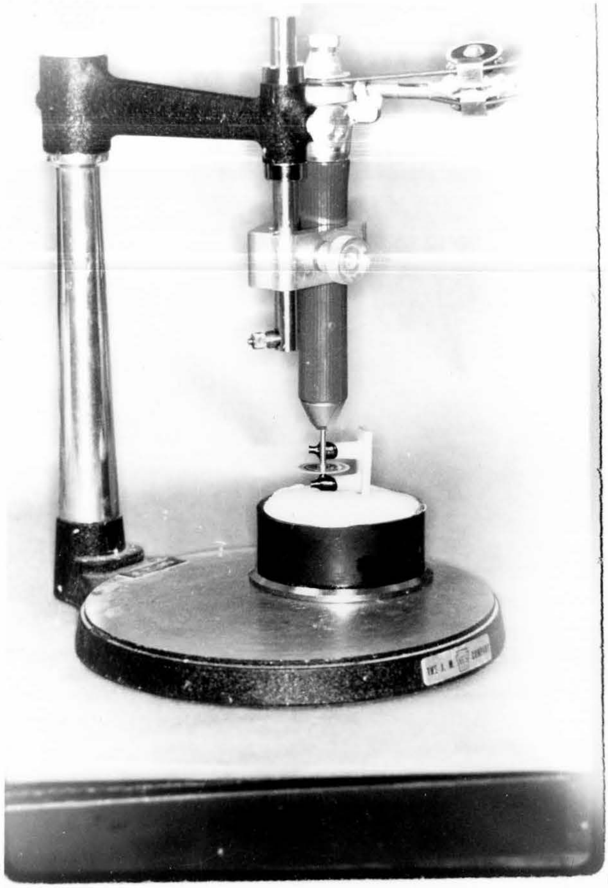

Figure 11. The experimental group specimen placed on the jig for slicing through the joint area.

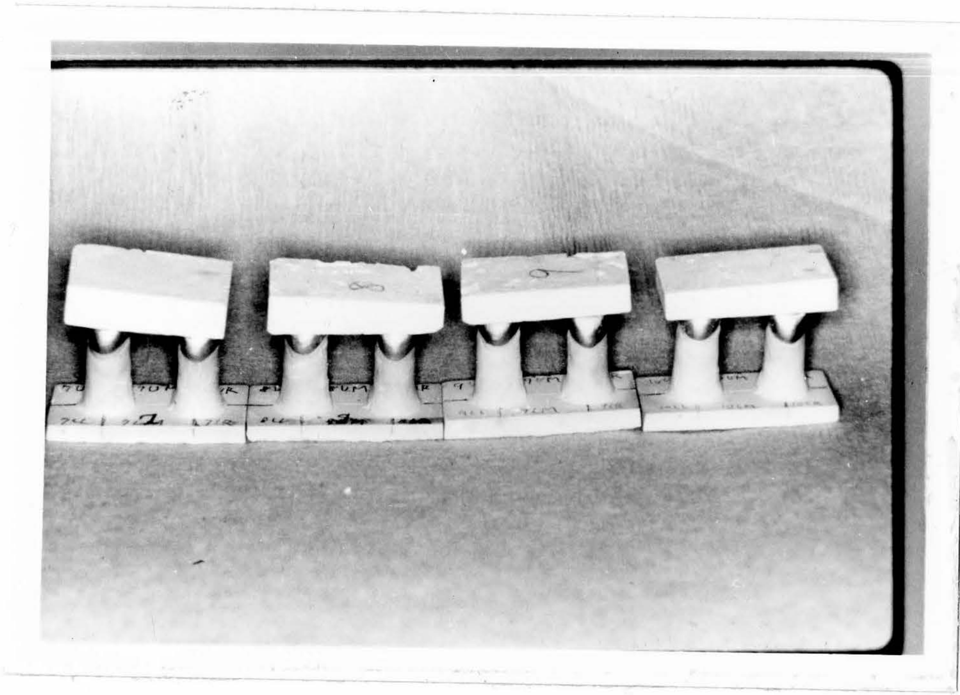

Figure 12. Occlusal indices.

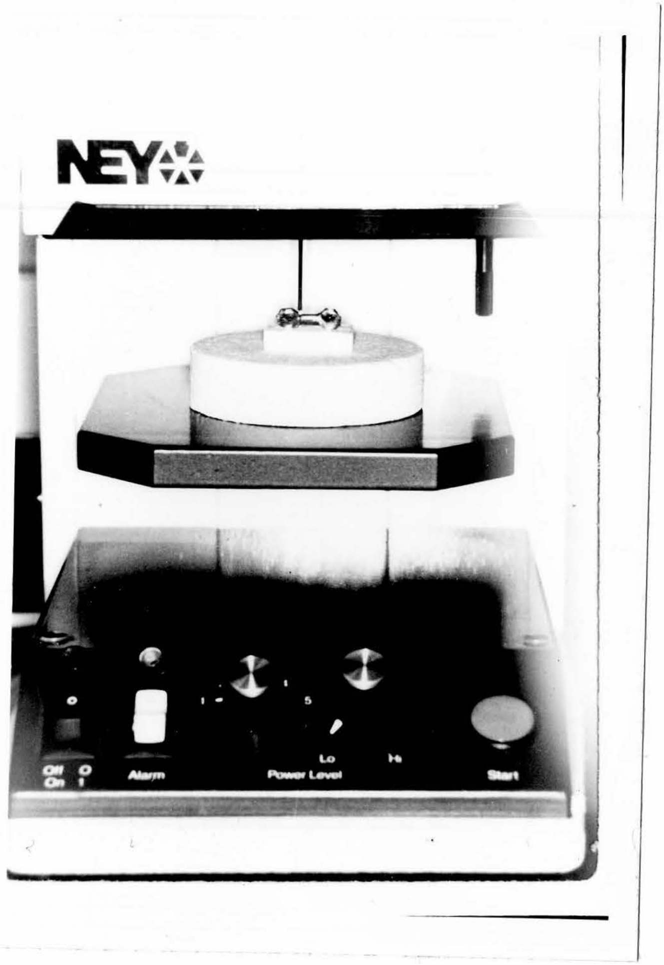

Figure 13. Infrared soldering machine.

Figure 14. Specimen embedded in clear epoxy resin.

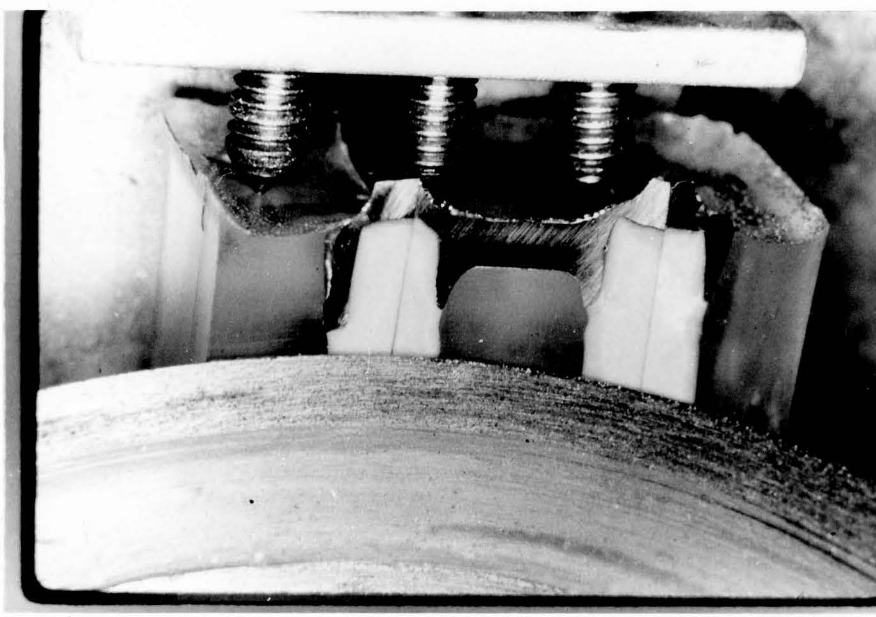

Figure 15. Sample block mounted on sectioning machine.

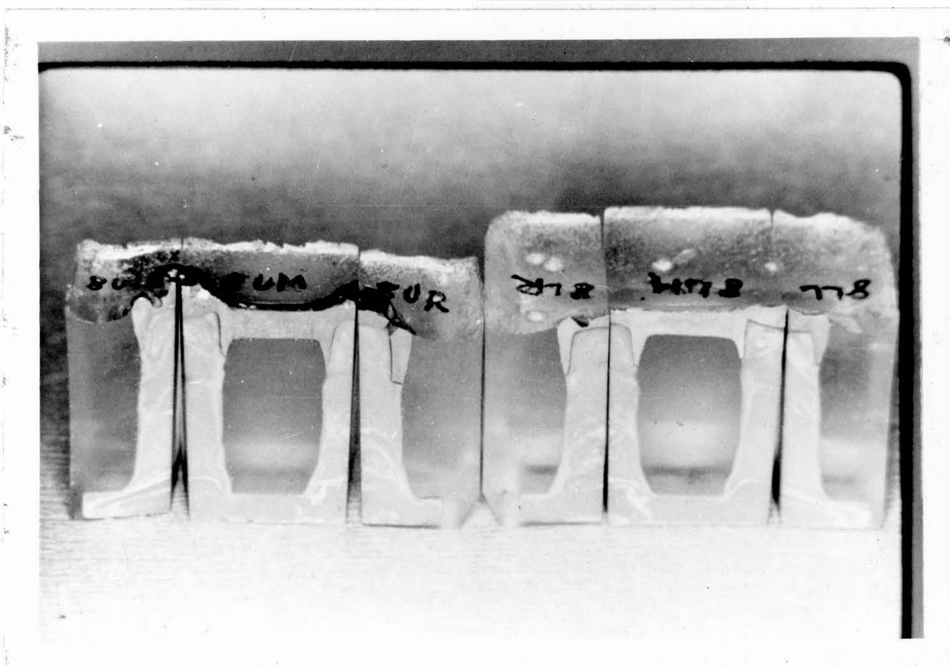

Figure 16. Cut sections of the sample.

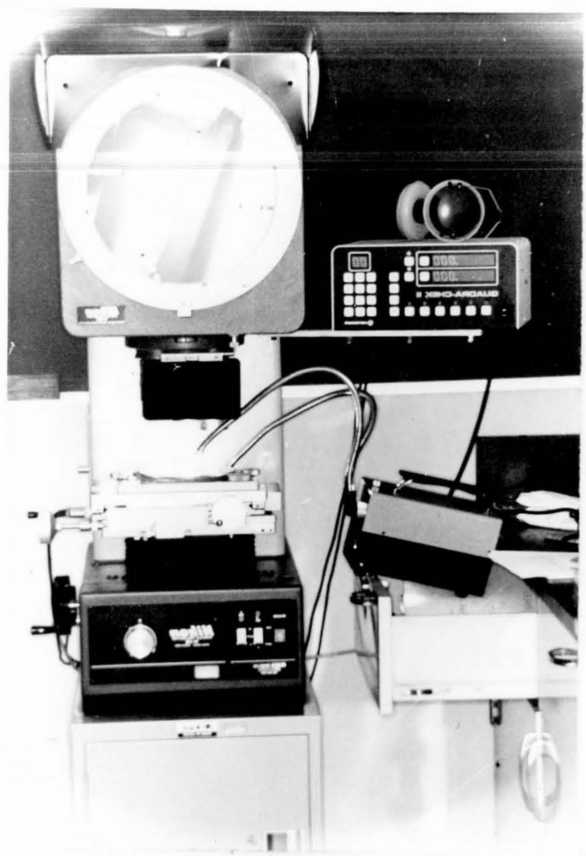

Figure 17. Profile projector used to measured the gap distance.

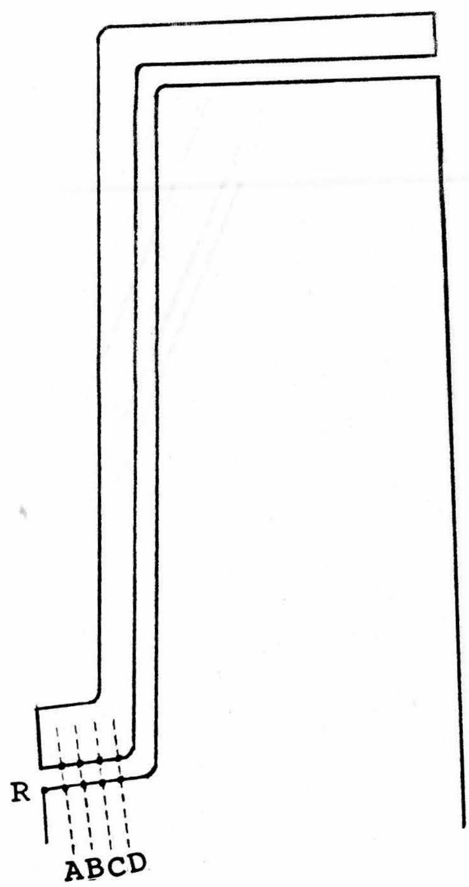

Figure 18. Measurement sites of the shoulder margin at 150 (A), 300 (B), 450 (C), and 600 (D) microns, respectively, from the preparation margin (R).

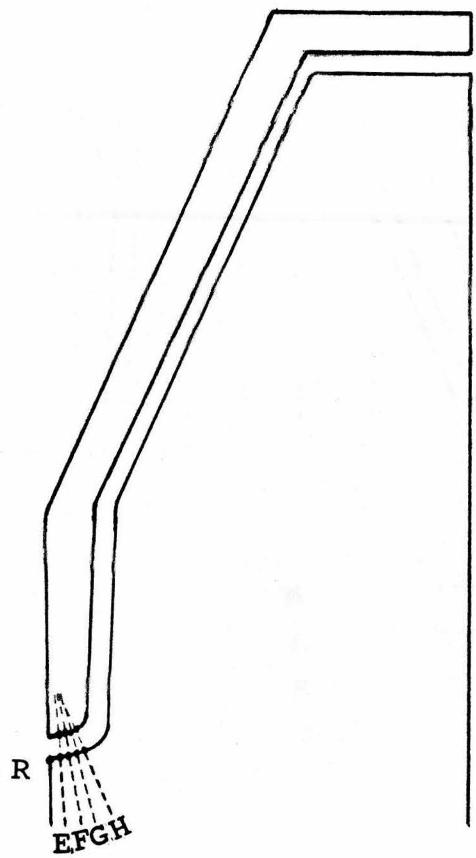

Figure 19. Measurement sites of the chamfer margin at 50 (E), 100 (F), 150 (G), and 200 (H) microns, respectively, from the preparation margin (R).

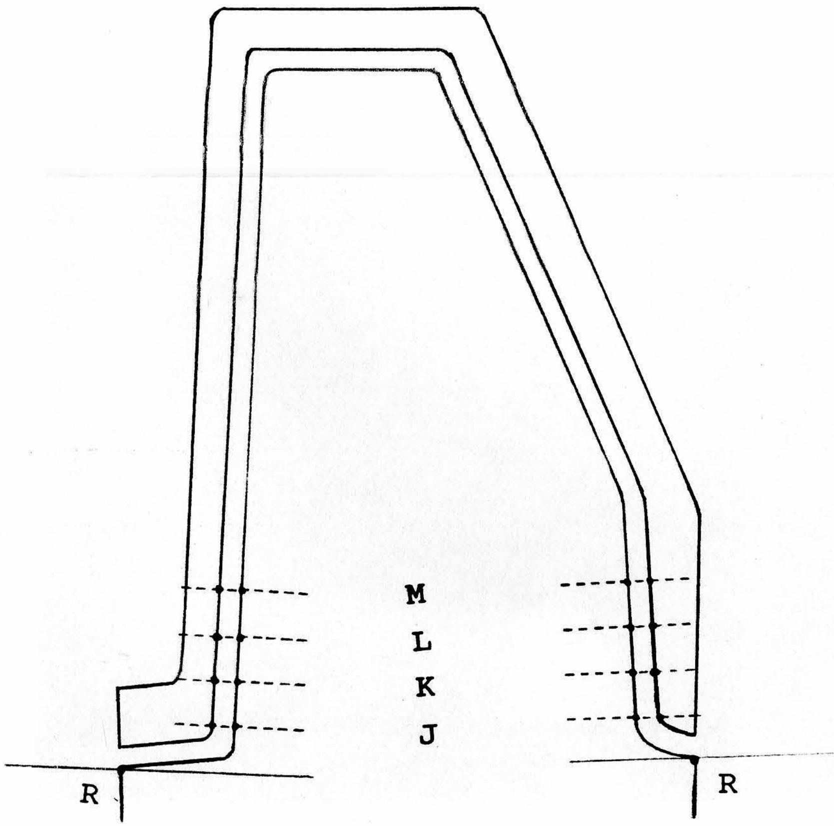

Figure 20. Measurement sites of the axial opening at 500 (J), 1000 (K), 1500 (L), and 2000 (M) microns, respectively, from the preparation margin (R).

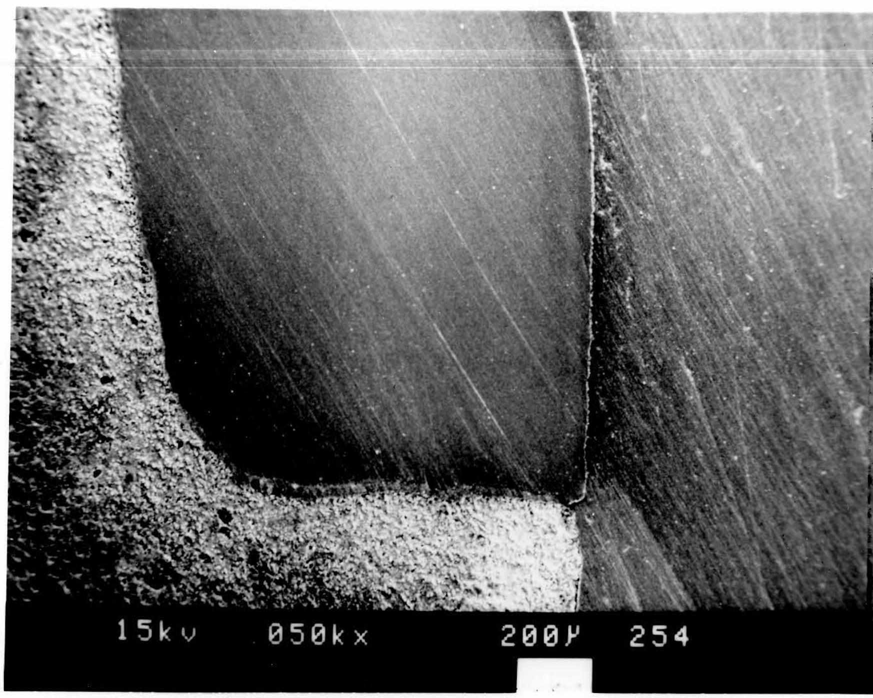

Figure 21. Photomicrograph of the shoulder area at 50x.

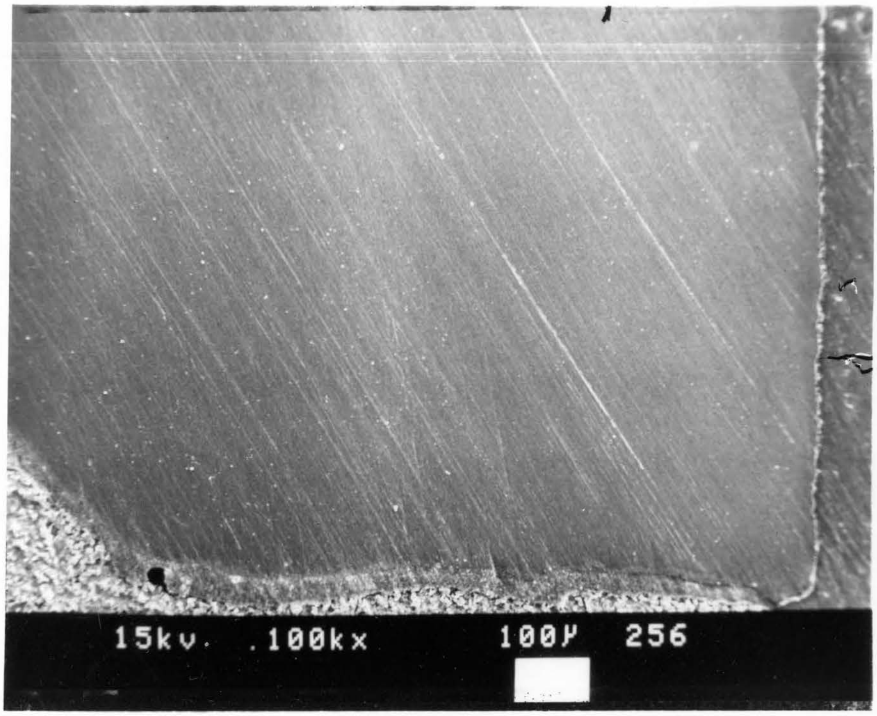

Figure 22. Photomicrograph of the shoulder area at 100x.

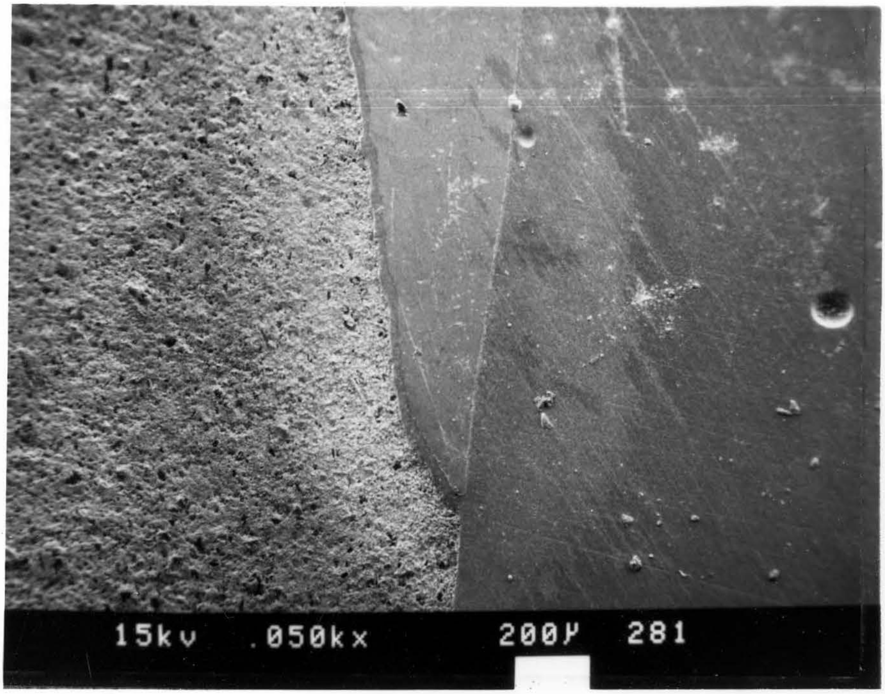

Figure 23. Photomicrograph of the chamfer area at 50x.

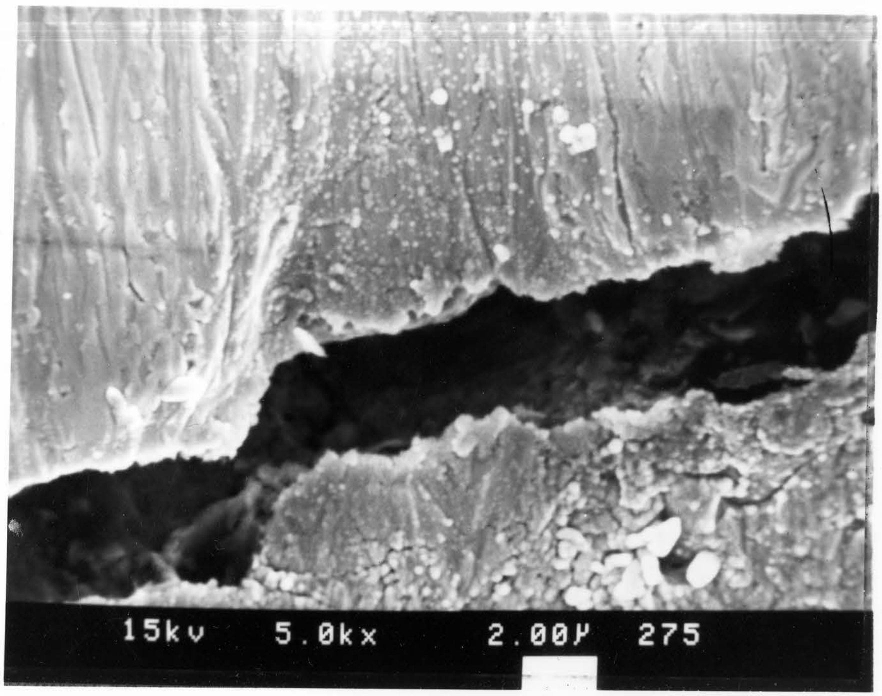

Figure 24. Photomicrograph of the soldered joint area at 5000x.

CHAPTER V

DISCUSSION

This study investigated the comparative accuracy of fit of 3-unit FPDs made by the one-piece casting technique and the infrared soldering technique. Individual abutment crowns were utilized for reference measurements.

Because of the inherent properties of stone, stone dies may occasionally have been abraded during seating of the crowns and reflowing of the margins. This may have resulted in some measurement errors. By comparison, use of a stainless steel die (3,4,6-8,24,27,28) may prevent such abrasion thus influencing the resulting data. Because of the impracticality of sectioning steel dies, one can only measure distances between superficial reference points. Since specimens were to be sectioned and axial and marginal gap widths measured, a system of stone dies was considered more practical.

Under microscopic examination, a slight rounding of the margins of the crowns could be observed. It is uncertain whether this was due to the investing or casting technique. Theoretically, such a rounding could affect the results of this investigation because it could result in higher gap widths for the measurement sites nearest to the preparation margin.

A pontic bar and flat connector surfaces were used instead of a conventional pontic with convex connector surfaces. A pontic bar of a chosen diameter was used to standardize the size of the connector area. If a more realistic pontic size and convex connector surface had been used, it would have been difficult to standardize the size of the joint and hence the flow of the solder or the adjacent surface.

In the literature, a wide range exists of reported recommended joint gap width. This ranges from tight contact to 0.5 mm (6,40,42,44,45,47,48,51,57,58,61). Because of this disparity, a joint gap width of 0.15 mm was selected arbitrarily, based on the thickness of a diamond sectioning disc required to create a joint space.

The wax pontic bar was replaced by a plastic one prior to investing in order to a) standardize pontic size and thence joint configuration and b) avoid distortion during handling one-piece waxings. As reported by Hinman et al. (28), a plastic bar is stiffer than a wax one and has a higher transition temperature which may distort the invested wax pattern during the setting expansion phase of the investment. This interabutment distortion might induce greater marginal opening in the one-piece cast group at the "external" margins than in the infrared soldered group. This should theoretically produce overhanging "external" margins which would be visible in SEM photographs.

The study by Sass and Eames (25) found that the shape of the casting rings did not affect the seating of the FPDs (one-piece castings). They suggested the use of large round rings that could produce FPDs with more complete seating than those produced in small round rings. However, in our pilot study, a large round ring produced undersized castings that did not seat on stone dies when an optimal investing water/powder ratio used by Byrne et al (12) was adopted. Therefore, standard rings which routinely produced castings with clinically acceptable adaptation were used.

Mounting stone was used as a soldering index instead of the commonly used Duralay resin because of its ease of manupulation, reported accuracy (plaster non-removal technique) (58), and the lack of necessity for investing immediately following indexing.

Various forces were used in previous studies (7,11,14,21,24,28) to seat crowns. A precise value for the optimal force is not known. Since no luting agent was used in this study, light finger pressure was used to seat the crowns on the dies. It is possible, however, for slight tipping to occur during seating either in a labio-lingual direction or a mesio-distal direction. Such a problem should be detectable at the appropriate measurement location.

The key to successful use of the infrared soldering machine is to position the pointer tip to the center of the solder joint occluso-gingivally and labio-lingually. The infrared energy is focused on the entire FPD and not just the joint area itself. When the FPD reaches the fusing temperature of the solder, the solder will flow to the hottest area by capillary action. During the infrared soldering procedure, the power level used to achieve soldering was always around the 5th setting of the power level control and the minimal setting of the fine tuning control. The soldering procedure was accomplished by almost constant power level. A small temperature differential may occur due to slight variations in soldering block size. It is not possible to control the soldering temperature exactly.

Gap measurements made under the profile projector, although magnified to 100x, are not necessarily precise because of difficulty in aligning the measuring lines. In addition, if one looks at the measuring lines from even a slightly different angle, the resulting reading will be different. However, it is convenient to operate and is superior to other available options. The scanning electron microscope gives more absolute evidence of casting fit. It could be used for measurement if cost and time permitted, although inaccuracies may result if specimen orientation is not carefully standardized.

Under the scanning electron microscope, the infrared soldered joint area showed no demarcation between solder and parent alloy (Figure 24). Etching the alloy may be needed to discern demarcation under the SEM. It is also possible that solder and parent alloy may have completely fused together because the high fusing temperature of the presolder may have caused grain growth which rendered the boundary indistinguishable.

None of the SEM examination (Figures 21-23) exhibited overhanging margins. Possibly, this can be explained by the shrinkage of the alloy when solidifing to room temperature.

Marginal and axial gap openings were smallest in the reference group (single crowns), with the soldered group next. The one-piece casting group had the largest values. Single-unit castings had the best fit; and 3-unit FPDs, whether one-piece cast or infrared soldered, exhibited larger gap widths. For any casting, marginal gaps at the labial side were consistently the smallest. Gap width at the labial side was also smaller than that at the lingual side. This may be due to slight facial tipping during seating. It would seem that there is a greater component of seating force directed toward the labial side because of the tooth shape and preparation geometry.

The values of standard deviation for the control group (cast FPDs) were relatively higher than for the other groups. Compared to the other techniques, results of the one-piece casting technique were inconsistent. This may be explained by the difficulty of handling the one-piece wax patterns or relatively parallel preparations.

When the overall marginal values are considered, they are smallest (13.4 μm) in the reference group and largest (34.0 μm) in the one-piece casting group. The one-piece casting technique produces the largest marginal gap width.

Comparison of the same sites between the control (one-piece castings) and experimental groups (infrared solderings) indicates that significant differences exist at the mesio-axial, and mesio-marginal sites of tooth #9, and at the disto-axial and disto-marginal sites of tooth #11 (i.e; external locations). This may result from a distortion phenomenon in the wax patterns during setting expansion of the investment.

Statistical analysis of retainers #9 vs. #11 within the control group reveals significant differences at the mesio-axial, mesio-marginal, disto-axial, and disto-marginal sites. This may indicate that more distortion occurs at the external sites than at the internal sites of cast 3-unit FPDs (6,24). Statistical analysis of retainer #9 and 11 within the experimental group shows significant differences at the linguo-axial and linguo-marginal sites. These are likely due to three dimensional distortion of the joint area produced during infrared soldering.

One way analysis of variance of the overall marginal values among three groups shows a significant difference at the p= 0.05 level. Further analysis using Tukey's Studentized

Range Test reveals significant differences between the control and reference groups and between the control and experimental groups. This again demonstrated that the one-piece casting technique resulted in larger marginal gap width than did the infrared soldering technique. No significant difference was demonstrated between the infrared soldered and the individual casting groups.

When means and standard deviations for the external and internal values are calculated, means and standard deviations of the external (32.4 μm for the axial, 65.2 μm for the marginal) site of the control group are much higher than the other two groups. One way analysis of variance of the axial values of the external and internal sites among three groups shows a difference among the external sites but not among the internal sites. Tukey's Test shows differences between the control and reference groups and between the control and experimental groups. One way analysis of variance and Tukey's Test of the marginal values have the same result as the axial values, except the former values also show a difference at the internal site between the control and reference groups. This means when a 3-unit FPD is cast in one piece, there is a significant distortion at the external sites. This finding is consistent with previously reported studies (6,24). The internal site may also be distorted by the one-piece casting technique but the distortion would appear to be less than that of the external site.

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A paired t test showed no significant difference between the external and internal sites in the individual casting and infrared soldered groups. Differences in the one-piece casting group revealed that severe interabutment distortion caused a much larger external gap width.

The comparisons described above demonstrate that results obtained with the infrared soldering technique result in superior adaptation than the one-piece casting technique. Axial and marginal fit of the FPDs are significantly worse under these experimental conditions. The distortion of the external site produced by the one-piece casting technique was significant.

Even though the mean marginal measurement at the mesial site of the anterior abutment of the 3-unit one-piece casting is as high as 70.1 μm, an overall mean marginal discrepancy of 34.0 μm is below the value of 49.1 μm reported by Huling et al. (2), the value of 42.0 μm reportrd by Ziebert et al. (6), and the value of 54.0 μm reported by Schiffleger et al. (24). Using these studies as a reference, it is therefore reasonable to state that both techniques used in this study can be considered satisfactory in terms of fit for 3-unit FPDs.

The following additional investigations seem warranted in the light of the present study:

1. Comparison of various soldering techniques.
2. Comparative accuracies for joining longer span

FPDs.

3. The effect of cementation on the adaptation of well fitting FPDs.

4. Study of infrared joint quality and strength.

CHAPTER VI

SUMMARY AND CONCLUSIONS

This project evaluated the fit of infrared soldered 3-unit FPDs. The FPDs were cast in 2 parts and then soldered. Five 3-unit FPDs fabricated as one-piece castings were used as a control. Two single castings were used for reference data.

Teeth #9 and #11 were prepared on crowns for a metal-ceramic FPD in a conventional manner. A silicone mold was made from die for the purpose of producing duplicate stone die. A standard wax pattern was made, an injection mold fabricated, and ten identical wax patterns produced. There were 3 groups in the study, i.e., (1) individual castings, (2) one-piece cast FPDs, and (3) infrared soldered FPDs. Investing, burnout, and casting procedures were standardized between and within each group, in compliance with manufacturer's instructions.

Each casting was examined macroscopically and microscopically (20x) for casting completeness and internal surface defects. Each casting was then seated on its respective stone die without luting agent, embedded in clear epoxy resin, and 3 sections were made labio-lingually and mesio-distally. Four measurements of the axial and marginal openings were taken in microns at each site using a profile projector (100x). The measurements were tabulated and analyzed statistically in terms of the overall marginal fit and axial fit.

Infrared soldering technique produced significantly better fitting FPDs than the one-piece casting technique and the result is comparable to single castings. One-piece castings have a significantly larger marginal opening at the mesial side of the anterior abutment and the distal side of the posterior abutment (the external margin). No significant difference was demonstrated at the internal margin between the experimental and control groups. All castings showed the best marginal fit at the labial side. Axial openings were smaller than the respective marginal openings.

Despite statistically significant differences in fit between and within various groups, all castings produced in the study are within the realm of clinical acceptability.

Conclusions

Based on the results of this investigation, the following conclusions are presented:

1. Infrared soldering was an easy and reliable technique for joining FPD units together. It produced consistently better fitting FPDs than the one-piece casting technique in terms of marginal and axial fits.

2. There was significant distortion at the external locations of the cast FPDs. The largest marginal gaps were found here.

3. The overall fit of soldered FPDs was superior to the cast FPDs both in axial and marginal locations.

4. The fit of the cast FPDs was not consistent. There was more variability in marginal openings among one-piece castings.

5. No significant difference in fit was demonstrated between the soldered FPDs and the single reference crowns.

6. There was no SEM evidence of overhanging at the external margins of the cast FPDs.

7. The marginal fit of all castings in the study was within the realms of clinical acceptability.

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