THE EFFECT OF SELECTED PIN RETENTION MATERIALS ON CERTAIN PROPERTIES OF DENTAL SILVER AMALGAM

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It is fitting that I record here the moral assistance and encouragement afforded to me by my wife Donna, and for the unselfish attitude displayed by her, and my two daughters, Lori Anne and Mona Lee, throughout the duration of this study.

ABSTRACT

The purpose of this study was to examine the effect of stainless steel pins on the compressive and tensile strength of dental amalgam and to determine whether any beneficial effect would result with the use of a pin which fused with the amalgam matrix. A pin, consisting of a core wire of platinum-gold-palladium electroplated with sterling silver, was developed which microscopically appeared to fuse with the amalgam matrix.

The effects of three types of pins on the mechanical properties of amalgam were determined by embedding one or more of each type in amalgam specimens made from three different types of alloy. Pins were positioned to simulate the clinical procedure where they are incorporated in amalgam restorations for retentive purposes. The specimens were prepared in specially designed moulds using a constant pressure condensing apparatus. Six hundred and forty-eight specimens representing all combinations of pins and alloy types were tested for ultimate compressive and ultimate tensile strength at one hour and twenty-four hour intervals after condensation. The results were compared statistically with those of control specimens which did not contain pins.

Three hundred and twenty-four specimens were prepared for tensile testing with pin placement parallel to the tensile force to simulate the effect of pins used as isthmus reinforcing agents in class two amalgam restorations. Tensile tests were performed one hour and twenty-four hours after the completion of condensation. To determine if resistance to withdrawal of pins from amalgam had a relationship to the reinforcing qualities of the pins, withdrawal tests were conducted with each combination of pin and alloy twenty-four hours after the completion of condensation of the specimens.

Residual mercury analysis of five hundred previously tested specimens demonstrated no correlation between strength values and residual mercury content.

In general all types of pins used for retention purposes caused a reduction in the compressive and tensile strength of amalgam when tested, after one hour and at the end of twenty-four hours. Compressive strength tests on specimens containing smooth stainless-steel and electroplated pins yielded similar results. Serrated stainless-steel pins demonstrated a different effect on compressive strength, which was thought to be due to the serrations. It was felt by this investigator that none of the pin materials demonstrated a weakening effect that was clinically significant at the twenty-four hour test time.

The electroplated pins proved to have less of a deleterious effect on the tensile strength of amalgam than did either of the stainless steel pins at both one hour and twenty-four hour test periods, when pins were positioned perpendicular to the tensile force.

When pins were positioned parallel to the direction of the applied tensile load, serrated stainless-steel and electroplated platinum-gold-palladium pins produced a significant increase in tensile strength of amalgam when tested at one hour and twenty-four hour intervals. After one hour, electroplated pins produced the greatest increase in tensile strength, whereas the serrated stainless-steel pins performed best after twenty-four hours.

The results of this study indicate that pins, capable of fusing with the amalgam matrix, improve certain mechanical properties of large amalgam restorations in which they are placed essentially for retentive purposes. It is suggested that further research be conducted to determine whether serrated platinum-gold-palladium pins, electroplated with sterling silver would increase the tensile strength of amalgam to a greater extent than either smooth electroplated or serrated stainless-steel pins.

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INTRODUCTION

Dental practitioners are frequently confronted with the problem of economically restoring teeth which have been severely affected by dental caries or congenital malformation. It is often found that such teeth do not have sufficient remaining supracoronal structure to retain and support a conventionally placed silver amalgam restoration.

Over the years a technique to manage such teeth has become increasingly popular. The procedure consists of drilling small holes into the remaining dentin of the tooth and cementing or otherwise fixing stainless steel wires or pins which project for some distance beyond the level of the dentin. The restoration is completed in the conventional manner by condensing amalgam around the pins. This procedure proved to be very successful for the restoration of many teeth which were previously considered to be beyond repair.

Little research, however, has been conducted to evaluate the effect of the embedded stainless-steel pins on the physical properties of silver amalgam.

REVIEW OF THE LITERATURE

Retention of plastic filling materials, such as gold foil and amalgam, has traditionally been achieved by producing adequate retention form within the walls of the cavity preparation. In teeth grossly mutilated by caries it is very difficult to develop adequate retention for these restorative materials. This led early practioners to seek other methods of gaining the required retention form.

In 1875, Davis[1] described a method of increasing the retention of gold foil restorations. After completion of the cavity preparation, small holes were drilled into the tooth structure and gold screws were placed into these holes. Part of each screw was left to project into the cavity preparation. The filling material was then condensed into the preparation and around the screws. In 1889, Storer[2] described a similar technique except that the screws were made of "Bright-metal", a name coined by Storer to describe the pure nickel he used instead of gold.

Failure of dental amalgams under masticatory forces led Bull[3,4,5,6] to investigate the effect on certain physical properties of amalgam when reinforcing agents were placed within dental amalgam restorations. Sterling silver plate, cut to the approximate outline of the cavity preparation, was embedded in the amalgam restoration. He felt that this would reduce the possibility of fracture of the amalgam and increase its transverse strength. He performed transverse strength tests on silver amalgam with and without the embedded sterling silver reinforcing plates. A 500 per cent increase in transverse strength and an 80 per cent increase in ultimate compressive strength was found in the reinforced samples. Flow or creep of the amalgam was reduced by 50 per cent. This technique did not become popular because of the time required to fabricate the silver plate and because of the difficulty encountered in condensing amalgam with the plate in place.

The use of stainless steel pins to retain large amalgam restorations was popularized by Markley[7] in 1958. Pins, made from threaded stainless-steel wire, were cemented part-way into holes previously drilled in the dentin. Amalgam was then condensed around the protruding pins. Markley postulated that amalgam restorations placed in this manner were:

> . . . as different from ordinary amalgam as the concrete in a sidewalk is different from the reinforced columns of a modern sky scraper, and by the same principle.

Markley felt that amalgam lacked adequate shear strength, and that the use of pins compensated for this deficiency. In later articles[8,9] Markley suggested that the use of stainless steel wires in dental amalgam would also increase the tensile and torsional strength values of the filling material.

Wright[10] investigated the galvanic action which occurred between silver amalgam and embedded stainless-steel pins. He found that the electromotive force generated between stainless steel and silver amalgam ranged between 0.53 to 0.65 volts, depending upon the silver content of the amalgam. He felt that this compared favorably with the electromotive force generated between high carat gold and silver amalgam which developed a force of 0.70 volts. Since it was felt by the author that no pulpal or other irritation resulted from the electromotive force developed between a gold inlay and a silver amalgam restoration, an amalgam containing stainless steel pins would not constitute a threat to the vitality of the tooth or surrounding structures. He also felt that the use of these pins would strengthen the amalgam restoration and render it less susceptible to fracture.

Several other investigators[11,12,13,14] have described techniques utilizing stainless steel pins. These authors have described the pin-reinforced amalgam restoration as capable of producing increased tensile strength values[13], and generally exhibiting better physical properties than unreinforced amalgam[11,12,13]. No experimental evidence was available, however, to substantiate such claims.

The effect of stainless steel pins on the microstructure and the physical properties of dental amalgam was examined by Wing[15] in 1965. He observed that the effect of stainless steel pins was to reduce the compressive strength of dental amalgam when tested at one hour and twenty-four hour intervals after condensation. Silver pins were also included in the study. The findings were similar to those with stainless steel pins at the one hour test period, but the decrease in strength using silver pins was not as marked at the twenty-four hour test period. He found that fracture occurred through the pins in the silver pin-reinforced specimens, whereas in the case of specimens with stainless steel pins, fracture occurred along the pins.

Wing also described the presence of a characteristic void around stainless steel pins in amalgam specimens. He explained this phenomenon as being caused by an accumulation of mercury around the pins, which, as the setting reaction proceeded, was drawn back into the amalgam. This could account for earlier fracture occurring in the specimens. He felt, however, that the additional retention gained by incorporating pins merited their use. He did suggest, however, that as few pins as possible should be used, and that they should be short and well spaced.

Decrease in the twenty-four hour compressive strength of dental amalgam which contained pins was also noted by

Going.[16] He found that the ultimate compressive strength was decreased when more than one pin was placed in an amalgam specimen. Later research by the same investigator[17] confirmed this finding. A significant decrease in twenty-four hour tensile strength was found when diametral tensile tests were conducted with the pins placed parallel or diagonal to the loading force. Later investigation by Going[18] indicated that the early compressive strength of dental amalgam was not affected by the inclusion of pins, when tests were conducted at one-half hour and two hours after condensation.

Smith[19] placed amalgam restorations in extracted teeth in which embedded stainless steel pins were used as retention devices. Similar restorations, placed in extracted teeth without the use of pins were used as controls. A compressive load, directed through a 0.5 inch diameter steel ball to simulate cuspal contact, was applied to the restoration in the tooth. Results of this investigation revealed that the pin-retained amalgam fractured at 386 pounds pressure, while the control specimens fractured at a mean load of 449 pounds. Although this difference was not statistically significant, he concluded that, where stainless steel pins were used for purposes of retention, strengthening of the restoration was not evident and a trend towards weakening was apparent.

Charlick[20] tested the compressive strength of amalgam alloys which contained stainless steel, gold-platinum, or gold-palladium pins. No difference in strength values was found when comparing specimens containing the three types of pins. He also investigated the effect of varying the amalgam specimen length and the influence of embedded short or long pins on compressive strength. No difference in strength was noted in the short samples, with either long or short pins, when compared to the control samples which contained no pins. The long samples showed a statistically significant increase in compressive strength. Charlick did not believe this to be of clinical significance.

White[21] attempted to increase the compressive and tensile strengths of amalgam by utilizing stainless steel pins which were electroplated with gold or silver, however, he found no advantage when using these materials.

Cecconi and Asgar[22] reported the effect of pin location on the tensile strength of dental amalgam. Spherical particle alloy was used in their study. Three types of pins were used, serrated stainless-steel pins, copperplated stainless-steel pins, and silver pins. When pin placement was such that the long axis of the pin was perpendicular to the tensile force, a decrease in tensile strength was found with all three types of pin material. Stainless steel and copperplated stainless-steel pins produced a greater decrease in strength than did the silver pins. With pin placement parallel to the tensile force, no difference in tensile strength was found between the control specimens without pins and those containing any of the three types of pin material.

The possibility of reinforcing dental amalgam with various types of fibers was investigated by Petersen[23] in 1968. He found no increase in strength with the use of glass, silverplated or steel fibers. All of the fibers, when used in small quantities, tended to increase the flow of the amalgam specimens.

Welk and Dilts[24] investigated the influence of pins on the compressive and transverse strength of dental amalgam. Smooth and serrated stainless-steel pins were used in their study. They found that both compressive and transverse strength values were reduced when pins were placed in the amalgam. There was no evidence of a proportionate decrease in strength value when the number of pins was increased.

Three techniques for providing pin retention are currently in vogue, using commercially available stainless steel pins. The cemented pin technique, advocated by Markley,[7,8,9] requires preparation of a pinhole that is 0.001 to 0.002 inches larger in diameter than the pin. The serrated stainless-steel pin is cemented into the hole with zinc phosphate cement.

The friction lock technique, described by Golstein,[25] depends on the elasticity of the dentin for retention. A hole is prepared 0.001 inches smaller in diameter than the pin and the pin is driven into the hole with a holder and mallet. The material used for this technique is smooth stainless-steel.

Going[16] described a third method for pin retention which also utilizes a pin that is larger than the hole. A threaded pin, 0.031 inches in diameter, is screwed into a 0.027 inch diameter hole. This procedure is also described as the self-threading pin technique.

The retentive properties of the three types of pins in tooth structure were studied by Welk, Dilts and Stowall[26] in 1968. The cemented pins proved to offer the least resistance to withdrawal, the friction lock pins required more force, and the self-threading pins were the most retentive. The force required to remove all types of pins increased as the depth of the pinhole increased from one to four millimeters. Self-threading pins, however, fractured at a depth of four millimeters.

The retentive properties of the three types of pins in dental amalgam were investigated by Welk and Dilts.[24] The serrated stainless-steel pins and the self-threading pins fractured when attempts were made to withdraw them from a depth of more than two millimeters. The smooth stainless-steel pin used with the friction lock technique proved to be the least retentive.

Investigation by Moffa, Rozzano, and Doyle[27] confirmed the results of Welk and Dilts.[24] They concluded that the optimal depth of pin embedment in amalgam was two millimeters, when using either threaded stainless-steel or self-threading pins.

STATEMENT OF THE PROBLEM

It has been suggested that the use of stainless-steel pins to enhance the retention of large amalgam restorations might adversely affect the mechanical properties of amalgam, possibly due to the absence of an intimate bond between pins of such composition and amalgam.

Such a condition could lead to the failure of the restorative material and jeopardize the tooth in which it has been placed.

Inconsistent results reported by previous authors indicated a need for further investigation, in vitro, into the phenomena associated with the effect of such pins on some mechanical properties of dental amalgam, and to determine what effect a pin of such a composition capable of fusing with amalgam would have on these properties.

METHODS AND MATERIALS

I. SELECTION OF MATERIALS

Three commercially available silver alloys were used in the present study. They were selected to be representative of the types of alloys commonly used by dental practitioners. The three alloys were:

1. A conventional alloy (20th Century fine grain alloy).* This alloy is manufactured by conventional methods, whereby filings are cut from a cast ingot. The fine grained alloy is recommended for use in the minimal mercury technique described by Eames.[28]
2. A dispersion phase alloy (Dispersalloy Spherical 400).** Inness and Youdelis[29] described an experimental alloy which was composed of regular alloy filings to which were added filings of a eutectic alloy of silver and copper. The eutectic alloy acted as a dispersion strengthening agent. The ratio of eutectic to silver alloy was one part eutectic to two parts alloy. For manufacturing reasons, the commercial product is produced by using spheralized dispersion particles instead of filings.

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* L. D. Caulk Co., Milford, Del.

** Western Metallurgical Co. Ltd., Edmonton, Alta.

3. A spherical particle alloy (Spheralloy).* This type of alloy came into prominence following Demaree and Taylor's[30] report of an amalgam made from spherical particle alloy produced by a process described by Probst et al[31] in 1961.

Three types of pins were used throughout the present investigation:

1. Serrated stainless-steel pins,** 0.022 inches in diameter. This material has been commonly used in the cemented pin technique advocated by Markley.[7]
2. Smooth stainless-steel pins,*** 0.022 inches in diameter. This material represents the pins used in the friction lock technique described by Goldstein.[25]
3. Platinum-gold-palladium pins,**** electroplated with sterling silver. Several investigators[15,21,27] have attempted to use pin materials which fuse with silver amalgam in order to reduce the deleterious effects of

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* Kerr Manufacturing Co., Detroit, Mich.

** Williams Gold Refining Co. of Canada Ltd., Fort Erie

*** K. C. Smith & Co., Monmouth, Great Britain

**** J. F. Jelenco & Co., Inc., New Rochelle, N. Y.

stainless steel on the physical properties of the amalgam. When silver pins were used, it was found that fracture occurred through the pin itself, which might render such a pin inadequate as a mechanism for retention. Stainless steel and ordinary steel pins, electroplated with gold, silver or copper, were also tried in an attempt to create fusion of the pin with the silver amalgam. It was found, however, that no beneficial effect accrued from their use.

An extremely accurate electroplating apparatus, shown in Figures 1 and 2, was used in an attempt to silverplate stainless steel and ordinary steel wires. It was found that a very poor bond existed between the base wire and the electroplated layer, and the plated surface could be stripped off the wire with moderate finger pressure. This occurred regardless of the plating current which varied from 2 milliamperes to 25 milliamperes.

An attempt was then made to copperplate ordinary steel wire and to subsequently cover the copper with an electroplated layer of sterling silver. Although an excellent bond was formed between the silver and the copper, large voids still existed between the copper layer and the base wire, as shown in Figure 3. Formation of oxides on the surface of the steel wire could account for the lack of close adapta-

Figure 1. Constant current electroplating apparatus

a) milliammeter
b) individual circuit controls
c) station selecter for monitoring current in individual circuits
d) electroplating bath

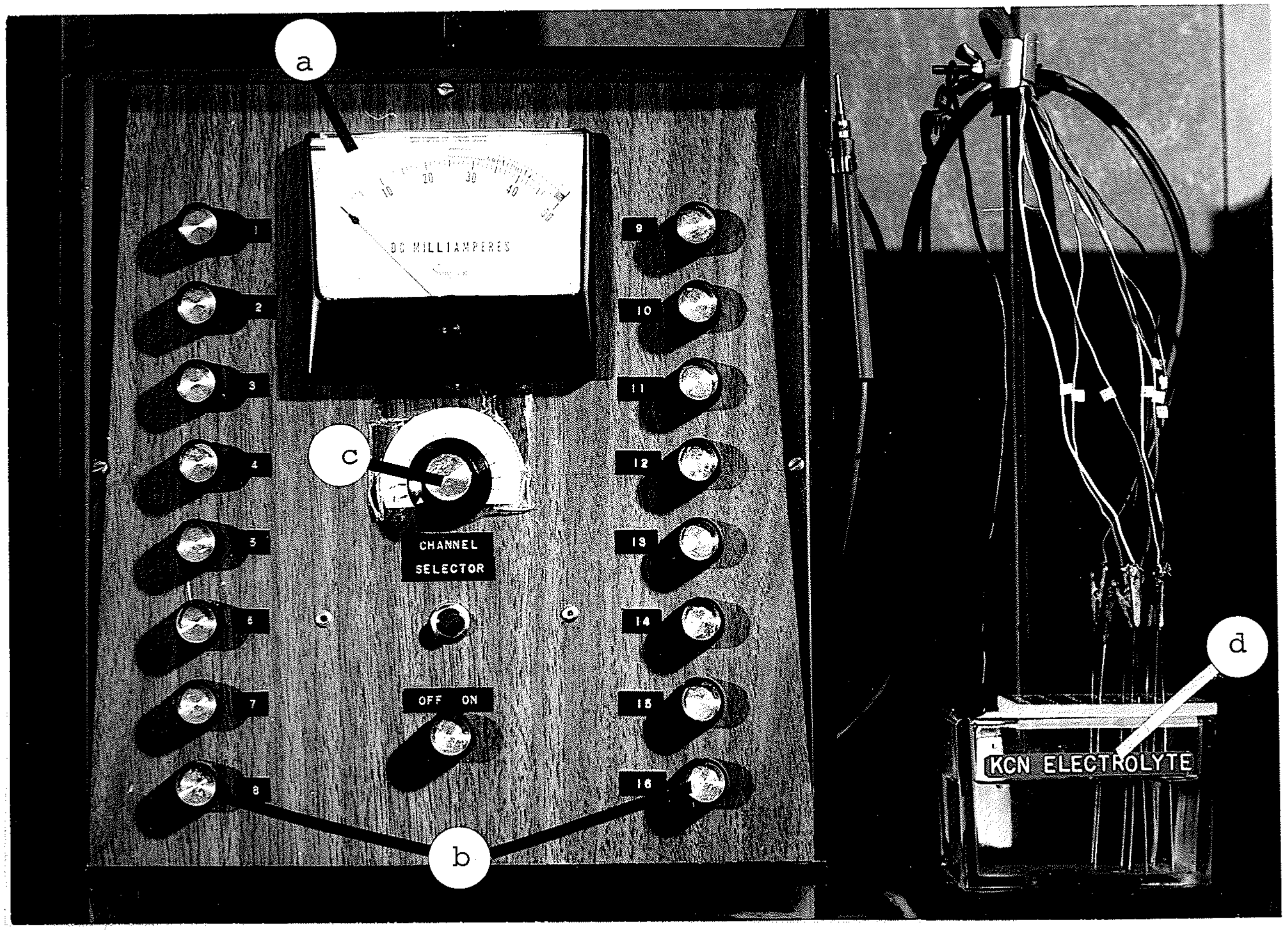
a
b
c
d
DC MILLIAMPERES
10 20 30 40 50
CHANNEL SELECTOR
OFF ON
KCN ELECTROLYTE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Fig. 1

Figure 2. Electrolyte bath of electroplating apparatus.

a) KCn solution
b) P.G.P. wires
c) individual electrode leads
d) common sterling silver anode

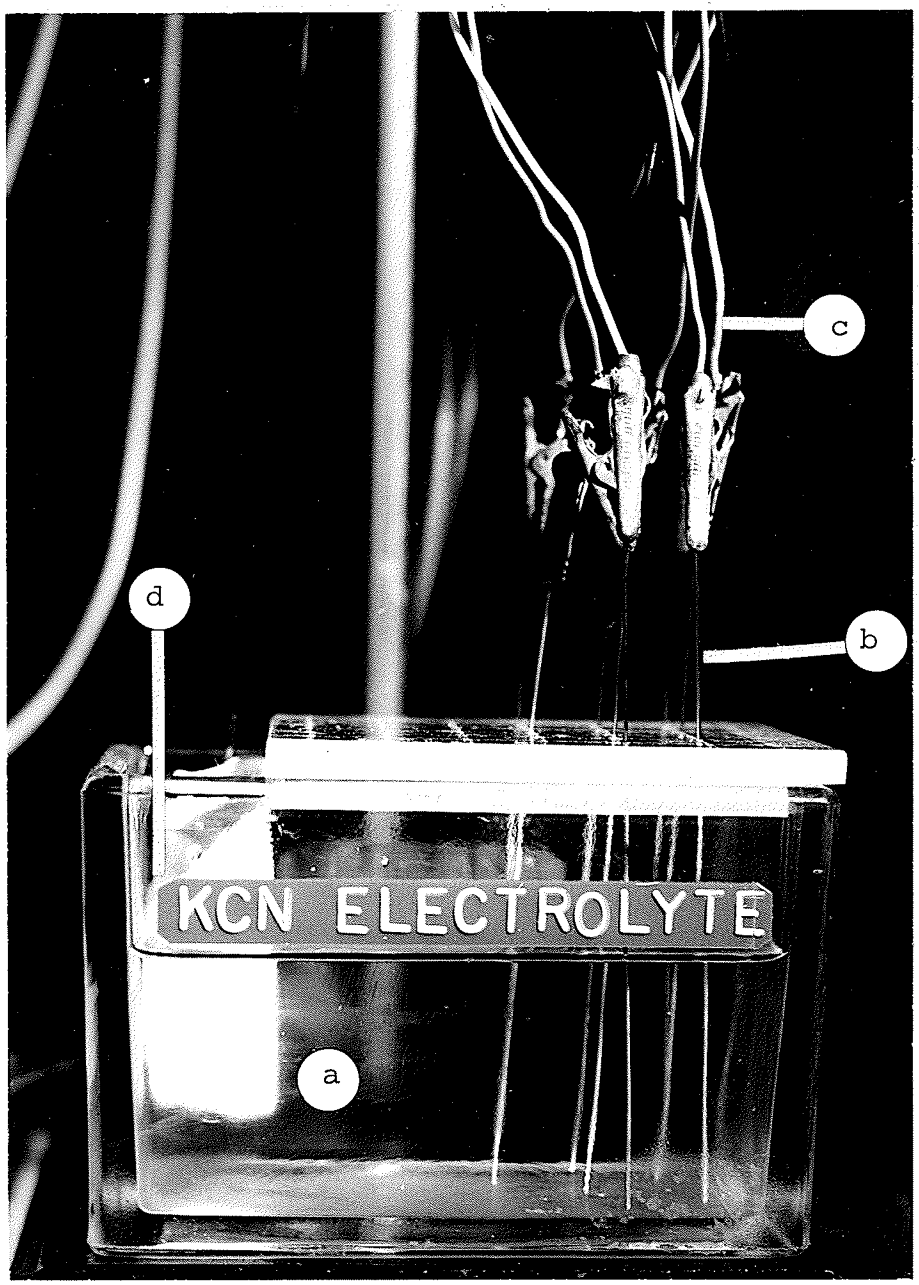

Fig. 2

tion of the copper during the plating procedure.

Failure of other investigators to find improvement in the strength values of amalgams containing surface plated pins could likewise be explained by the inadequate bond between the reactive surface of the pin and the base metal core, rather than to a lack of fusion of the amalgam to the surface layer of the pin.

To overcome the problem of oxide formation, a noble metal wire composed of platinum-gold-palladium was selected. The wire was electroplated with sterling silver, using an electrolyte of potassium cyanide with a plating current of fifteen milliamperes. The electroplating apparatus was so designed that the current to each wire could be regulated independently and maintained at a constant flow. It was found that a plating time of eight minutes was required to deposit a layer of sterling silver 0.0005 inches thick. The diameter of the base wire of platinum-gold-palladium used for the investigation was 0.022 inches in diameter. Thus a plated wire was produced with a total diameter of 0.023 inches. Figure 4 illustrates the intimate adaptation of the plated material to the base wire.

The three types of pins used in this study are illustrated in Figure 5.

Figure 3. Photomicrograph of steel wire plated with copper and silver (original magnification x 160)

a) steel pin
b) copper plating
c) silver plating
d) void

Figure 4. Photomicrograph of platinum-gold-palladium wire plated with sterling silver (original magnification x 160)

a) P.G.P. wire
b) sterling silver plate

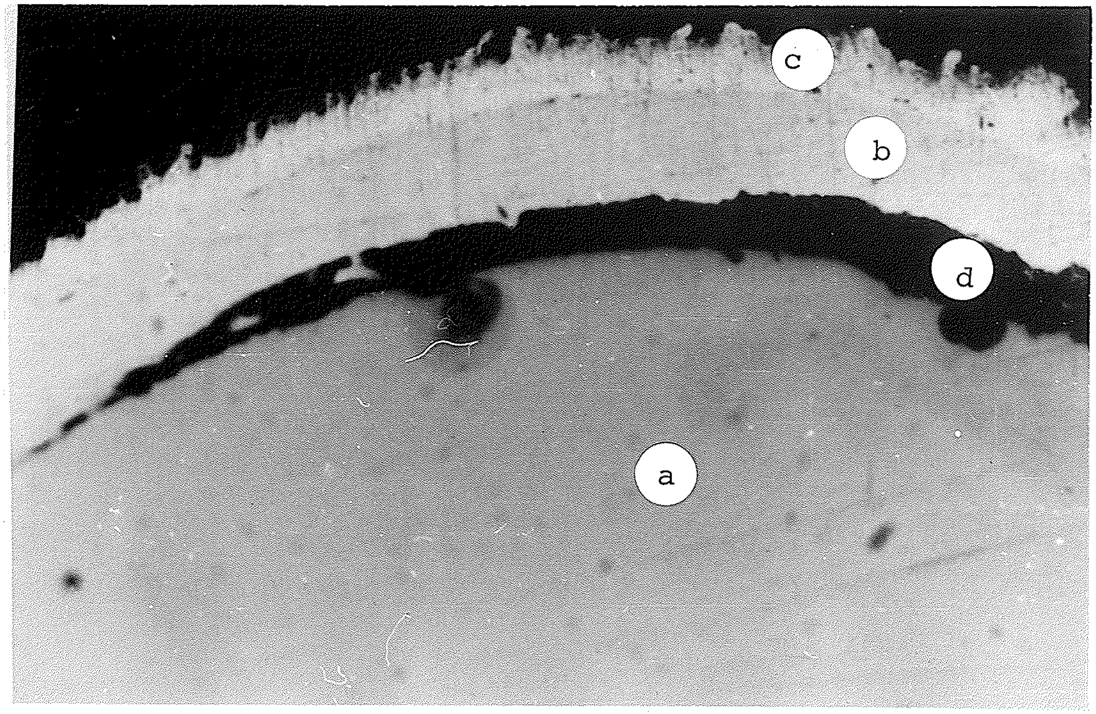

Fig. 3

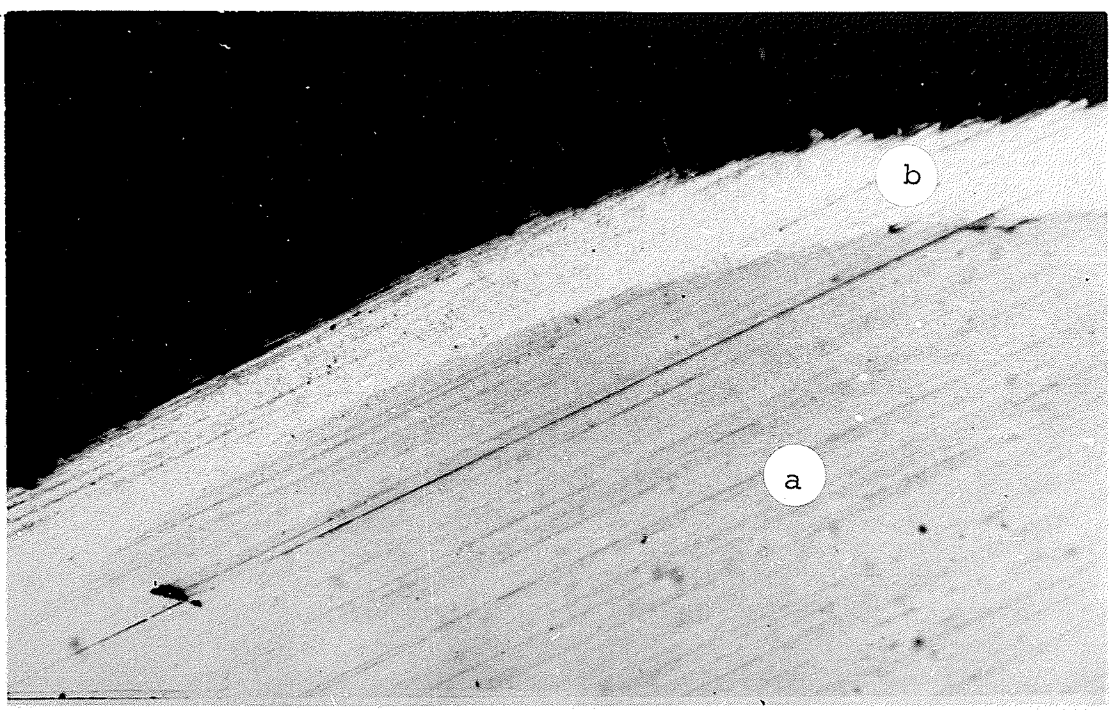

Fig. 4

Figure 5. Three types of pins used in the investigation

a) serrated stainless steel pins
b) electroplated P.G.P. pins
c) smooth stainless steel pins

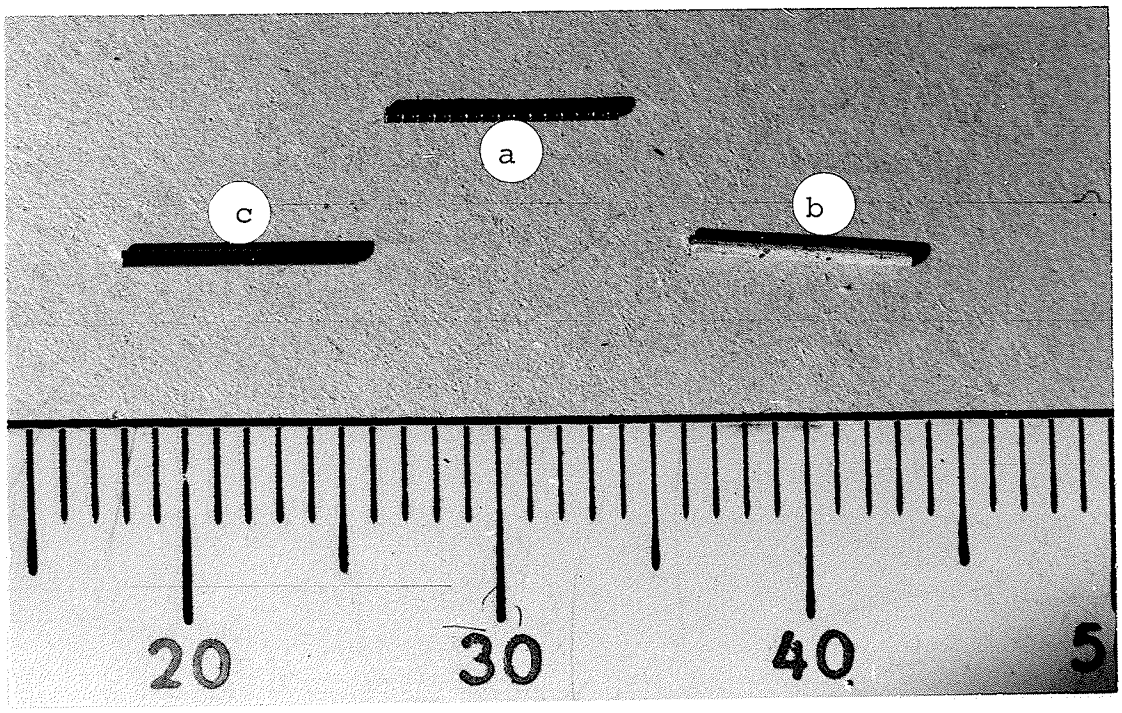

Fig. 5

II. SELECTION OF PHYSICAL TESTS

Several tests were chosen to evaluate the effect of pins on the physical properties of dental amalgam, and to determine if the silver-coated pin would influence the properties differently than would the stainless steel materials.

The ultimate compressive strength of dental amalgam has long been used as a criterion for amalgam strength. Phillips[32] and Taylor et al[33] were among those who investigated the compressive strength of silver amalgam at various time intervals ranging between fifteen minutes and six months after the completion of condensation. They found that amalgam continued to increase in strength over a six month period. Because of the long interval of time necessary for amalgam to achieve its final strength, one hour and twenty-four hour intervals were selected to obtain early setting strength and final strength values recognizing that the twenty-four value was found to be between 86 per cent to 96 per cent of the final strength.[32,33]

Granath,[34,35] using photoelastic stress analysis, demonstrated that tensile stress might be a leading cause of amalgam failure. His studies have shown that the forces generated by occlusal contact are not of sufficient magnitude to cause compressive failure of silver amalgam, however, tensile stresses, induced during occlusal contact, may be of sufficient magnitude to exceed the low tensile strength of the material. Because tensile forces can occur in two basic directions in relation to pins placed in dental amalgam, tensile strength tests were conducted with the long axis of the pins perpendicular to the tensile force, and again with the long axis of the pins placed parallel to the tensile force.

The resistance to withdrawal of pins from amalgam is important for measuring the bond achieved between the surface of the pin and the amalgam matrix. Withdrawal tests were performed using each type of pin with each type of amalgam. These were conducted twenty-four hours after the completion of condensation.

ULTIMATE COMPRESSIVE STRENGTH

The mould used to prepare the specimens for compressive strength testing is shown in Figure 6. The cylindrical mould measured 0.750 inches in length. The center hole was bored the complete length of the mould and measured 0.198 inches in diameter to yield a specimen with a cross sectional area of 0.0308 square inches. Four plungers were constructed 0.196 inches in diameter to fit into the amalgam mould. One plunger had a smooth face, for condensing samples without pins.

Figure 6. Disassembled specimen mould, base, and plunger.

a) mould
b) base
c) plunger
d) hole for small end of plunger

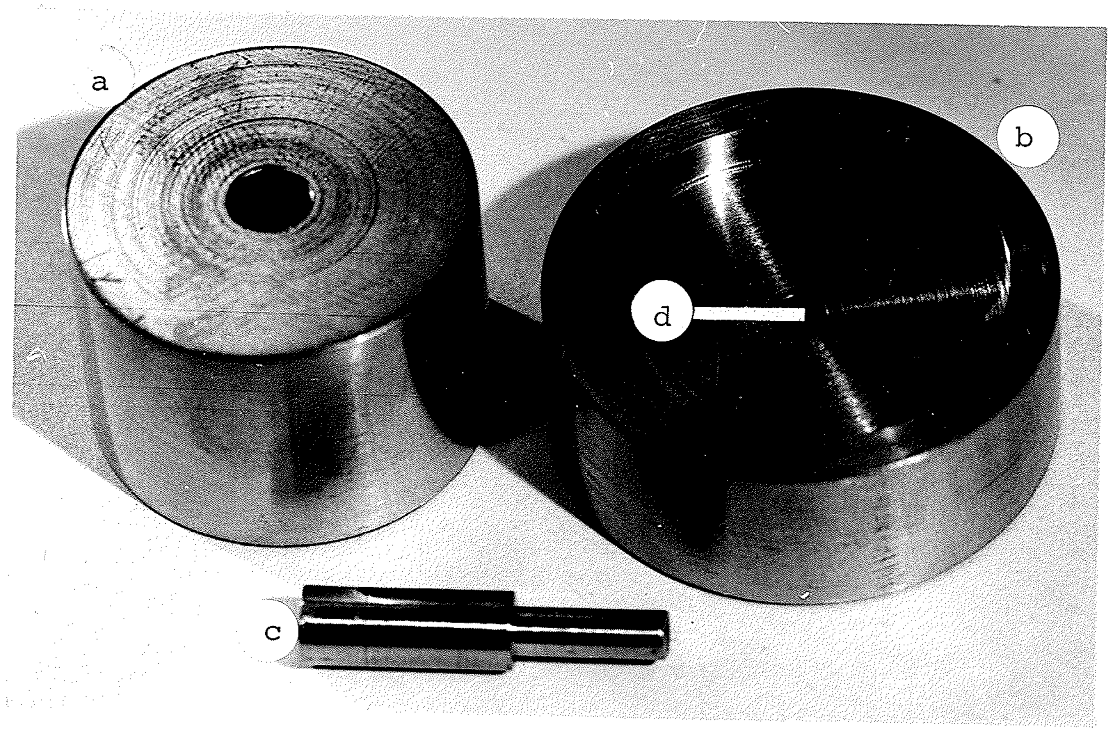

Fig. 6

Each of the other plungers were tapped with one, two or four holes 0.024 inches in diameter in order that pins could be placed in them and held securely while the amalgam was being condensed around them. The pins were cut manually to a length of 0.2960 inches (s = 0.0020 inches) and the ends finished perpendicular to the long axis of the pin. Table I illustrates the length of specimen produced by the use of each of the four plungers, and the resultant length of the pin embedded in the amalgam sample. Figure 7 demonstrates pin location with each of the plungers used in this study. For the one pin plunger, a hole was tapped in the center of the plunger. The holes in the two-pin plunger were tapped one millimeter from the edge of the plunger on a line passing through the geometric center of the top of the plunger. The holes in the four-pin plunger were tapped similarly, with the additional two holes placed on a line at right angles to a line connecting the other two pin holes.

Preparation of Specimens

Conventional Silver Amalgam. The alloy used was a fine grain alloy containing zinc, supplied in pellet form. The weight of each pellet, as stated by the manufacturer, was six grains (0.3894 grams). However, on checking the weight of the pellets it was found that the true weight of each

TABLE I

THE EFFECT OF THE VARIOUS PLUNGERS ON SPECIMEN LENGTH, AND THE LENGTH OF PINS EMBEDDED THEREIN

PLUNGER	PLUNGER LENGTH (inches)	SPECIMEN LENGTH (inches)	PIN HOLE DEPTH (inches)	PIN LENGTH IN AMALGAM (inches)
Control (no pins)	0.507	0.243	-----	-----
1 Pin	0.510	0.240	0.1655	0.1303
2 Pin	0.509	0.241	0.1617	0.1341
4 Pin	0.514	0.236	0.1591	0.1417

Figure 7. Compressive strength specimen assembly

a) assembled mould
b) control plunger (no pins
c) one pin plunger with plated pin
d) two pin plunger with serrated stainless steel pins
e) four pin plunger with smooth stainless steel pins

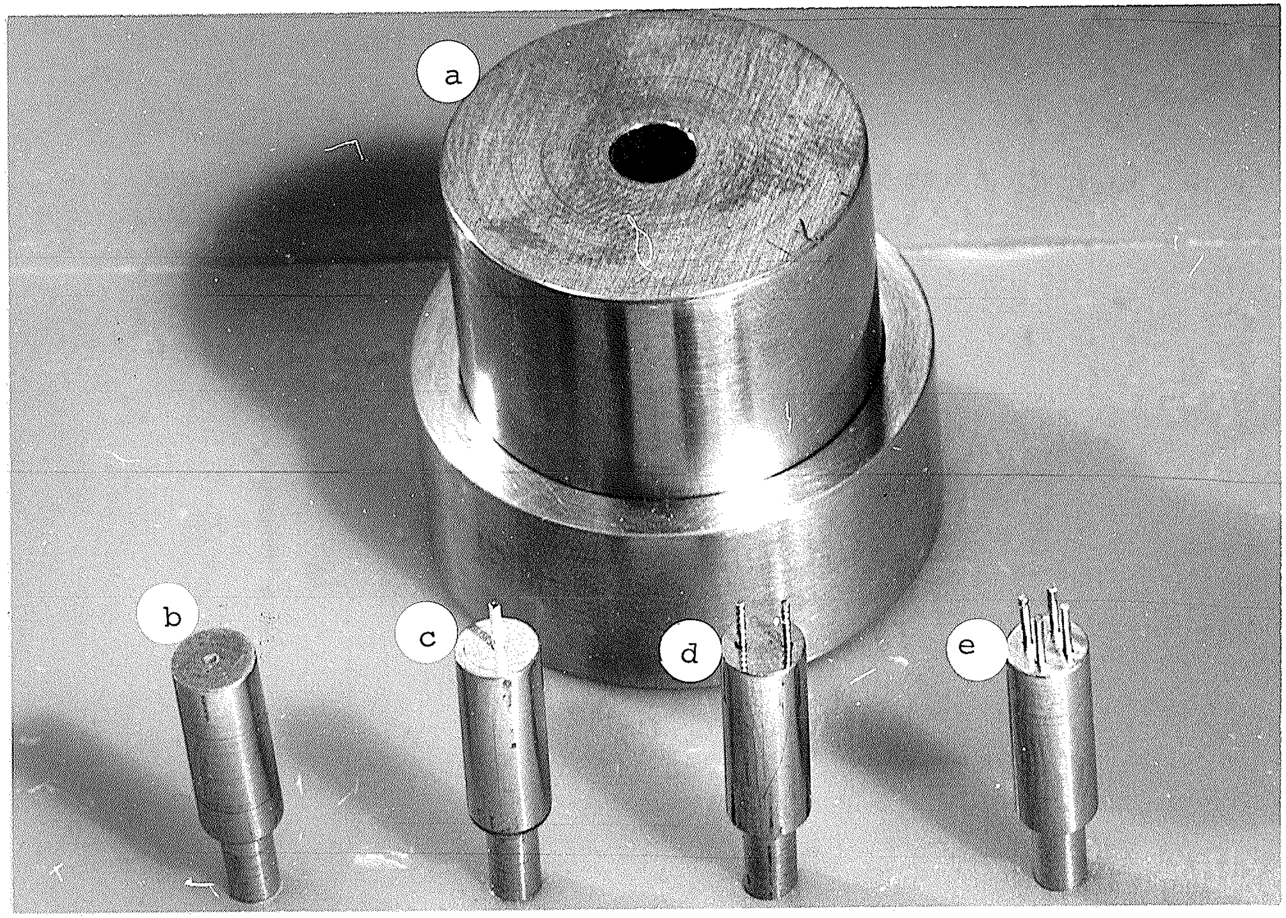

Fig. 7

pellet was 0.3883 grams (s = 0.0025 grams).

Mercury, which meets the American Dental Association specification, was proportioned using a Caulk Mercury dispenser with an "E" plunger. The plunger, illustrated in Figure 8, was claimed by the manufacturer to deliver a spill of mercury weighing six grains (0.3894 grams). By actual measurement, the average weight of a spill was found to be 0.3496 grams (s = 0.0014 grams). This combination produced a mix containing 50.40 per cent mercury by weight, rather than 50 per cent, as stated by the manufacturer.

Alloy and mercury were triturated in a plastic capsule containing a metal pestle* using a mechanical amalgamator.* A trituration time of twenty seconds was used, followed by a five second mull with the pestle removed from the capsule. This is a commonly accepted technique for trituration of amalgam when using the minimal mercury technique as described by Eames.[28] The mixing and mulling times were held constant regardless of the size of the mix. The amalgamator and capsule used are shown in Figure 8.

The assembled mould with the appropriate plunger was placed in a device designed to ensure constant condensation pressure of the amalgam. The design of the apparatus was

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* Crescent Dental Mfg. Co., Chicago, Illinois

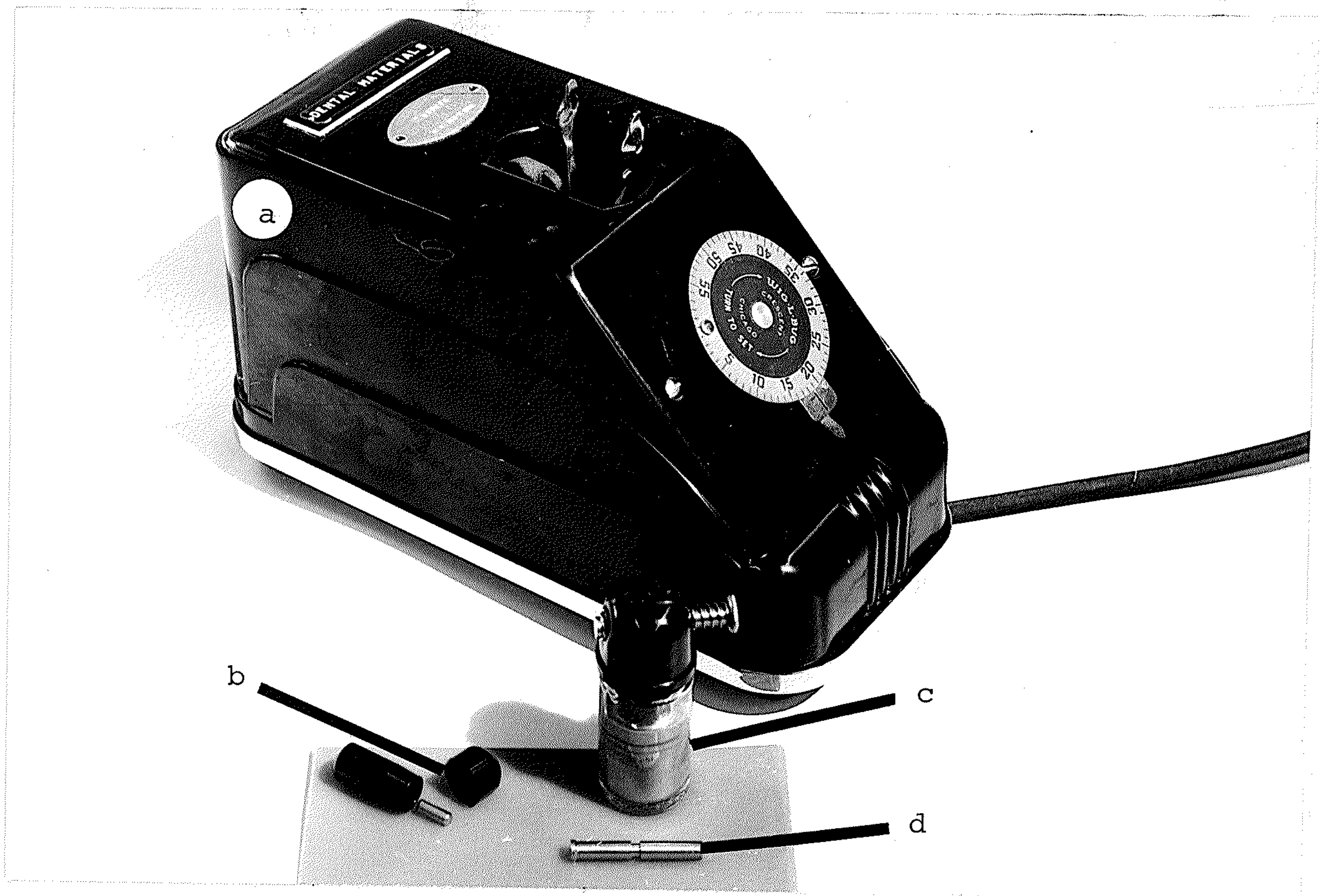

Fig. 8

modified from similar equipment described by Hollenback.[36] Basker and Wilson[37] have shown that clinically, the average thrust of an amalgam condenser is 1.3 kilograms, slightly less than three pounds. Eames[28,38] also suggested a condensing thrust of three pounds when using the minimal mercury technique. The apparatus was adjusted so that three pounds of thrust on the mould was necessary to activate the lever action. The apparatus is shown in Figure 9.

Depending on the plunger selected, the correct number of plated, serrated or smooth stainless-steel pins were placed into the tapped holes prior to the commencement of trituration.

A two-pellet mix of amalgam was prepared as described previously and placed on a washed rubber dam for ease of handling. Using an Ash 5 X L* amalgam carrier as shown in Figure 10, the mix was divided into three increments, each of which consisted of two carrier loads. Each portion was condensed with a round smooth-faced condenser 0.043 inches in diameter (Figure 10) by applying thirty strokes with three pounds pressure. Mercury, which was brought to the surface during condensation, was removed following the condensation of the second and third increments. A single-

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* Claudius Ash, Sons & Co. Ltd., London, England

Figure 9. Constant pressure condensing apparatus.

a) mould in place
b) hand rest
c) fulcrum
d) weight
e) small balance weights

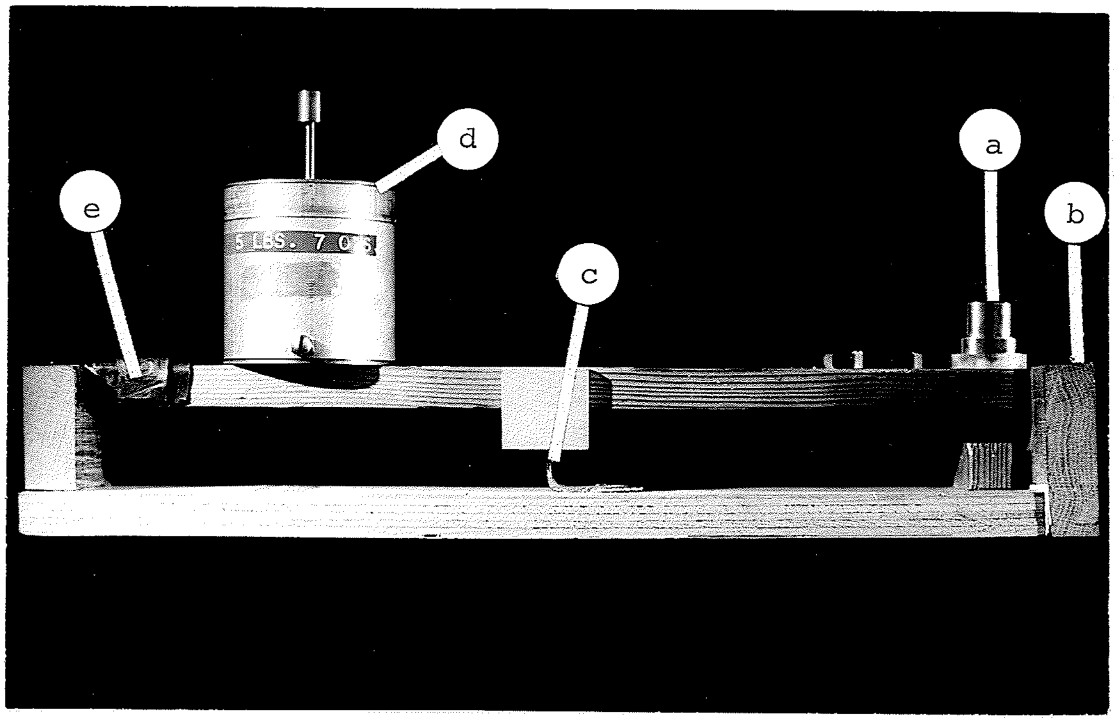

Fig. 9

Figure 10. Amalgam carrier and condensers used in the study.

a) amalgam carrier
b) 0.043 inch diameter condenser
c) 0.068 inch diameter condenser
d) 0.101 inch diameter condenser

Fig. 10

pellet mix of amalgam was then made and divided into three portions, each of which consisted of one carrier load. The first two increments were condensed with a round, smooth-faced condenser 0.068 inches in diameter. The same pressure and number of strokes were used as previously described. This procedure completely filled the mould. The final increment was added to overfill the mould and condensed with a slightly larger round, smooth-faced instrument 0.101 inches in diameter. After trimming the amalgam with a razor blade flush with the top of the mould, the specimen was ejected from the mould and stored for the required length of time before testing.

Ten sets, each containing at least six specimens, were prepared for testing after one hour, and an additional ten sets were prepared for testing after twenty-four hours. The interval of time at which tests were conducted was computed from the time condensation of a specimen was completed.

One set in each group of ten contained no pins, and acted as a control. The remaining sets of specimens contained either one, two or four of one of the three types of materials investigated in the study. A total of one hundred and thirty-two specimens were prepared.

Dispersion Strengthened Amalgam. Dispersion strengthened alloy, containing zinc, was used in pellet form. The manufacturer's stated weight for each pellet was six grains (0.3894 grams). Weighing of a random sample of pellets, however, showed the actual weight of each pellet was 0.3959 grams (s = 0.0028 grams). Initially the amalgam mix was made using the "E" plunger in the Caulk dispenser. The resultant amalgam contained 49.91 per cent mercury by weight. Inconsistent compressive strength values were found when specimens were tested with this proportion of mercury and alloy. Subsequent amalgam mixes were proportioned using the "D" plunger in the mercury dispenser. It was found that this plunger dispensed 0.4053 grams (s = 0.0037 grams). This yielded an amalgam with a mercury content of 50.59 per cent by weight.

Trituration and condensation of the amalgam was accomplished by the same method as described previously with the exception that a round, smooth-faced condenser, 0.068 inches in diameter, was substituted for the 0.043 inch diameter condenser used with the conventional amalgam. This was necessary because of the increased plasticity of the mix, which permitted the 0.043 inch condenser to penetrate the amalgam rather than condense it.

Ten sets of specimens were prepared for each test period similar to that described previously for conventional amalgam. A total of one hundred and twenty specimens were prepared and tested.

Spherical Particle Amalgam. The spherical particle alloy, supplied in pellet form, was proportioned using the device supplied by the manufacturer illustrated in Figure 11. The proportioner was set to deliver a mercury spill of 0.300 grams, but the actual weight of the mercury spill was 0.2999 grams (s = 0.0005 grams). According to the manufacturer's statement, each pellet weighed 0.300 grams. The true weight of each pellet was found to be 0.2999 grams (s = 0.0020 grams). The resultant amalgam mix had a mercury content of 49.92 per cent by weight.

The alloy and mercury were triturated as previously described. The capsule and pestle used for trituration was the one recommended by the manufacturer for this alloy (Figure 11).

Condensation and finishing of the specimens was accomplished using the same method described for the dispersion phase alloy. Because of the smaller size of this mix, only two increments could be obtained from a two-pellet mix. Therefore, the second mix was also made with two pellets and the third large increment was taken from this mix. Ten sets of specimens were prepared for each test period in the

Figure 11. Spherical particle alloy and mercury dispenser with capsule for trituration.

a) mercury reservoir
b) alloy reservoir
c) variable mercury control
d) capsule and pestle

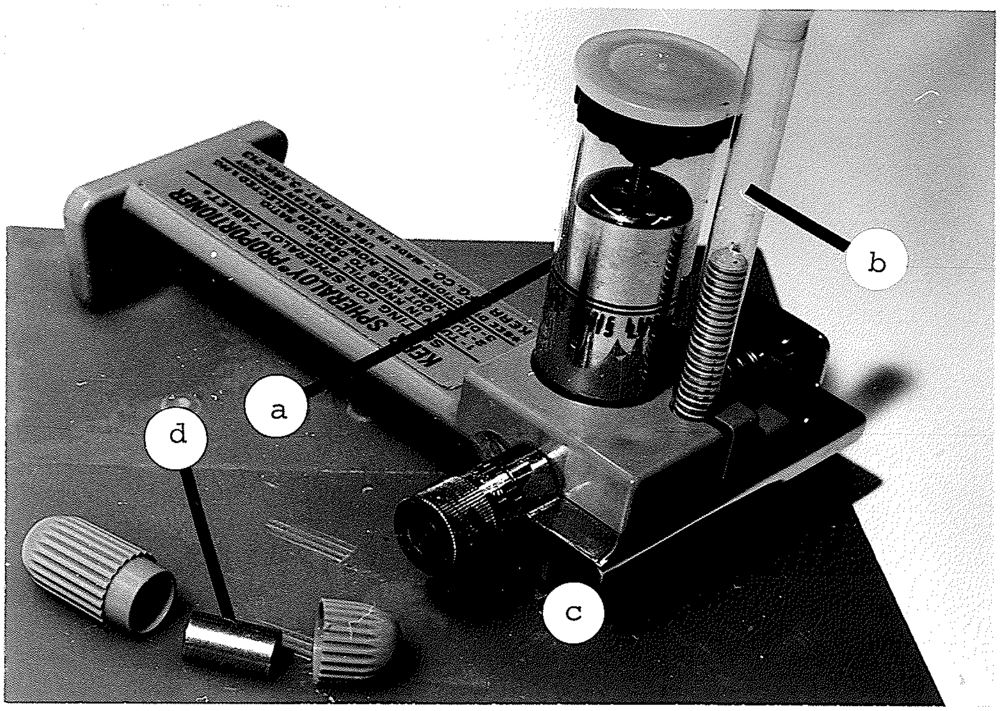

Fig. 11

manner described for the other alloys in the study. A total of one hundred and thirty-two specimens were prepared for testing.

Method of Testing

Compressive strength tests were performed using a Riehle Universal Screw Power Testing Machine, model number FS-5* shown in Figure 12.

The control samples, which did not contain pins, were placed on the lower bearing plate of the machine. Because it was not possible to surface plane the ends of most specimens because of the presence of pins, a small square of moistened blotting paper was interposed between the specimen and the metal bearing surface to distribute the pressure equally over the surface area of the bottom of the specimen (Figure 13).

To align the holes in the blotter with the pins protruding from the specimen, small rubber stamps were made from self-curing rubber base impression material. The surface of the two-pin and four-pin plungers were impressed with the impression material, which served as a rubber stamp

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* Riehle Testing Machine Division, American Machine and Metals, Inc. East Moline, Illinois

Figure 12. Riehle universal screw type testing machine.

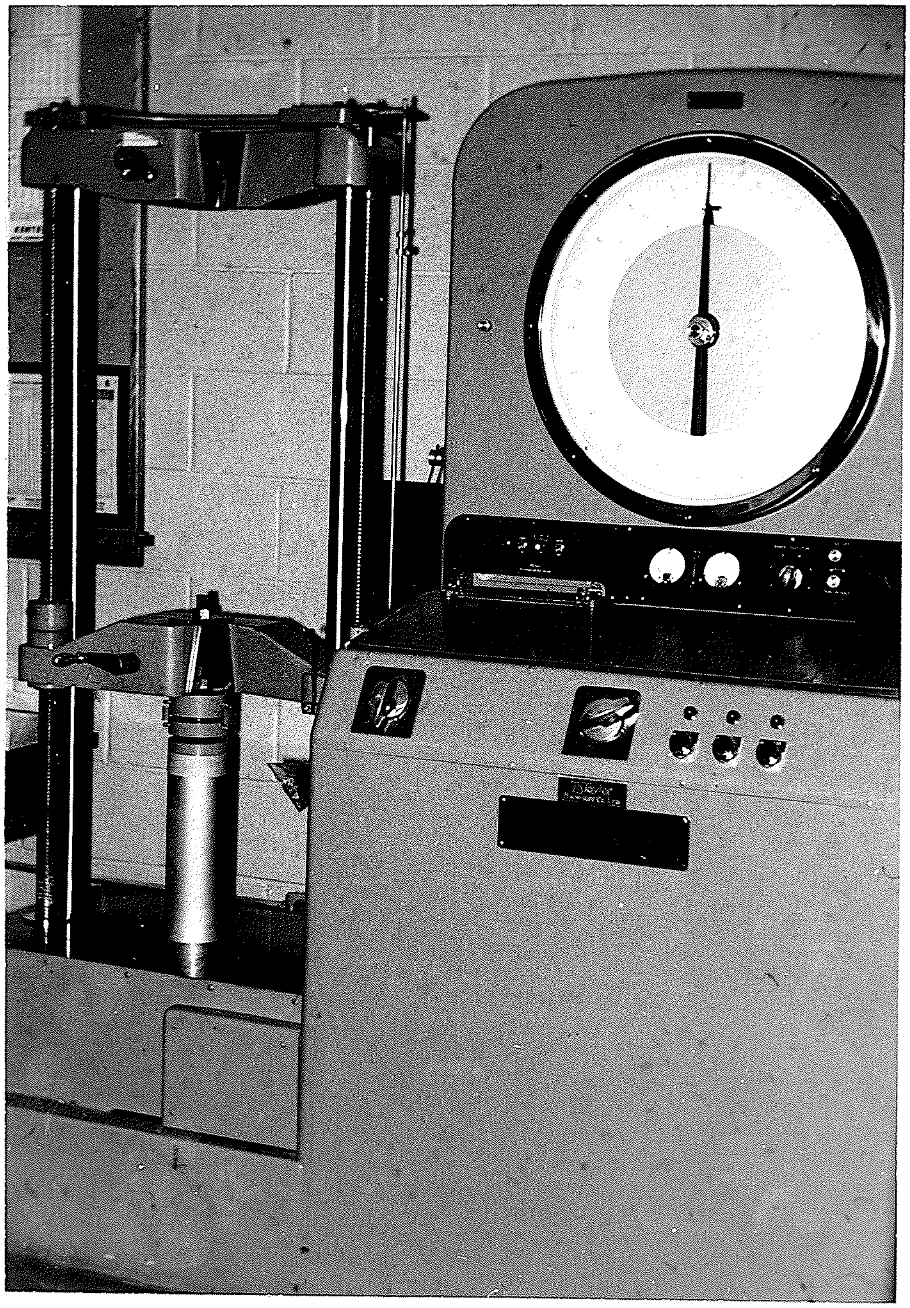

Fig. 12

Figure 13. Specimen in position for compressive testing.

a) bearing heads of testing machine
b) blotting paper
c) specimen

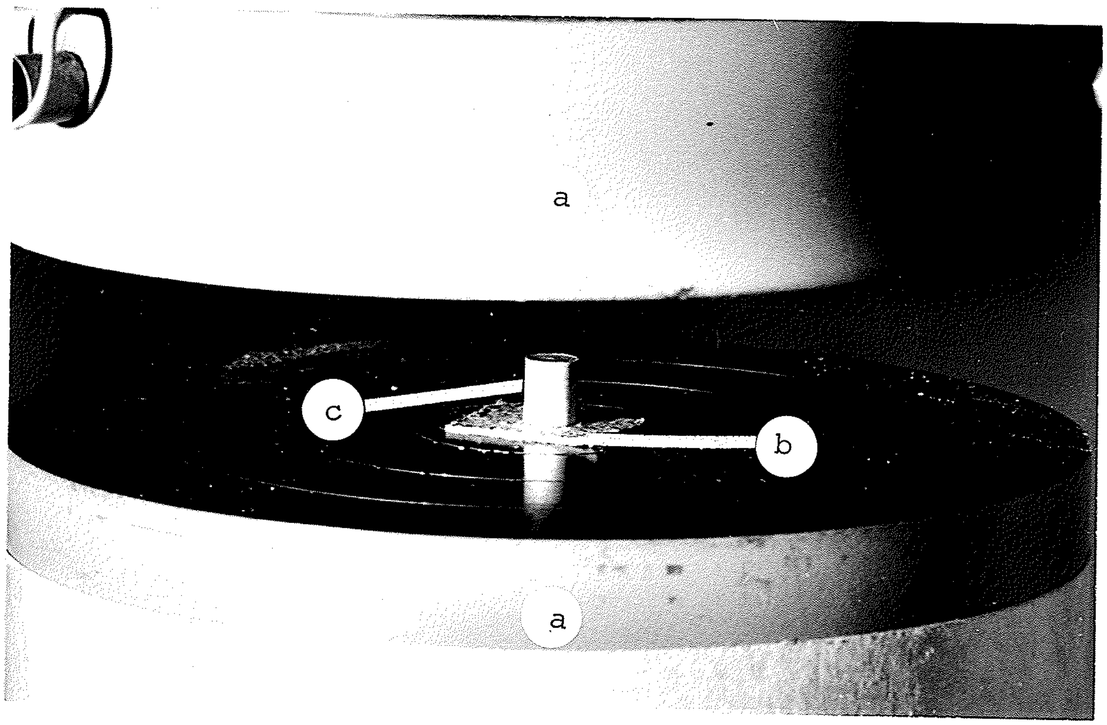

Fig. 13

to mark the location of the pins on the blotter. Holes were punched with a rubber-dam punch.

In order that the specimens with pins could be accommodated for testing, it was necessary to machine special lower bearing plates capable of accepting specimens with pins protruding from them. Such an arrangement simulates the clinical use of pins in amalgam restorations. The assembly for testing is illustrated in Figure 14.

Tests were performed one hour after the completion of condensation with a variability of fifteen seconds. Twenty-four hour tests were made within fifteen minutes of the twenty-four hour period. For all tests, a cross-head speed of 0.022 inches per minute was used.

Three samples from each set of specimens were retained after compressive testing, for residual mercury determination, to ensure standardization of specimen preparation. The method used for the determination was that described by Crawford and Larsen,[39] and the apparatus used is shown in Figure 15. A total of 192 residual mercury determinations were performed on the compressive strength specimens.

ULTIMATE TENSILE STRENGTH

Specimens With Pins Positioned Perpendicular to the Tensile Force.

Figure 14. Apparatus and materials used for compressive strength testing of specimens

a) rubber dam punch
b) base for one pin and two pin specimens
c) base for four pin specimens
d) rubber stamps for marking blotters
e) blotters with holes marked and punched

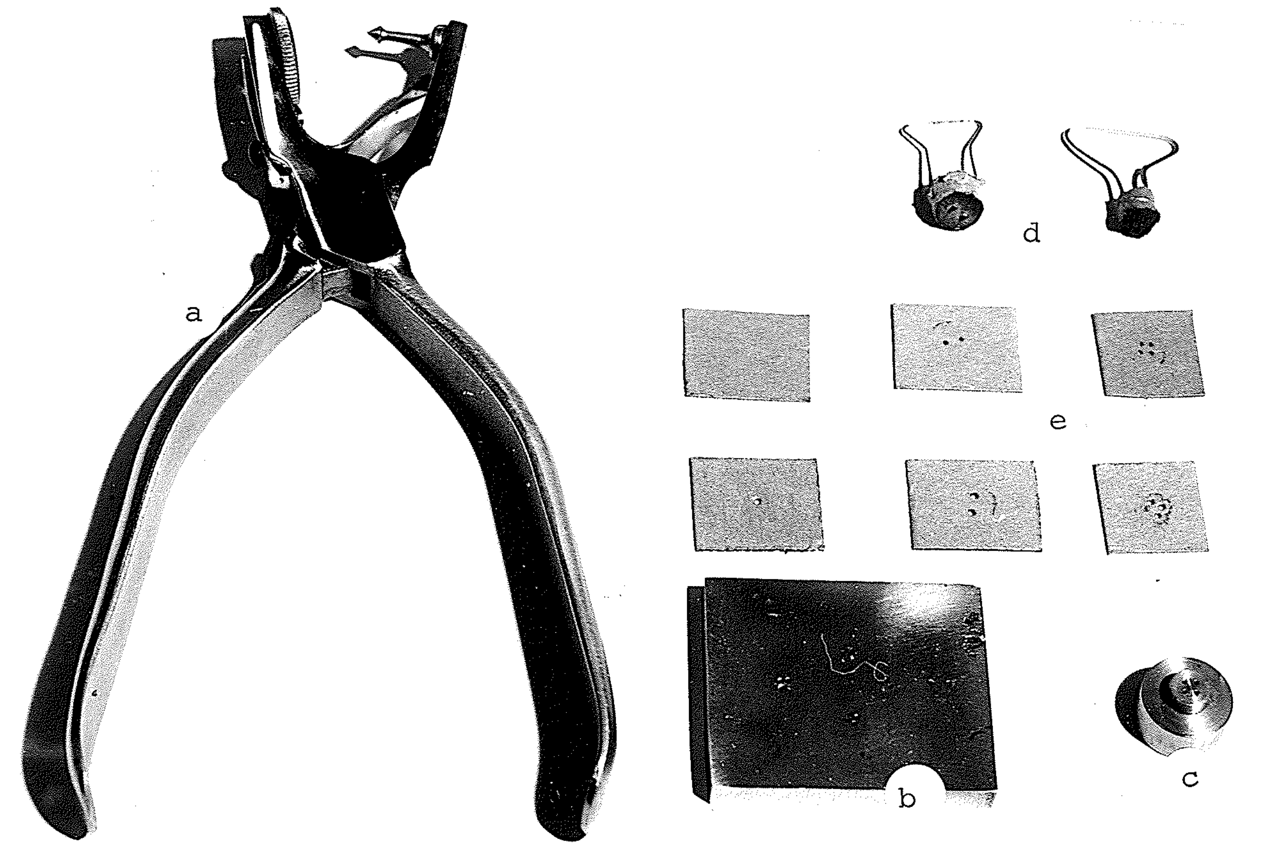

Fig. 14

Figure 15. Residual mercury determination apparatus.

a) electronic temperature control
b) thermocouple
c) nitrogen tank
d) transformer
e) furnace
f) pyrex tube
g) air and mercury vapor trap
h) suction device for air evacuation

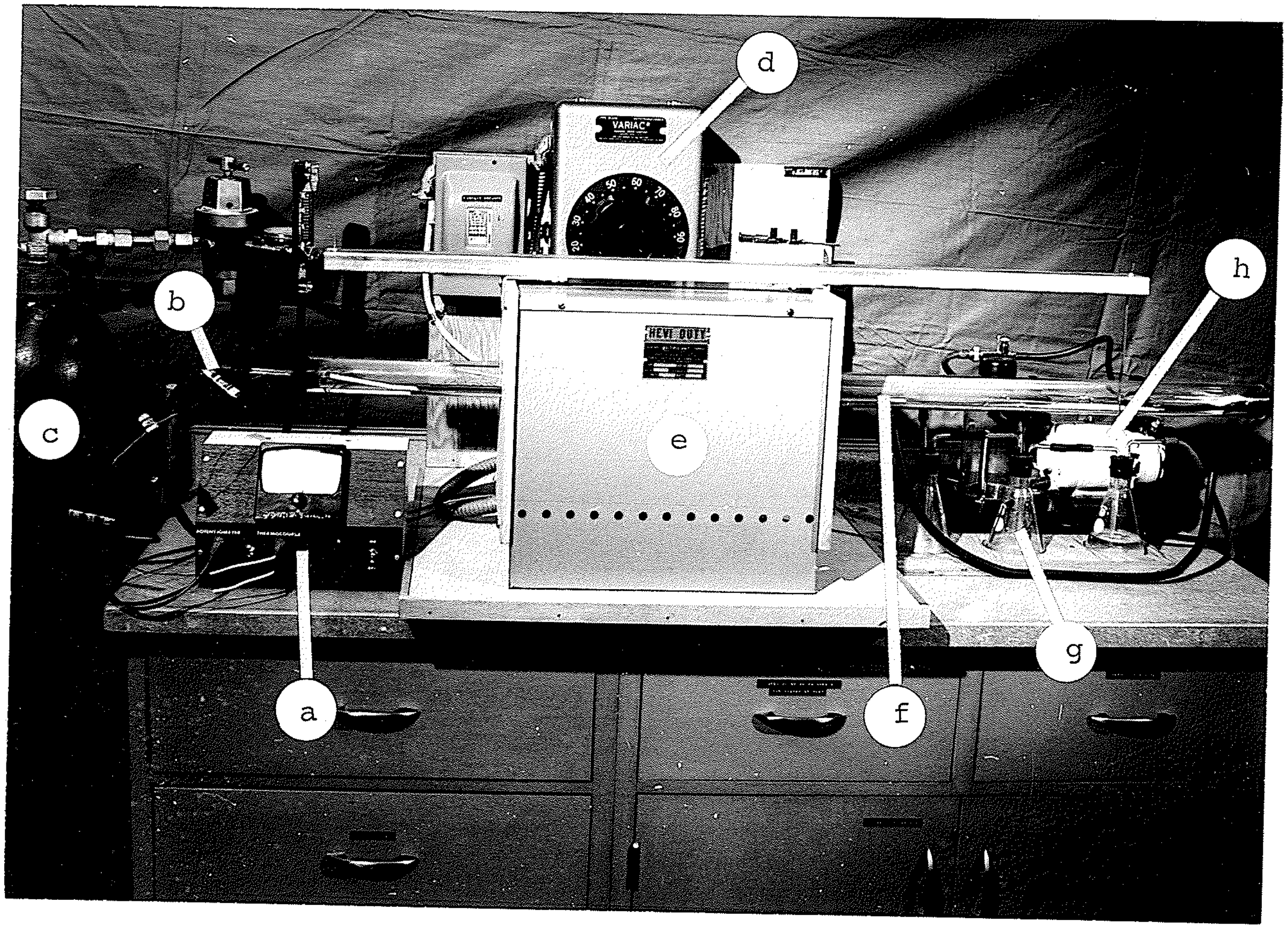

Fig. 15

Sets of specimens of each of the three silver alloys were prepared for testing at one hour and twenty-four hours. One set of samples, without pins, acted as a control. Each of the other sets contained one or two of one of the three types of pin materials. The specimens were prepared using the same methods and materials as described in the preparation of specimens for compressive testing. A total of two hundred and fifty-two specimens were prepared.

The diametral or splitting tensile test, described by Asgar,[40] was adopted for use in this study. The cylindrical specimens were laid on their side between the bearing heads of the Riehle Testing Machine, as shown in Figure 16. A compressive force was applied to the specimen using a head speed of 0.022 inches per minute until failure of the specimen occurred. The tensile strength of the material was calculated from the formula:

$$T = \frac{2P}{\pi l d}$$

Where:

T = splitting tensile strength, in pounds per square inch.

P = maximum applied load, indicated by the testing machine in pounds.

Figure 16. Diametral tensile test

a) bearing heads of testing machine
b) specimen in position

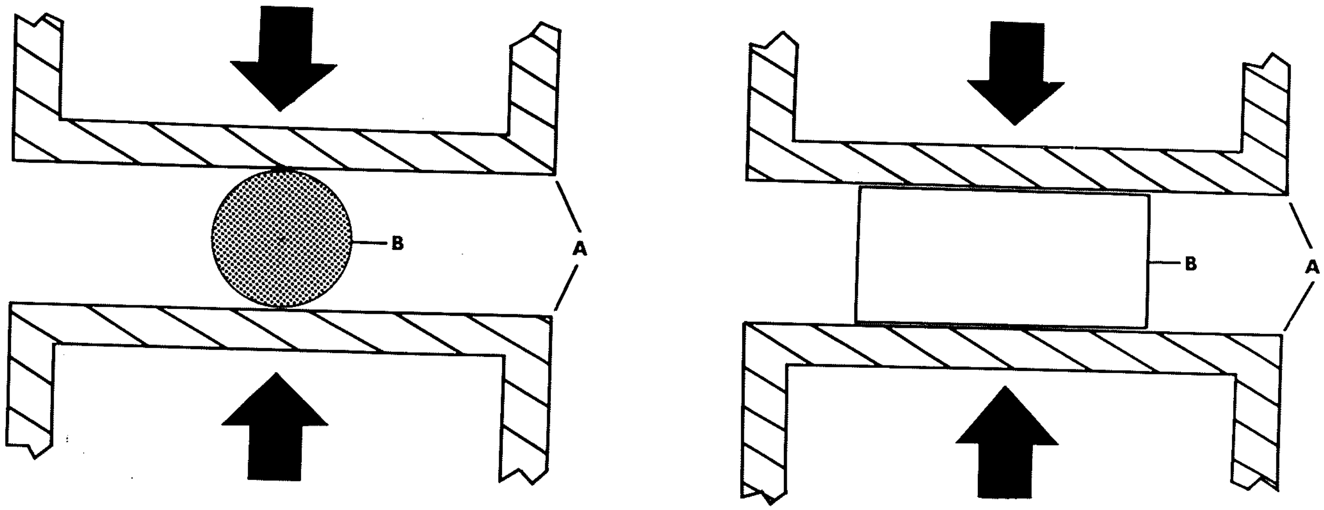

Fig. 16

l = length of the specimen in inches.

d = diameter of the specimen in inches.

Figure 17 demonstrates the area and direction of tensile stress occurring within the specimen when the diametral tensile test is applied.

Prior to testing, the edges of each specimen were smoothed with a hand file to provide even contact between the specimen and the bearing plates of the testing machine.

In order to ensure that pins were directly in the area of tensile stress generated within the sample, the two-pin samples were placed so that an imaginary line connecting the two pins was at right angles to the bearing surfaces of the testing device. Figure 18 demonstrates the position of the two pin specimens between the heads of the testing apparatus.

Three specimens from each set were retained after tensile testing, for residual mercury determination. One hundred and twenty-six determinations were made.

Specimens With Pins Positioned Parallel to the Tensile Force.

The mould used to produce specimens for this test was the same as that described for the previous two tests. There were, however, slight modifications in order that the

Figure 17. Stress distribution in diametral tensile test.

a) bearing heads of testing machine
b) specimen in position
c) area of tensile stress
d) direction of tensile stress

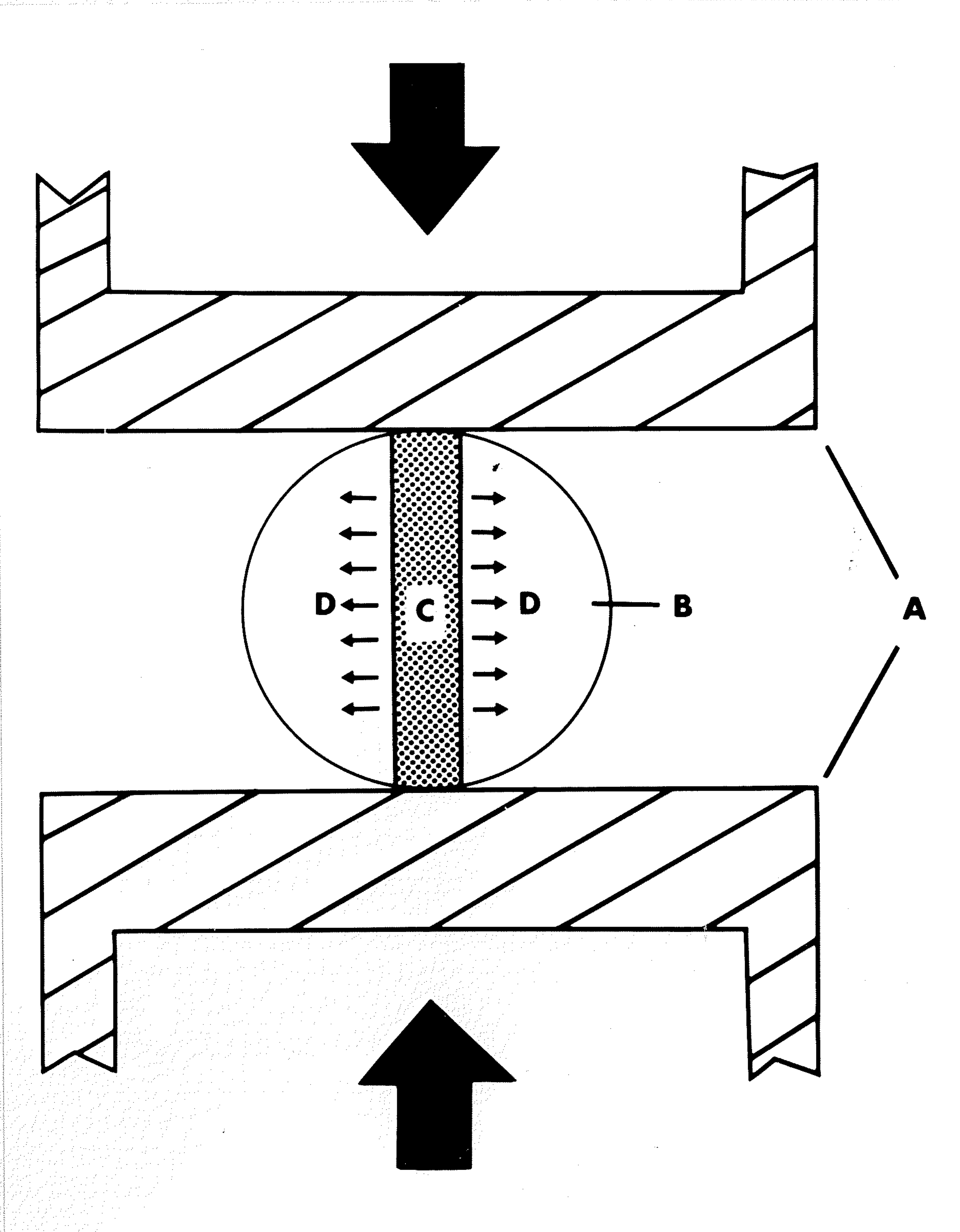

Fig. 17

Figure 18. Placement of two-pin specimens for diametral tensile test.

a) bearing heads of machine
b) specimen in position
c) pins

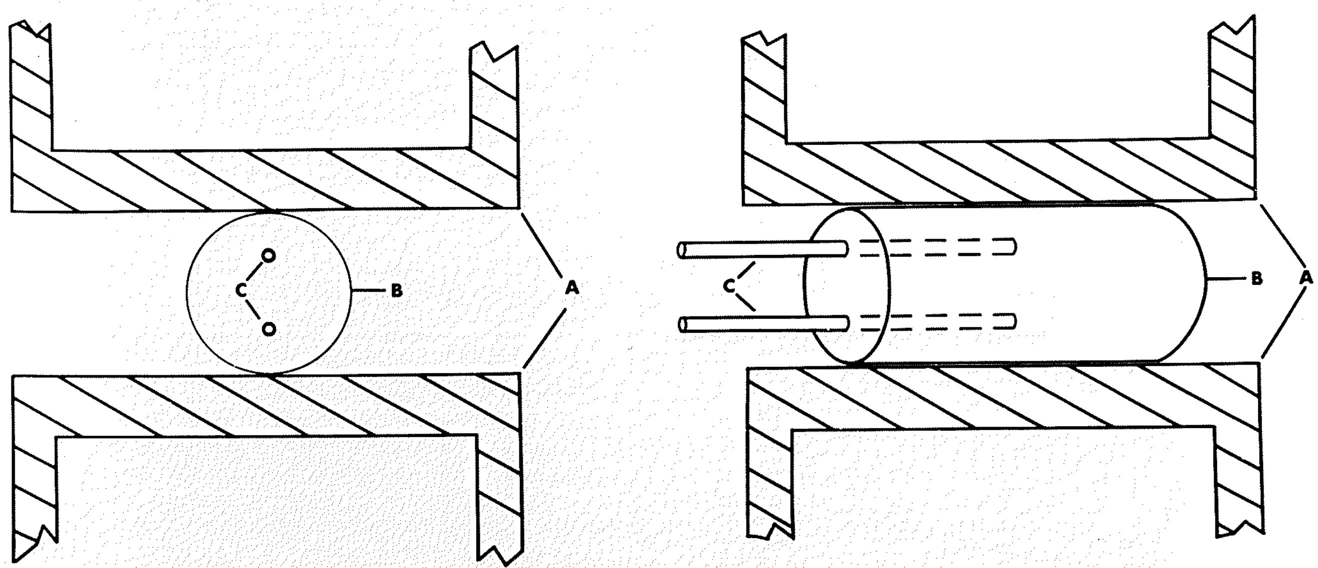

Fig. 18

pins could be aligned properly. The plunger without holes was the only one used in the mould. The top of the mould was marked with a line to permit visual alignment of the pins within the specimen.

The pins, which measured 0.1764 inches in length (s = 0.00005), were placed in the amalgam specimen so that the long axis of the pin was at right angles to the long axis of the specimen. The direction of the pin was determined by visually aligning the pin with the line scribed on the top of the mould (Figure 19).

In the one-pin specimens, pins were positioned after the second increment of amalgam had been condensed in the mould. The pin was placed in its correct position with small tweezers and tamped into the amalgam using the 0.101 inch diameter condenser. The remainder of the mould was filled with amalgam and finished as described previously. Prior to ejecting the specimen from the mould, a line was scribed on the specimen to facilitate orientation of the pins, as shown in Figure 20.

The two-pin specimens were prepared in the same manner with the exception that a pin was placed after condensation of both first and third increments of amalgam.

Preparation of the three-pin specimens was accomplished similarly except that a pin was placed after condensation of

Figure 19. Modification of mould for horizontal tensile test showing pin placement.

a) line scribed on surface of mould
b) pin alligned

Figure 20. Finished horizontal tensile test specimen

a) line on mould
b) line on specimen placed with felt pen

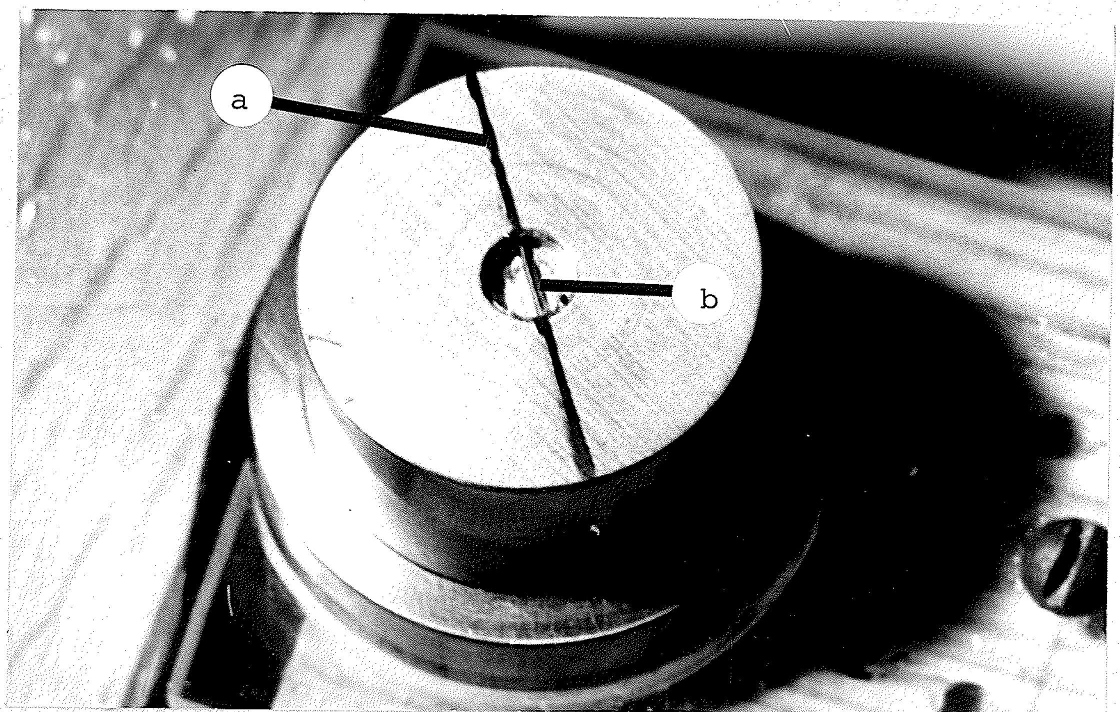

Fig. 19

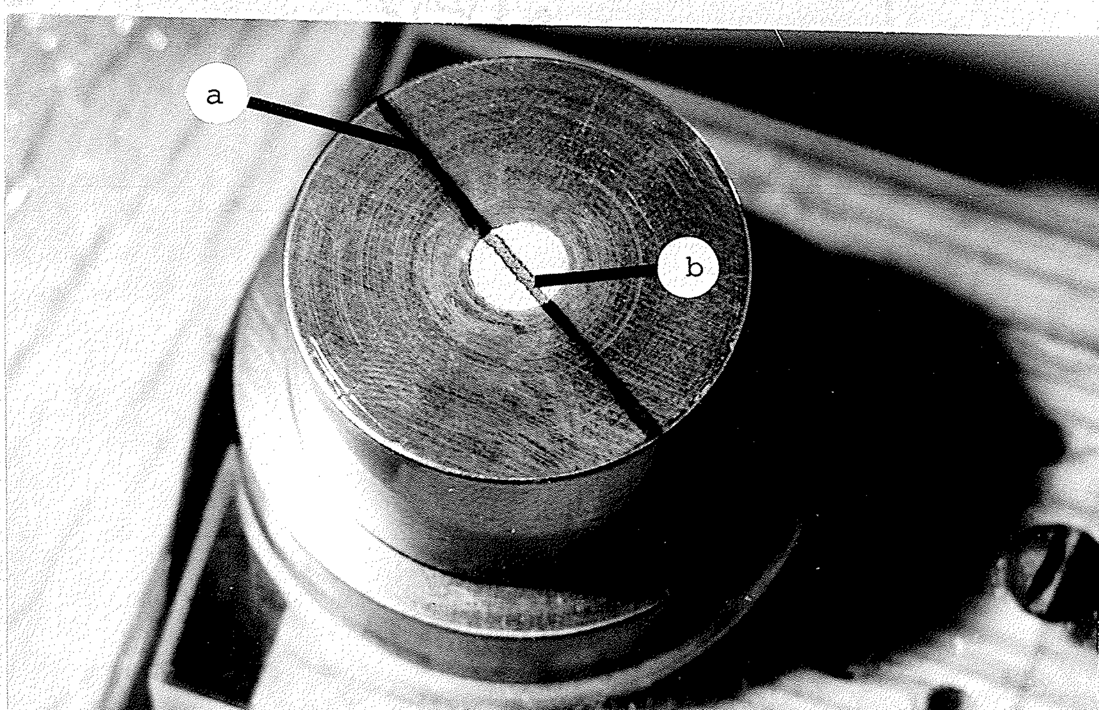

Fig. 20

the first, second and third increments of amalgam.

The results obtained from the control specimens for the previous tensile tests were used as control values for this portion of the investigation.

Nine sets, consisting of a minimum of six specimens each, were prepared for testing after one hour for each type of alloy. A similar number of sets was prepared for the twenty-four hour test period. The three types of pins, previously described, were used for this investigation. A total of three hundred and twenty-four specimens were prepared for diametral tensile testing.

Prior to testing, the edges of each specimen were finished as previously described. To ensure that the pins were parallel to the tensile force during loading, the line drawn on the end of the specimen was aligned to be parallel with the bearing heads of the testing machine (Figure 21).

Three specimens were retained from each set after testing, for residual mercury analysis. A total of one hundred and sixty-two analysis were made.

RESISTANCE TO WITHDRAWAL OF PINS FROM AMALGAM

The mould used to prepare the specimens for this portion of the study was similar in design to that previously described. The mould was reduced in length from 0.750 inches

Figure 21. Horizontal tensile test specimen in place for testing.

a) loading heads
b) specimen
c) line placed parallel to head of machine

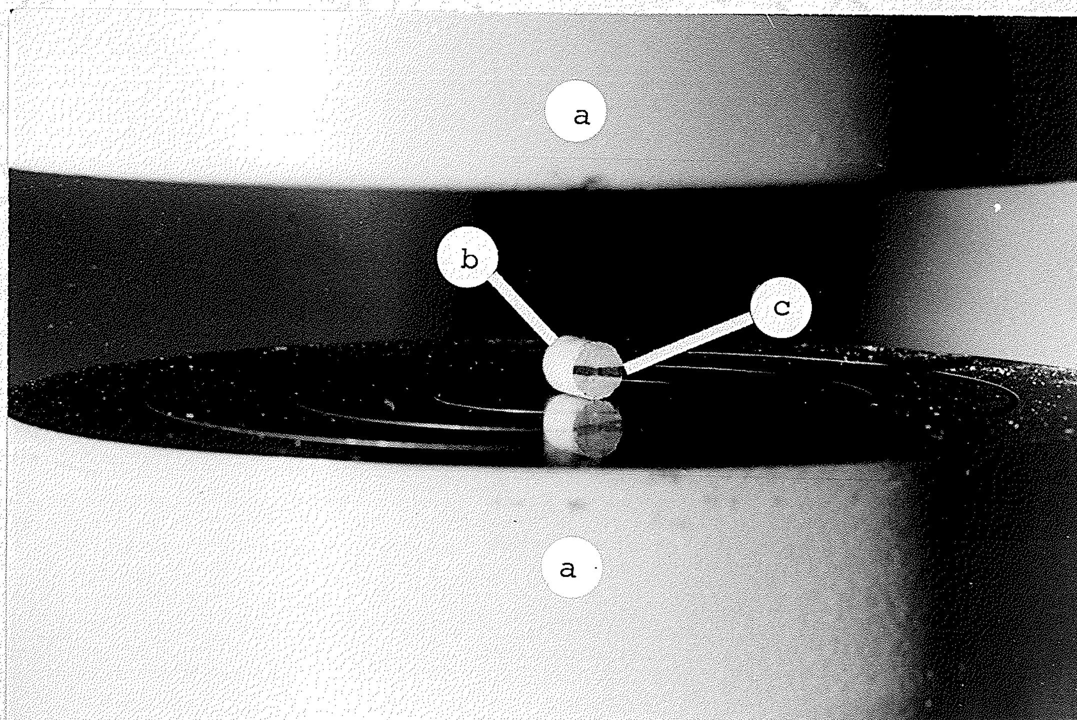

Fig. 21

to 0.608 inches. With the one-pin plunger in position, an amalgam specimen 0.098 inches in length was produced.

Conventional amalgam. With the mould in position on the constant pressure condensing apparatus, a long pin one and one-half inches in length was placed in the hole of the one-pin plunger. This allowed some of the pin to protrude above the top of the mould. A two-pellet mix of conventional silver amalgam was prepared as previously described. Increments, each consisting of two carrier loads of amalgam, were condensed using the 0.043 inch condenser. The number of strokes and the pressure used were the same as described earlier. Two increments of amalgam were sufficient to fill the mould. A single carrier load of amalgam was then condensed using the 0.101 inch condenser and the excess was carved away with a sharp razor blade. Each of the sets, consisting of six specimens, contained one of the three types of pin material. A condensed specimen still in the mould is shown in Figure 22.

Dispersion-strengthened and spherical-particle amalgam specimens were prepared in a like manner except that the first two increments were condensed using a 0.068 inch diameter condenser. A total of fifty-four specimens were prepared for testing.

Twenty-four hours after the completion of condensation, the specimens were placed in a specially designed set of grips

Figure 22. Specimen prepared for testing resistance to withdrawal of pins from amalgam.

a) mould
b) amalgam specimen
c) pin

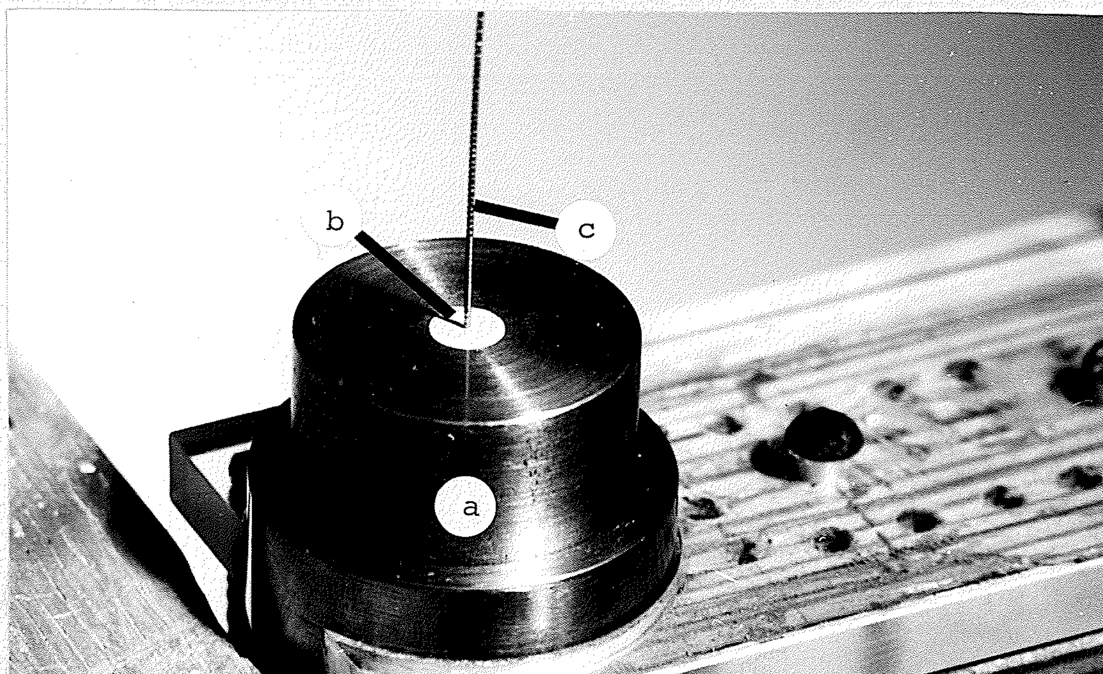

Fig. 22

shown in Figure 23. The protruding wire was first placed in the upper grip and the chuck was tightened. The lower grip was then suspended from the amalgam sample and allowed to find its own plumb. The testing machine was activated at a head speed of 0.022 inches per minute until a maximum strength value was reached. The value for each test was recorded as a tensile load, in pounds.

Throughout the entire investigation, the silver alloy used for each portion of the study was drawn from a single batch of alloy from each manufacturer. Different batches of each type of alloy were used for compressive and tensile testing.

Figure 23. Grips used for pin withdrawal tests with specimen in place.

a) upper grip
b) specimen in place
c) lower grip suspended from specimen

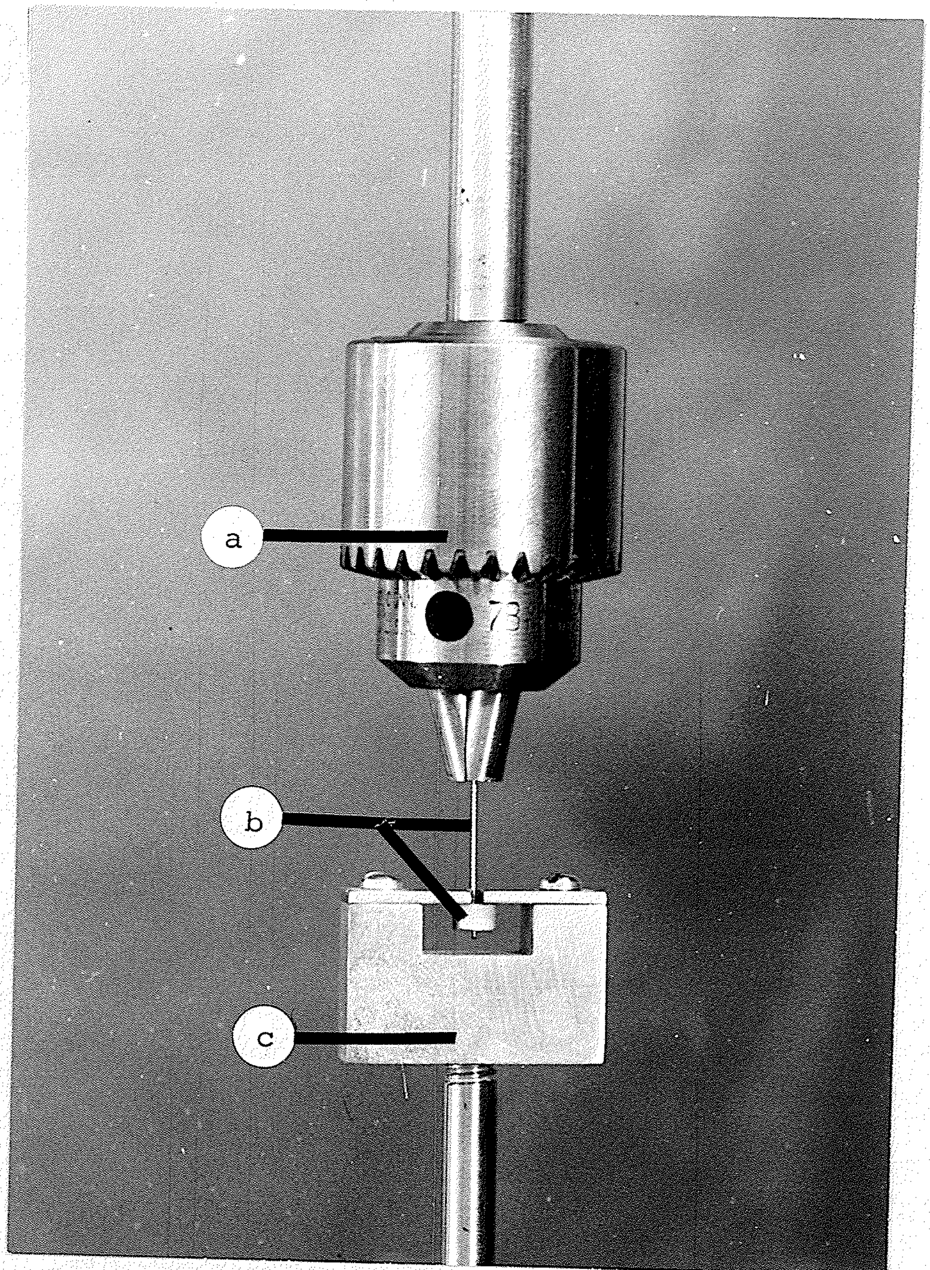

Fig. 23

RESULTS

REACTION BETWEEN PLATED PINS AND AMALGAM

Photomicrographs of serrated and smooth stainless-steel pins, embedded in amalgam, are shown in Figures 24 and 25. A void of considerable magnitude can be seen to exist at the interface of the pin and the amalgam matrix.

An electroplated platinum-gold-palladium pin, embedded in amalgam, is shown in Figure 26. Microscopically, it appears that there is a metallurgical union between the amalgam and the surface plated pin. An electron photomicrograph, shown in Figure 27, reveals the bond achieved between the platinum-gold-palladium pin and the electro-deposited sterling silver, as well as the interface between the sterling silver and the amalgam matrix.

ULTIMATE COMPRESSIVE STRENGTH

The residual mercury concentration of the specimens tested were found to range between 43.6 per cent and 47.8 per cent for all alloys. A covariance analysis, designed for correction of the compressive strength values for the percentage of mercury, produced a pooled regression coefficient of 12.49 $\pm$ 146.2. This revealed an absence of any relationship between compressive strength and residual mercury concentration, within the range of residual mercury concentration in this study. Correction of the compressive strength for mercury content was therefore unwarranted.

Figure 24. Photomicrograph of a serrated stainless steel pin embedded in amalgam (original magnification x 160)

a) serrated stainless steel pin
b) reacted silver amalgam
c) void at interface of pin and amalgam

Figure 25. Photomicrograph of a smooth stainless steel pin embedded in amalgam (original magnification x 160)

a) smooth stainless steel pin
b) reacted silver amalgam
c) void at interface of pin and amalgam

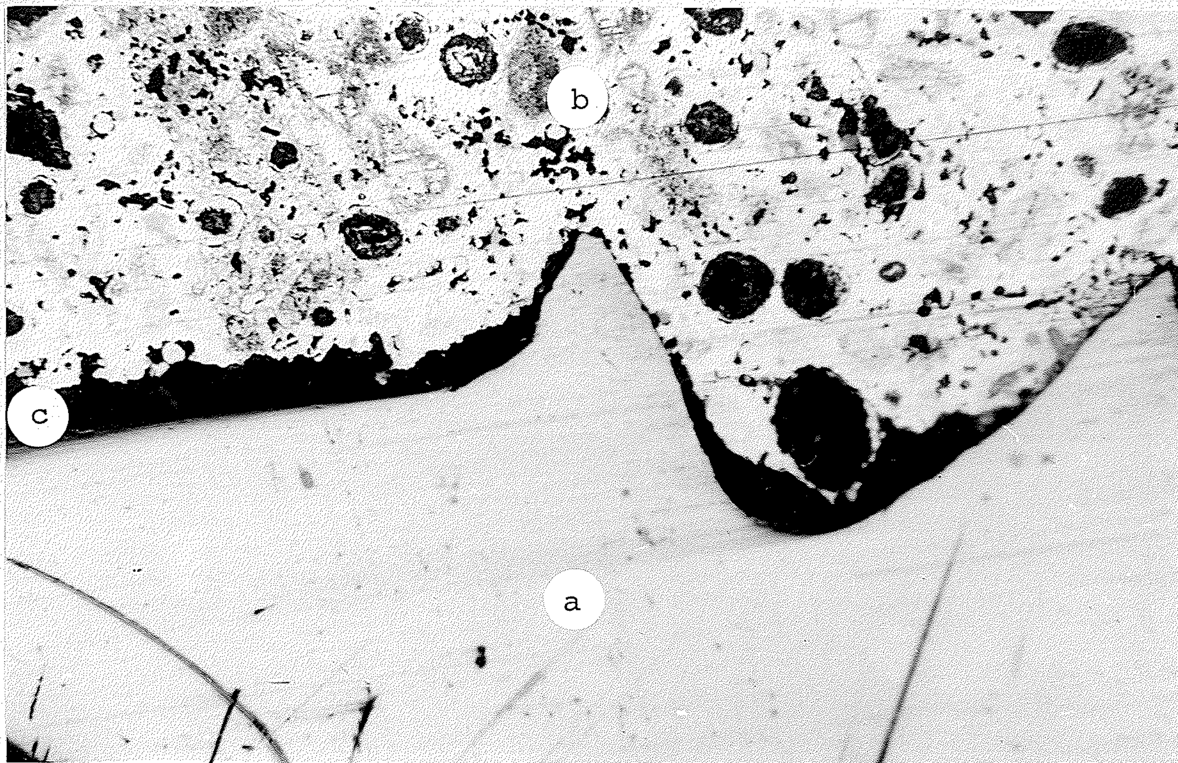

Fig. 24

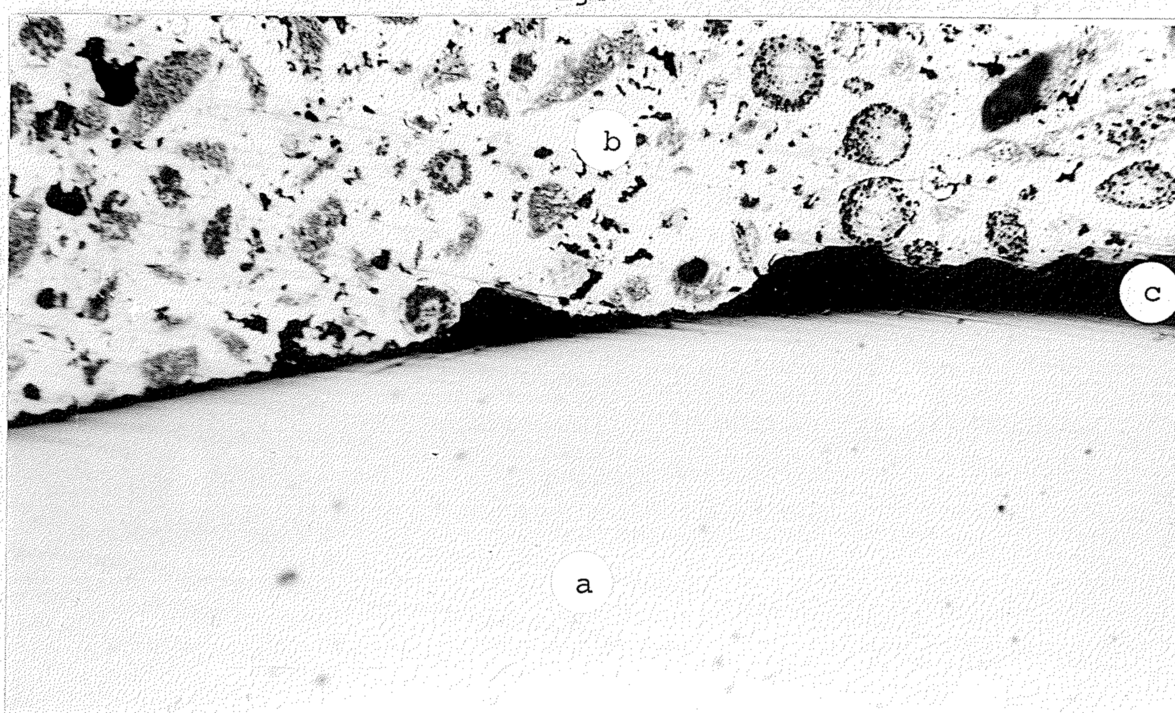

Fig. 25

Figure 26. Photomicrograph of electroplated platinum-gold-palladium pin embedded in amalgam (original magnification x 160)

a) P.G.P. pin
b) electroplated sterling silver
c) reacted silver amalgam

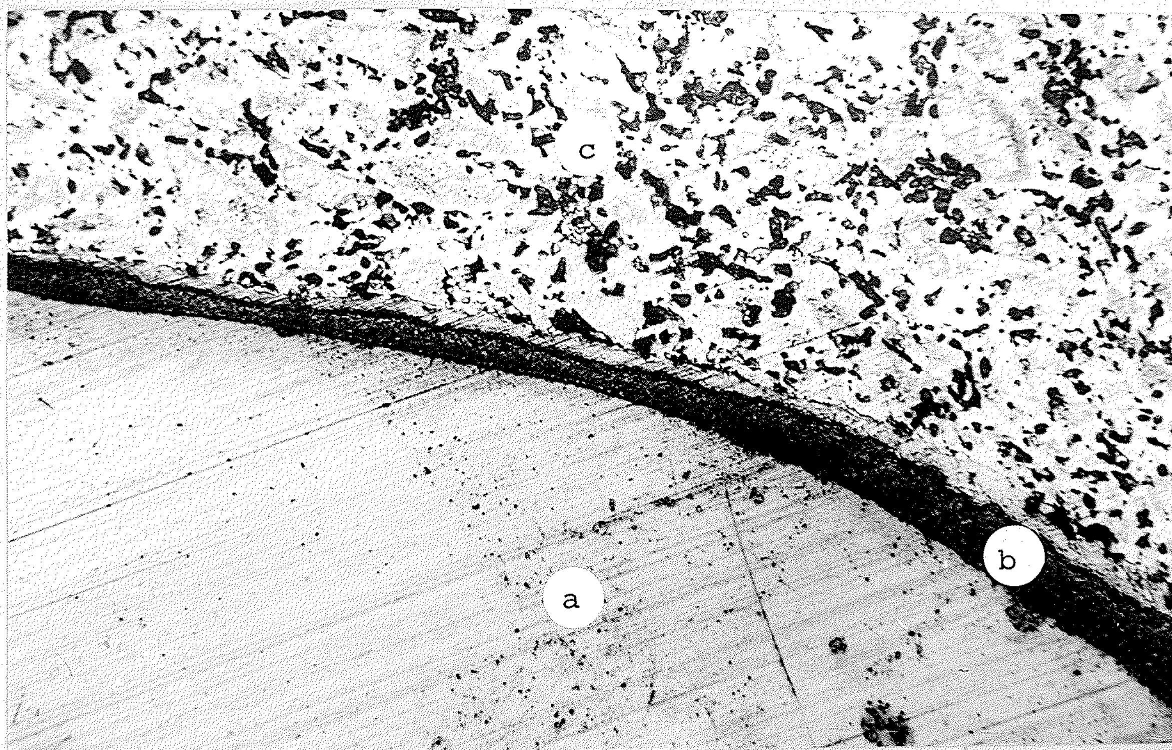

Fig. 26

Figure 27. Electron photomicrograph of electroplated platinum-gold-palladium pin embedded in amalgam (original magnification x 22,000)

a) P.G.P. pin
b) electrodeposited sterling silver--pin interface
c) sterling silver - amalgam interface

Fig. 27

The mean values for all combinations of pins and alloys, tested at one hour, are shown in Table II. The mean values for all combination of pins, irrespective of alloy are shown in the last column.

Analysis of the results was obtained by utilizing an analysis of variance, followed by a Duncan's Multiple Range Test.

A bar graph, shown in Figure 28, illustrates the effect of the three pin materials on the one-hour compressive strength of amalgam, irrespective of alloy type. The statistical analysis of the values in the bar graph is shown in Table III.

The influence of pins on the one-hour compressive strength of conventional, dispersion phase and spherical particle alloy is illustrated graphically in Figures 29 to 31 respectively. The corresponding statistical analysis are shown in Tables IV to VI.

A similar analysis was conducted on the values obtained from tests on twenty-four hour specimens. Similar graphs and tables are illustrated in Figures 32 to 35 and Tables VII to XI.

Decreased compressive strength values were observed when results of specimens containing all types and number of pins were compared to the results of control specimens. Increasing the number of pins in the specimens caused a corresponding decrease in the compressive strength, except with the use of serrated stainless-steel pins. In this instance, specimens containing one or two serrated stainless-steel pins showed a trend similar to those containing smooth stainless-steel and plated platinum-gold-palladium pins. Specimens containing four serrated stainless-steel pins, however, demonstrated a significant increase in strength when compared to the two-pin specimens, except in the case of the dispersion phase alloy shown in Figure 34.

TABLE II

THE EFFECT OF VARIOUS PIN MATERIALS ON THE ONE HOUR COMPRESSIVE STRENGTH OF THREE DENTAL AMALGAMS

PIN	ULTIMATE COMPRESSIVE STRENGTH (P.S.I. x 1000)			
	ALLOY			
Type and No.	Conventional	Dispersion	Spherical	Mean
Control (no pin)	19.07	21.64	23.20	21.24
1 SS	18.70	20.68	23.32	20.90
1 P	18.27	20.91	22.16	20.45
1 SSS	18.32	22.23	22.41	20.99
2 SS	18.25	18.41	20.54	19.07
2 P	16.95	19.95	21.95	19.62
2 SSS	18.06	19.50	21.40	19.65
4 SS	19.40	20.25	21.26	20.31
4 P	16.64	19.41	20.11	18.82
4 SSS	17.65	18.97	20.07	18.96

SS - Serrated Stainless Steel
P - Smooth Plated P.G.P.
SSS - Smooth Stainless Steel

Figure 28. The effect of pins on the one hour compressive strength of amalgam, irrespective of alloy type

TABLE III. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 28

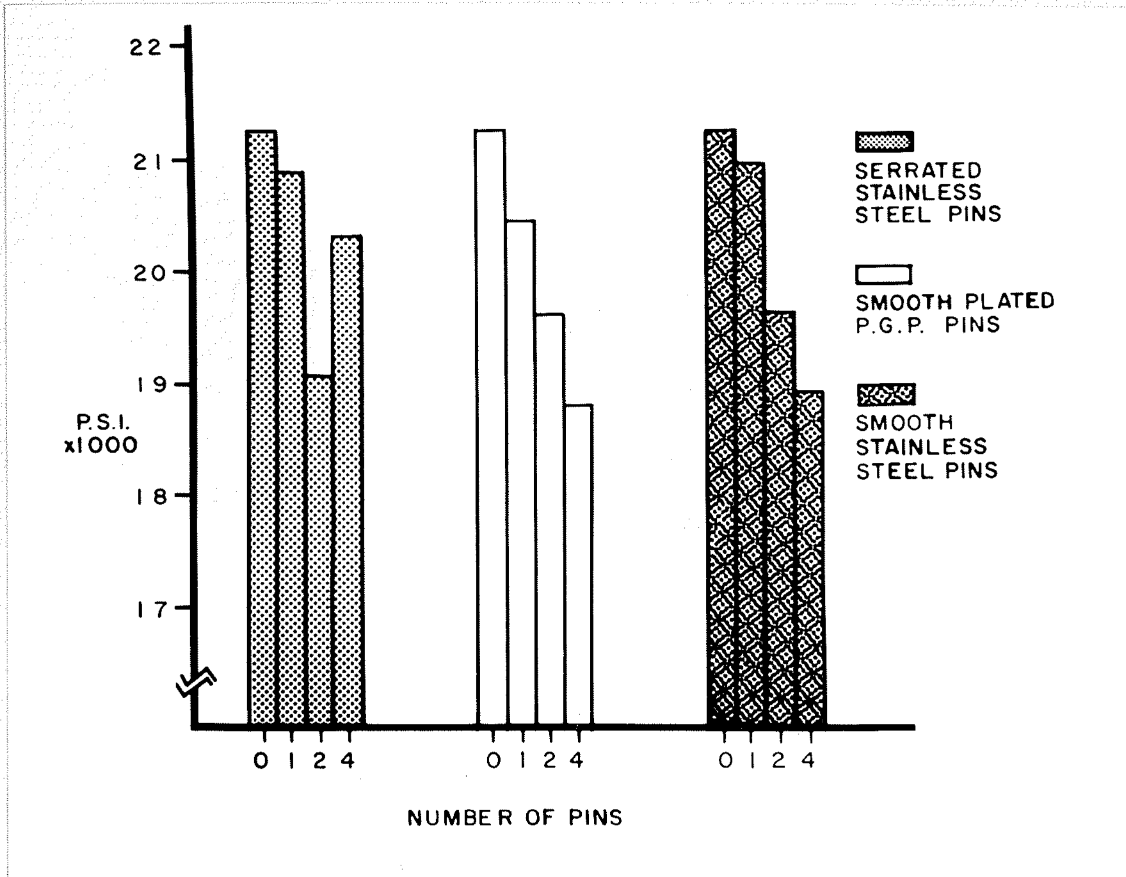

Fig. 28

TABLE III

1SSS	1-SS	1-P	4-SS	2SSS	2-P	2-SS	4SSS	4-P	
NS	NS	**	**	**	**	**	**	**	NOPN
	NS	NS	*	**	**	**	**	**	1SSS
		NS	*	**	**	**	**	**	1-SS
			NS	**	**	**	**	**	1-P
				*	*	**	**	**	4-SS
					NS	*	*	**	2SSS
						*	*	**	2-P
							NS	NS	2-SS
								NS	4SSS

SS - Serrated Stainless Steel

SSS - Smooth Stainless Steel

P - Plated

NOPN- Control (no pin)

* - P < .05

** - P < .01

Figure 29. The effect of pins on the one hour compressive strength of amalgam made using conventional alloy

TABLE IV. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 29

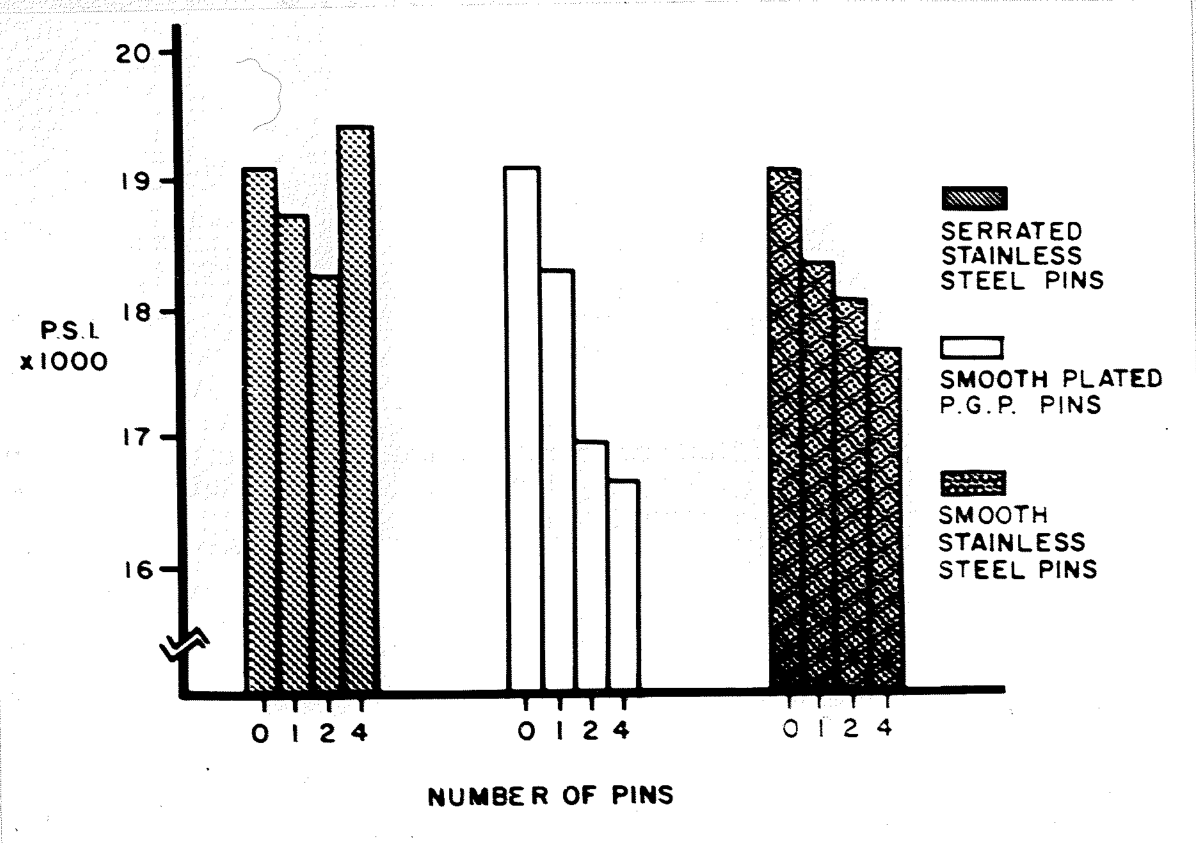

Fig. 29

TABLE IV

NOPN	1-SS	1SSS	1-P	2-SS	2SSS	4SSS	2-P	4-P	
NS	NS	*	*	*	*	**	**	**	4-SS
	NS	NS	NS	NS	*	**	**	**	NOPN
		NS	NS	NS	NS	NS	**	**	1-SS
			NS	NS	NS	NS	**	**	1SSS
				NS	NS	NS	**	**	1-P
					NS	NS	**	**	2-SS
						NS	*	**	2SSS
							NS	*	4SSS
								NS	2-P

SS - Serrated Stainless Steel
SSS- Smooth Stainless Steel
P - Plated
NOPN- Control (no pin)
* - P <.05
** - P <.01

Figure 30. The effect of pins on the one hour compressive strength of amalgam made using dispersion strengthened alloy

TABLE V. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 30

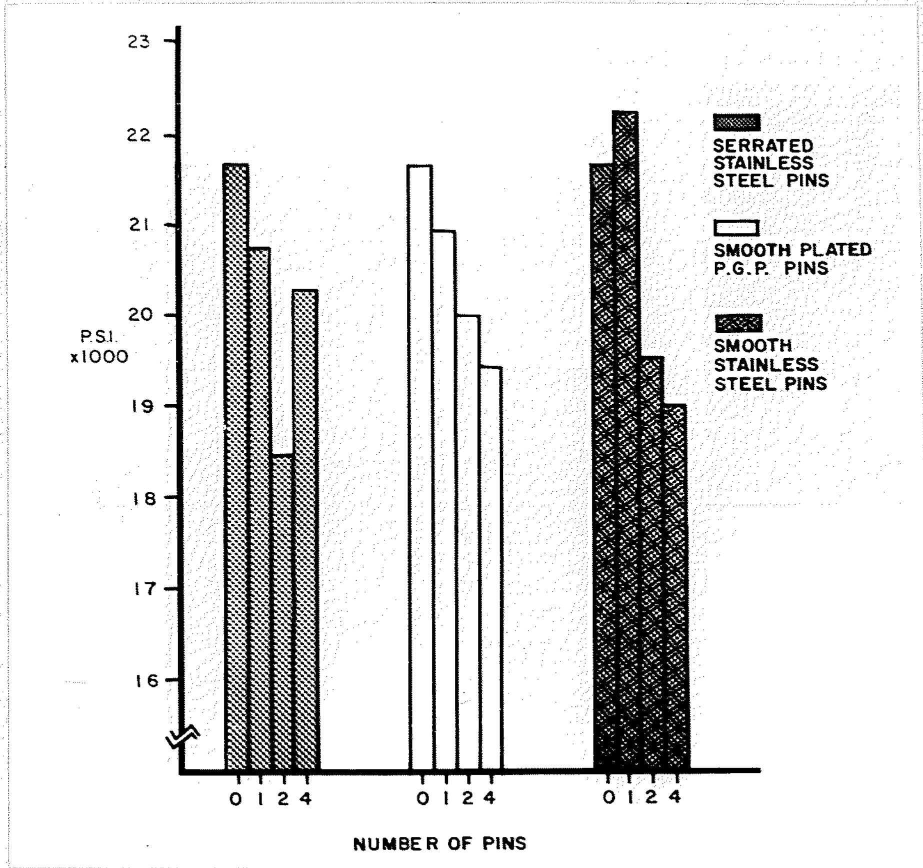

Fig. 30

TABLE V

NOPN	1-P	1-SS	4-SS	2-P	2SSS	4-P	4SSS	2-SS	
NS	**	**	**	**	**	**	**	**	1SSS
	NS	NS	**	**	**	**	**	**	NOPN
		NS	NS	NS	**	**	**	**	1-P
			NS	NS	*	*	**	**	1-SS
				NS	NS	NS	*	**	4-SS
					NS	NS	NS	**	2-P
						NS	NS	*	2SSS
							NS	*	4-P
								NS	4SSS

SS- Serrated Stainless Steel

SSS- Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - P <.05

** - P <.01

Figure 31. The effect of pins on the one hour compressive strength of amalgam made using spherical particle alloy

TABLE VI. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 31

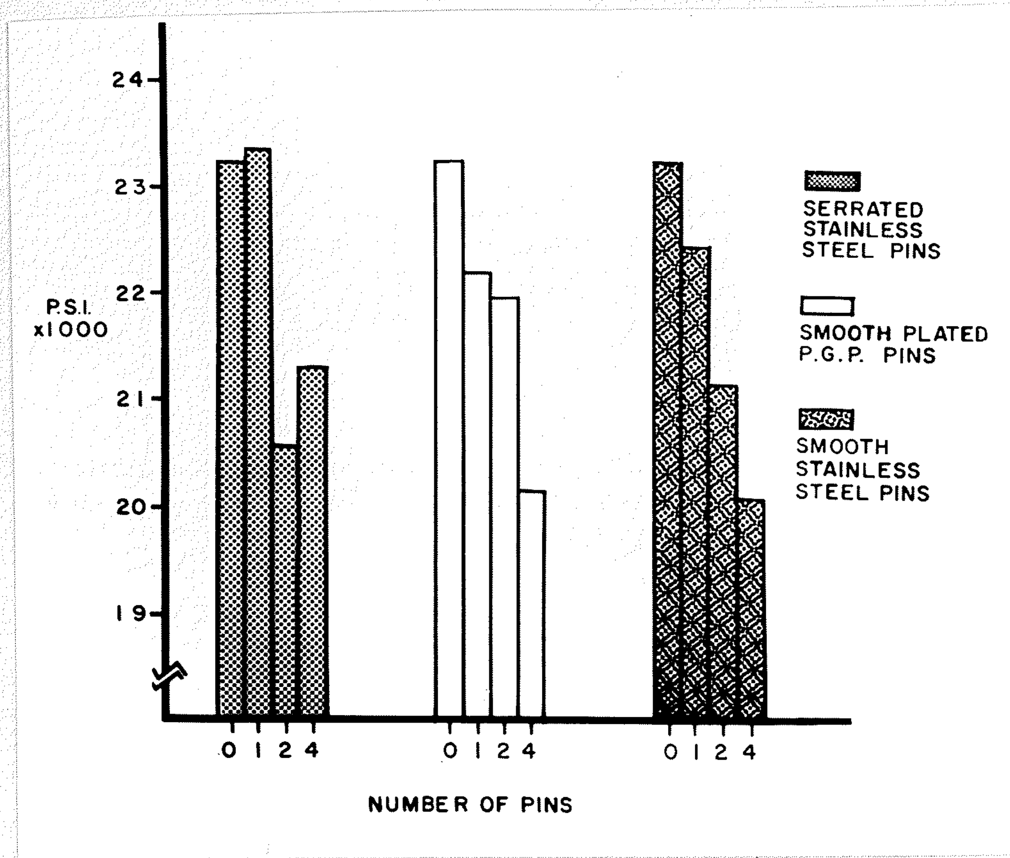

Fig. 31

TABLE VI

NOPN	1SSS	1-P	2-P	2SSS	4-SS	2-SS	4-P	4SSS	
NS	NS	*	**	**	**	**	**	**	1-SS
	NS	*	**	**	**	**	**	**	NOPN
		NS	NS	NS	*	**	**	**	1SSS
			NS	NS	NS	**	**	**	1-P
				NS	NS	**	**	**	2-P
					NS	NS	**	**	2SSS
						NS	*	*	4-SS
							NS	NS	2-SS
								NS	4-P

SS - Serrated Stainless Steel

SSS- Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - P <.05

** - P <.01

TABLE VII

THE EFFECT OF VARIOUS PIN MATERIALS ON THE TWENTY-FOUR HOUR COMPRESSIVE STRENGTH OF THREE DENTAL AMALGAMS

PIN	ULTIMATE COMPRESSIVE STRENGTH (P.S.I. x 1000) ALLOY			
Type and No.	Conventional	Dispersion	Spherical	Mean
Control (no pin)	55.63	62.01	56.53	57.27
1 SS	52.71	59.12	53.92	55.25
1 P	50.35	57.52	52.88	53.55
1 SSS	52.95	62.47	55.60	57.01
2 SS	48.63	54.13	51.81	51.51
2 P	51.53	55.98	53.65	53.73
2 SSS	51.51	58.52	53.87	54.63
4 SS	51.83	52.88	54.64	53.12
4 P	50.46	48.55	51.21	50.07
4 SSS	49.08	53.87	51.87	51.61

SS - Serrated Stainless Steel
P - Smooth Plated P.G.P.
SSS - Smooth Stainless Steel

Figure 32. The effect of pins on the twenty-four hour compressive strength of amalgam, irrespective of alloy type

TABLE VIII. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 32

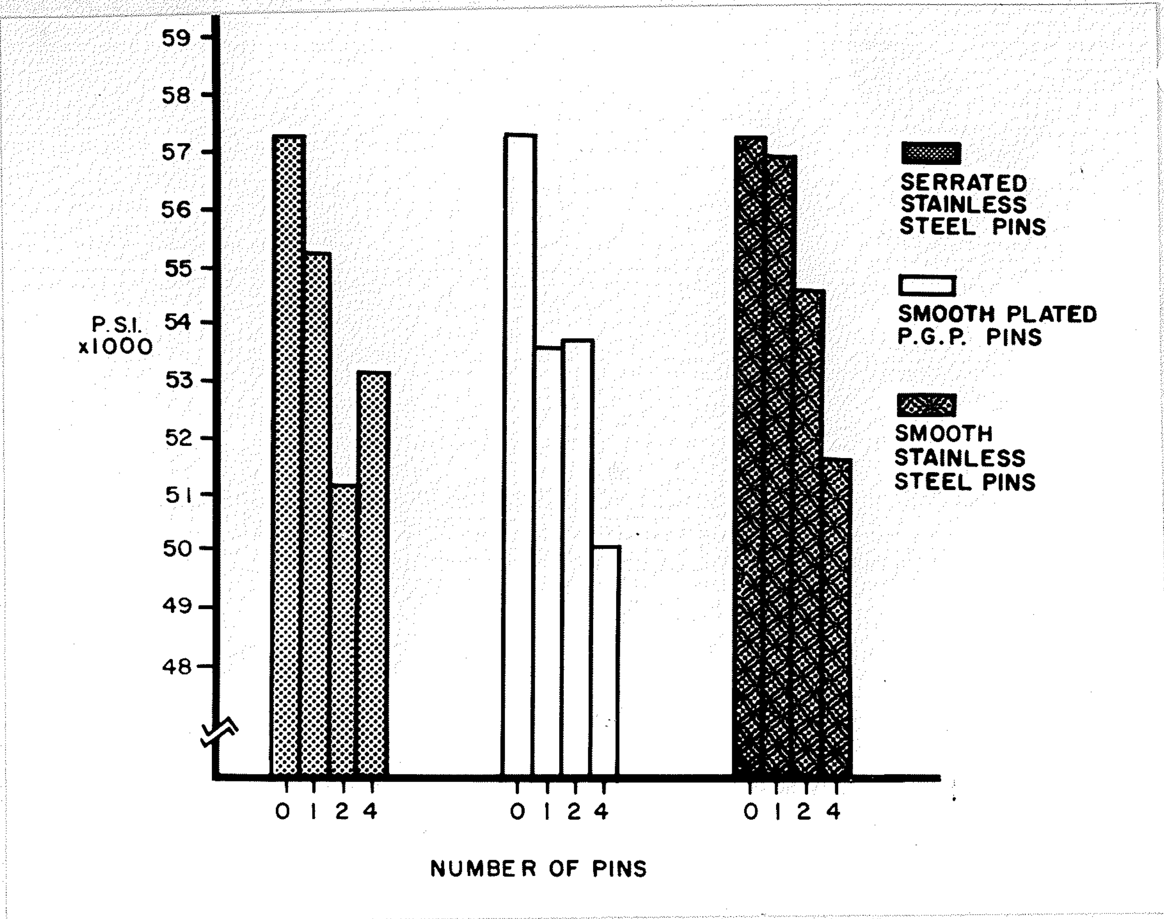

Fig. 32

TABLE VIII

1SSS	1-SS	2SSS	2-P	1-P	4-SS	4SSS	2-SS	4-P	
NS	**	**	**	**	**	**	**	**	NOPN
	**	**	**	**	**	**	**	**	1SSS
		NS	**	**	**	**	**	**	1-SS
			NS	*	**	**	**	**	2SSS
				NS	NS	**	**	**	2-P
					NS	**	**	**	1-P
						**	**	**	4-SS
							NS	**	4SSS
								**	2-SS

SS - Serrated Stainless Steel

SSS- Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - P <.05

** - P <.01

Figure 33. The effect of pins on the twenty-four hour compressive strength of amalgam made using conventional alloy

TABLE IX. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 33

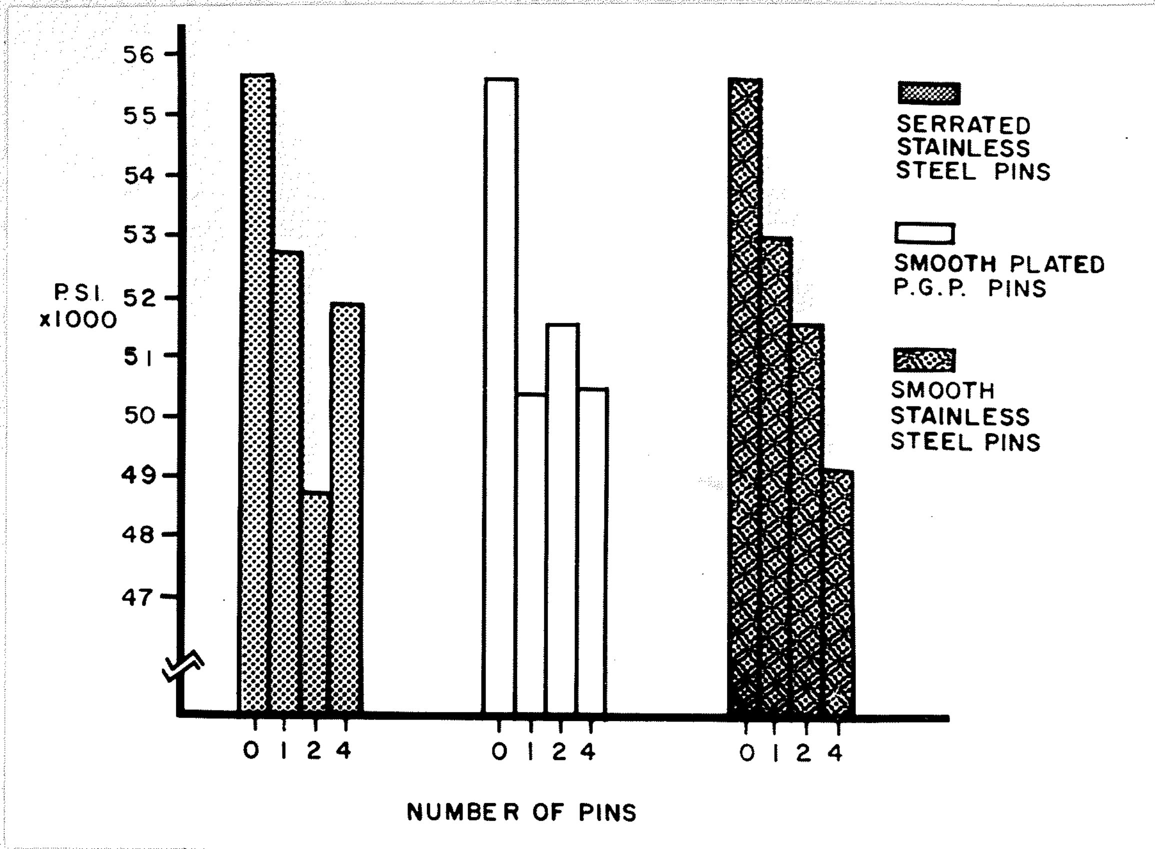

Fig. 33

TABLE IX

1SSS	1-SS	4-SS	2-P	2SSS	4-P	1-P	4SSS	2-SS	
**	**	**	**	**	**	**	**	**	NOPN
	NS	NS	NS	NS	*	*	**	**	1SSS
		NS	NS	NS	*	*	**	**	1-SS
			NS	NS	NS	NS	**	**	4-SS
				NS	NS	NS	*	**	2-P
					NS	NS	*	**	2SSS
						NS	NS	*	4-P
							NS	NS	1-P
								NS	4SSS

SS - Serrated Stainless Steel

SSS- Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - P <.05

** - P <.01

Figure 34. The effect of pins on the twenty-four hour compressive strength of amalgam made using dispersion strengthened alloy

TABLE X. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 34

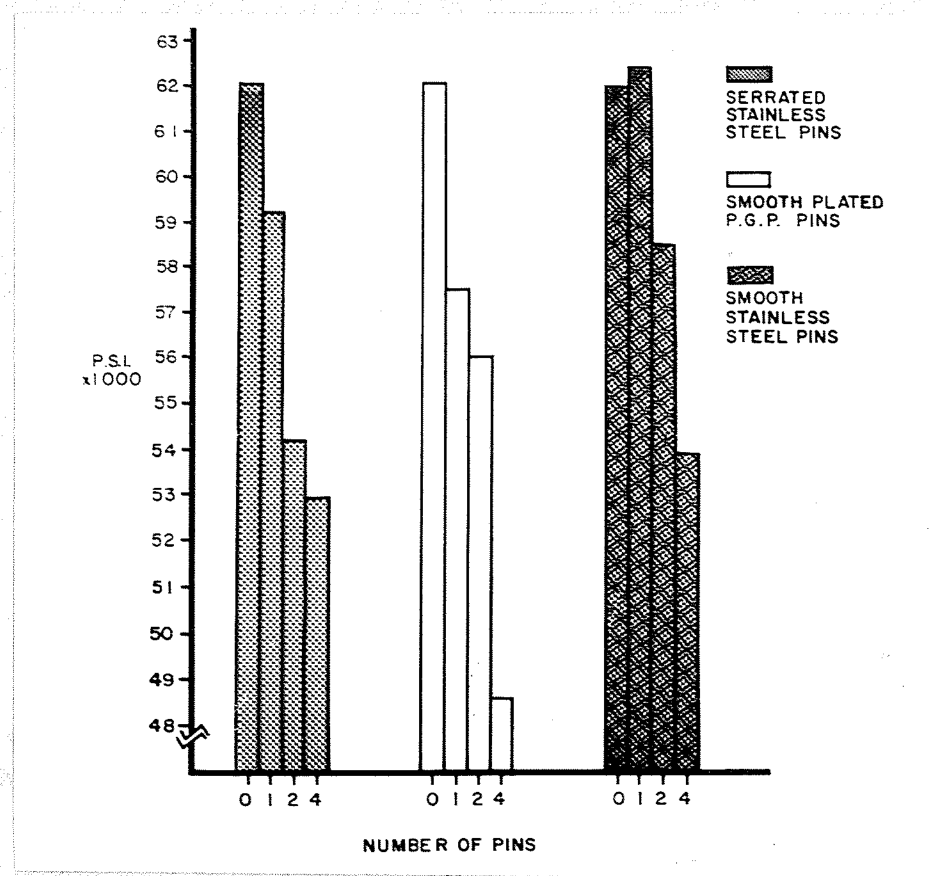

Fig. 34

TABLE X

NOPN	1-SS	2SSS	1-P	2-P	2-SS	4SSS	4-SS	4-P	
NS	**	**	**	**	**	**	**	**	1SSS
	**	**	**	**	**	**	**	**	NOPN
		NS	NS	**	**	**	**	**	1-SS
			NS	**	**	**	**	**	2SSS
				NS	**	**	**	**	1-P
					*	*	**	**	2-P
						NS	NS	**	2-SS
							NS	**	4SSS
								**	4-SS

SS - Serrated Stainless Steel

SSS-Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - P <.05

** - P <.01

Figure 35. The effect of pins on the twenty-four hour compressive strength of amalgam made using spherical particle alloy

TABLE XI. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 35

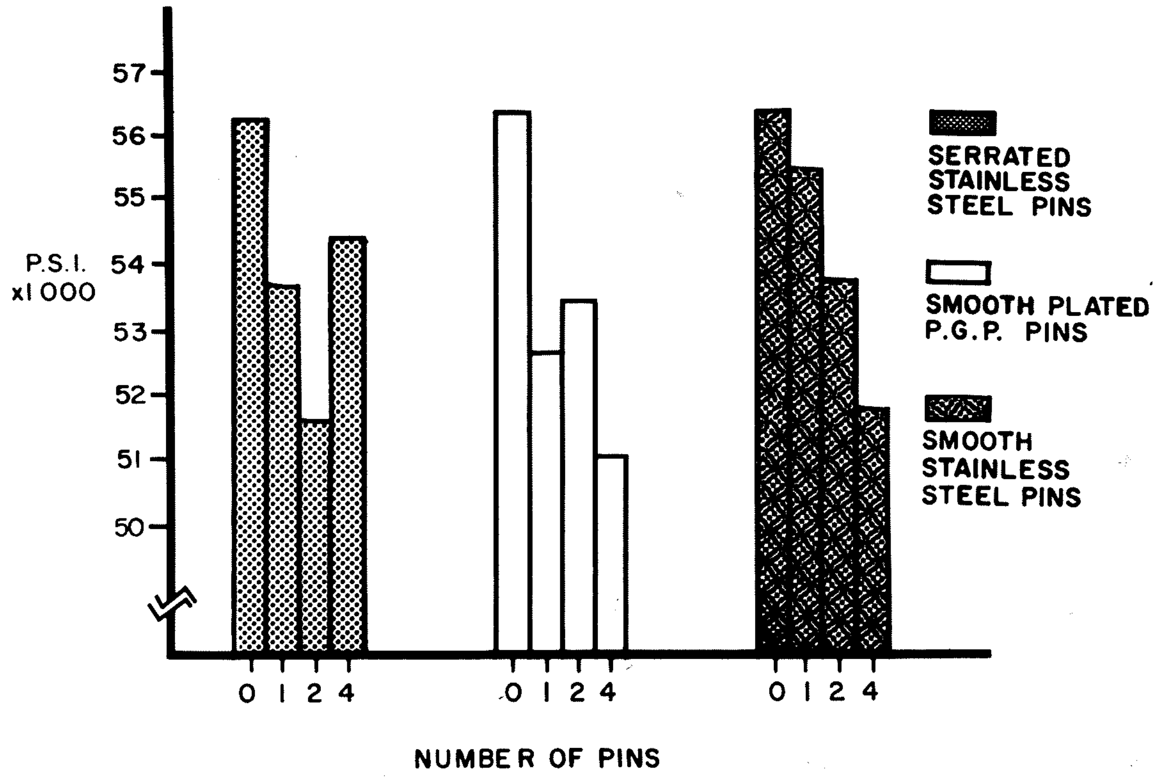

Fig. 35

TABLE XI

1SSS	4-SS	1-SS	2SSS	2-P	1-P	4SSS	2-SS	4-P	
NS	*	**	**	**	**	**	**	**	NOPN
	NS	NS	NS	NS	**	**	**	**	1SSS
		NS	NS	NS	NS	**	**	**	4-SS
			NS	NS	NS	*	*	**	1-SS
				NS	NS	*	*	**	2SSS
					NS	NS	NS	*	2-P
						NS	NS	NS	1-P
							NS	NS	4SSS
								NS	2-SS

SS - Serrated Stainless Steel
SSS- Smooth Stainless Steel
P - Plated
NOPN - Control (no pin)
* - P <.05
** - P <.01

ULTIMATE TENSILE STRENGTH

PINS POSTITIONED PERPENDICULAR TO THE TENSILE FORCE

The mercury content of the specimens tested ranged from 43.85 per cent to 47.50 per cent by weight. A covariance analysis was undertaken as described previously. The pooled regression coefficient was 17.69 $\pm$ 122.85. Again this indicated an absence of a relationship between tensile strength and residual mercury concentration, within the range studied.

The mean values for all combinations of pins and alloys, tested at one hour, are shown in Table XII. Statistical analysis of the results was accomplished as described previously.

The effect of the three pin materials on the tensile strength of amalgam, irrespective of alloy type, has been illustrated by means of the bar graph in Figure 36. The corresponding Duncan's analysis is shown in Table XIII.

The effect of pins on the tensile strength of conventional, dispersion phase and spherical particle amalgam have been graphically illustrated in Figures 37 to 39 respectively. The corresponding Duncan's multiple range tests are shown in Tables XIV to XVI.

A similar analysis was conducted on the values obtained from tests on twenty-four hour specimens. Similar graphs and tables are illustrated in Figures 40 to 43, and Tables XVII.

A decrease in tensile strength was evident when the results of specimens containing one pin were compared to those of control specimens, irrespective of the type of pin employed. The specimens containing two pins demonstrated ultimate tensile strengths correspondingly lower than did the specimens containing one pin. Of the three types of pins tested, the smooth stainless-steel pins resulted in the greatest decrease in tensile strength, and the plated platinum-gold-palladium pins demonstrated the least decrease in strength.

At one hour test time, as illustrated in Figure 36, the overall effect of the plated pins as compared to the stainless-steel pins was most notable when the results of specimens containing two pins were considered. Twenty-four hour test results demonstrated the greatest difference when specimens containing one pin were compared, as shown in Figure 40.

TABLE XII

THE EFFECT OF VARIOUS PIN MATERIALS ON THE ONE HOUR TENSILE STRENGTH OF THREE DENTAL AMALGAMS. (PINS PLACED PERPENDICULAR TO THE TENSILE FORCE)

PIN	ULTIMATE TENSILE STRENGTH (P.S.I. x 100) ALLOY			
Type and No.	Conventional	Dispersion	Spherical	Mean
Control (No Pin)	19.64	21.44	26.13	22.40
1 SS	16.91	19.83	21.53	19.42
1 P	17.31	21.37	23.10	20.60
1 SSS	16.71	13.56	19.79	16.68
2 SS	13.24	15.23	21.24	16.57
2 P	16.48	18.34	22.77	19.20
2 SSS	17.76	16.27	15.62	16.55

SS - Serrated Stainless Steel
P - Smooth Plated P.G.P.
SSS - Smooth Stainless Steel

Figure 36. The effect of pins on the one hour tensile strength of amalgam irrespective of alloy type. (Pins placed perpendicular to the tensile force)

TABLE XIII. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 36

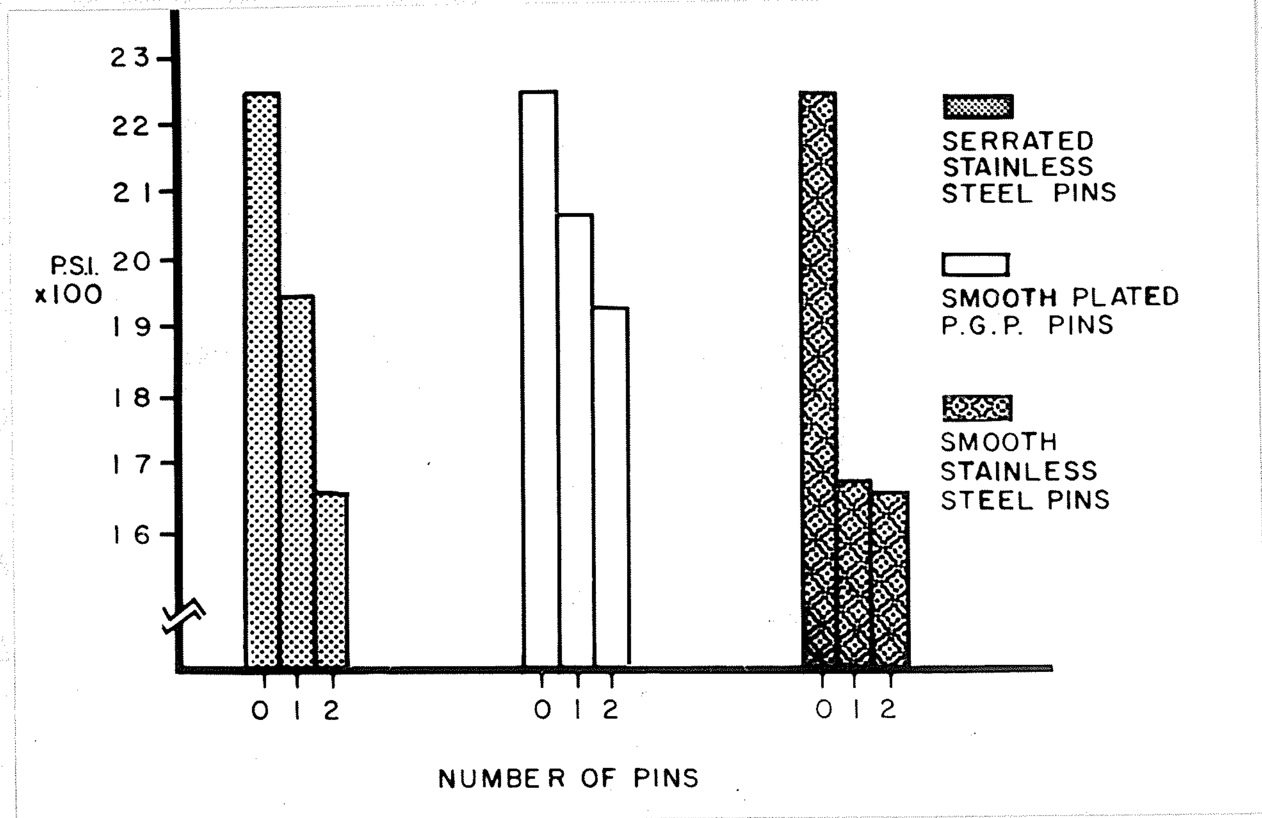

Fig. 36

TABLE XIII

	1-P	1-SS	2-P	1SSS	2-SS	2SSS
NOPN	*	**	**	**	**	**
1-P		NS	NS	**	**	**
1-SS			NS	**	**	**
2-P				**	**	**
1SSS					NS	NS
2-SS						NS

SS - Serrated Stainless Steel

SSS- Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - P <.05

** - P <.01

Figure 37. The effect of pins on the one hour tensile strength of amalgam made using conventional alloy. (Pins placed perpendicular to the tensile force)

TABLE XIV. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 37

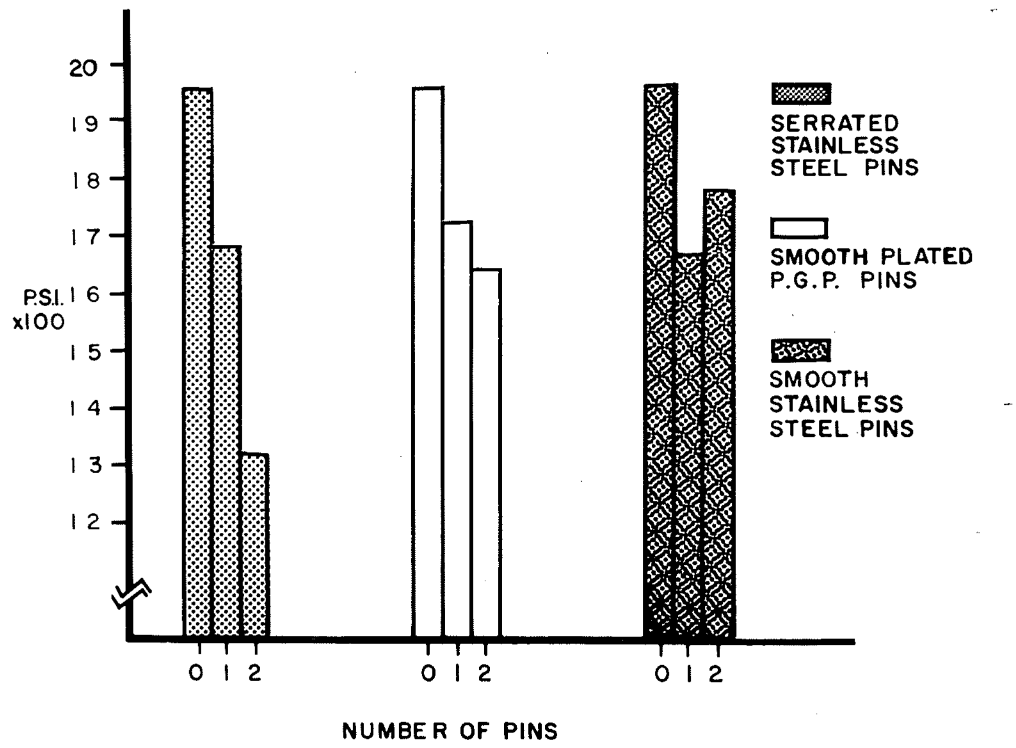

Fig. 37

TABLE XIV

	2SSS	1-P	1-SS	1SSS	2-P	2-SS
NOPN	NS	NS	NS	*	*	**
2SSS		NS	NS	NS	NS	**
1-P			NS	NS	NS	**
1-SS				NS	NS	*
1SSS					NS	*
2-P						*

SS - Serrated Stainless Steel

SSS- Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - $P < .05$

** - $P < .01$

Figure 38. The effect of pins on the one hour tensile strength of amalgam made using dispersion strengthened alloy. (Pins placed perpendicular to the tensile force)

TABLE XV. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 38

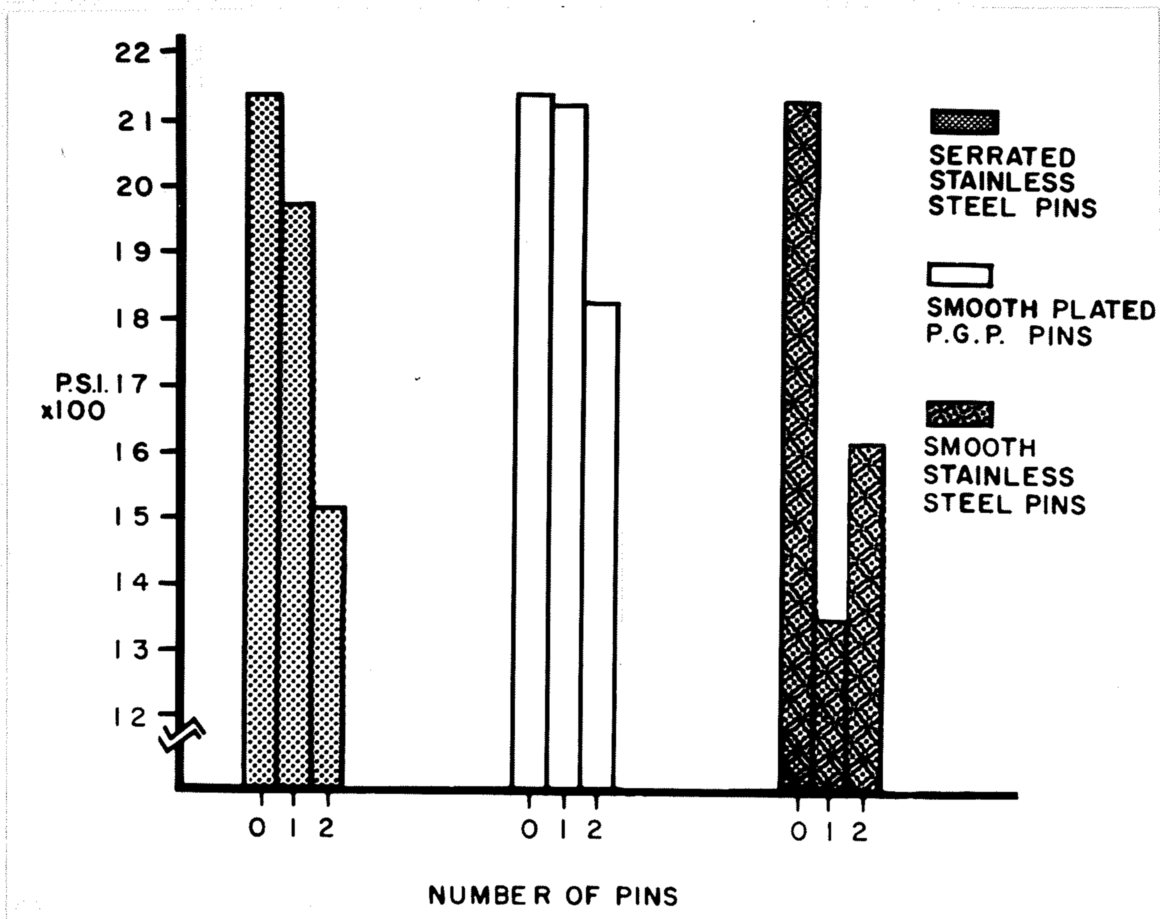

Fig. 38

TABLE XV

1-P	1-SS	2-P	2SSS	2-SS	1SSS	
NS	NS	*	**	**	**	NOPN
	NS	*	**	**	**	1-P
		NS	*	**	**	1-SS
			NS	*	**	2-P
				NS	NS	2SSS
					NS	2-SS

SS - Serrated Stainless Steel

SSS- Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - P <.05

** - P <.01

Figure 39. The effect of pins on the one hour tensile strength of amalgam made using spherical particle alloy. (Pins placed perpendicular to the tensile force)

TABLE XVI. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 39

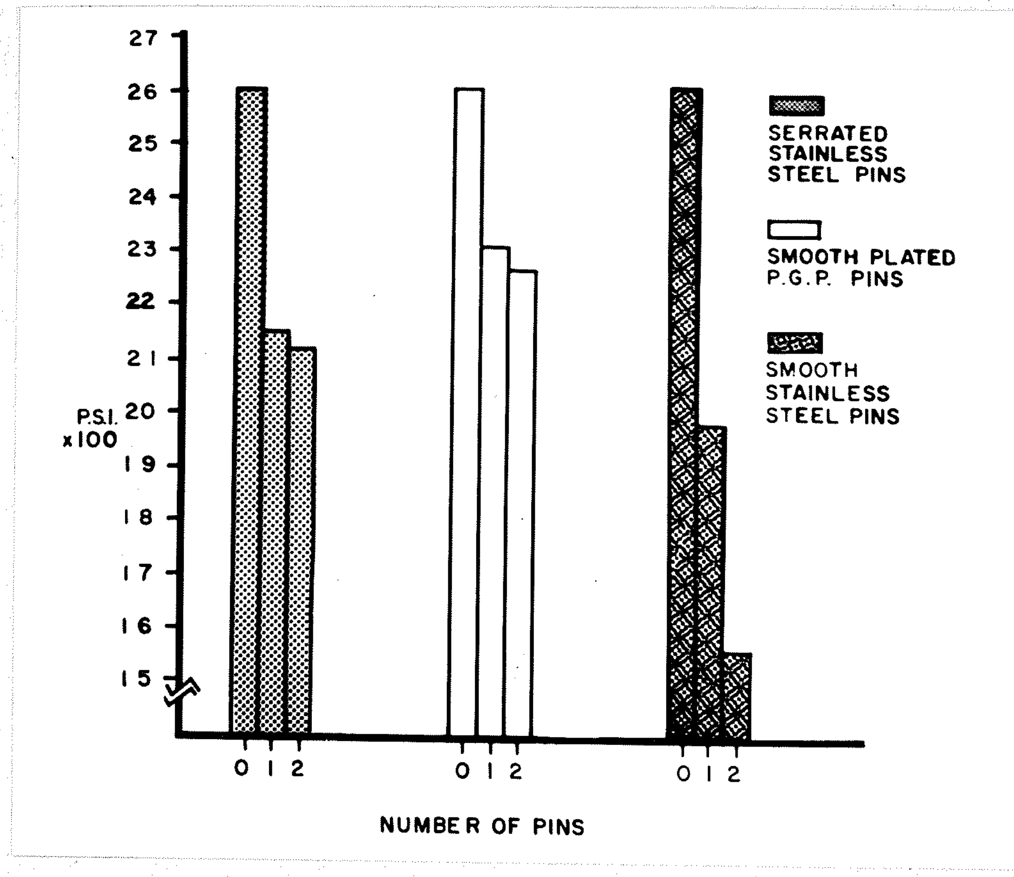

Fig. 39

TABLE XVI

1-P	2-P	1-SS	2-SS	1SSS	2SSS	
*	*	**	**	**	**	NOPN
	NS	NS	NS	*	**	1-P
		NS	NS	*	**	2-P
			NS	NS	**	1-SS
				NS	**	2-SS
					**	1SSS

SS - Serrated Stainless Steel

SSS- Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - P <.05

** - P <.01

TABLE XVII

THE EFFECT OF VARIOUS PIN MATERIALS ON THE TWENTY-FOUR HOUR TENSILE STRENGTH OF THREE DENTAL AMALGAMS. (PINS PLACED PERPENDICULAR TO THE TENSILE FORCE)

PIN	ULTIMATE TENSILE STRENGTH (P.S.I. x 100) ALLOY			
Type and No.	Conventional	Dispersion	Spherical	Mean
Control	86.68	59.54	72.33	72.85
1 SS	65.30	60.97	55.03	60.43
1 P	72.40	68.03	68.34	69.59
1 SSS	58.11	37.61	58.73	51.49
2 SS	50.42	42.50	55.03	47.54
2 P	55.31	41.07	56.51	50.97
2 SSS	36.71	36.18	38.45	37.12

SS - Serrated Stainless Steel

P - Smooth Plated P.G.P.

SSS - Smooth Stainless Steel

Figure 40. The effect of pins on the twenty-four hour tensile strength of amalgam irrespective of alloy type. (Pins placed perpendicular to the tensile force)

TABLE XVIII. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 40

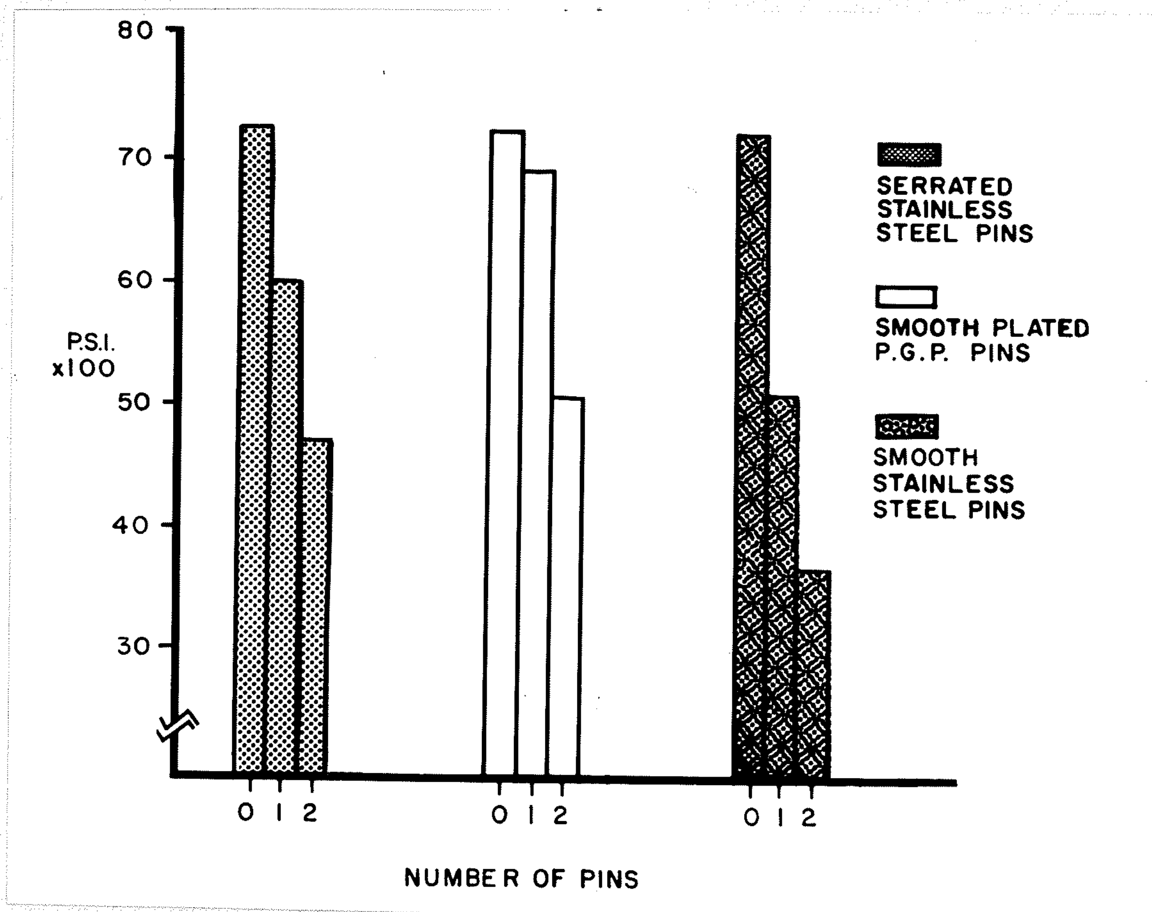

Fig. 40

TABLE XVIII

1-P	1-SS	1SSS	2-P	2-SS	2SSS	
NS	**	**	**	**	**	NOPN
	**	**	**	**	**	1-P
		**	**	**	**	1-SS
			NS	NS	**	1SSS
				NS	**	2-P
					**	2-SS

SS - Serrated Stainless Steel

SSS- Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - P <.05

** - P <.01

Figure 41. The effect of pins on the twenty-four hour tensile strength of amalgam made using conventional alloy. (Pin placed perpendicular to the tensile force)

TABLE XIX. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 41

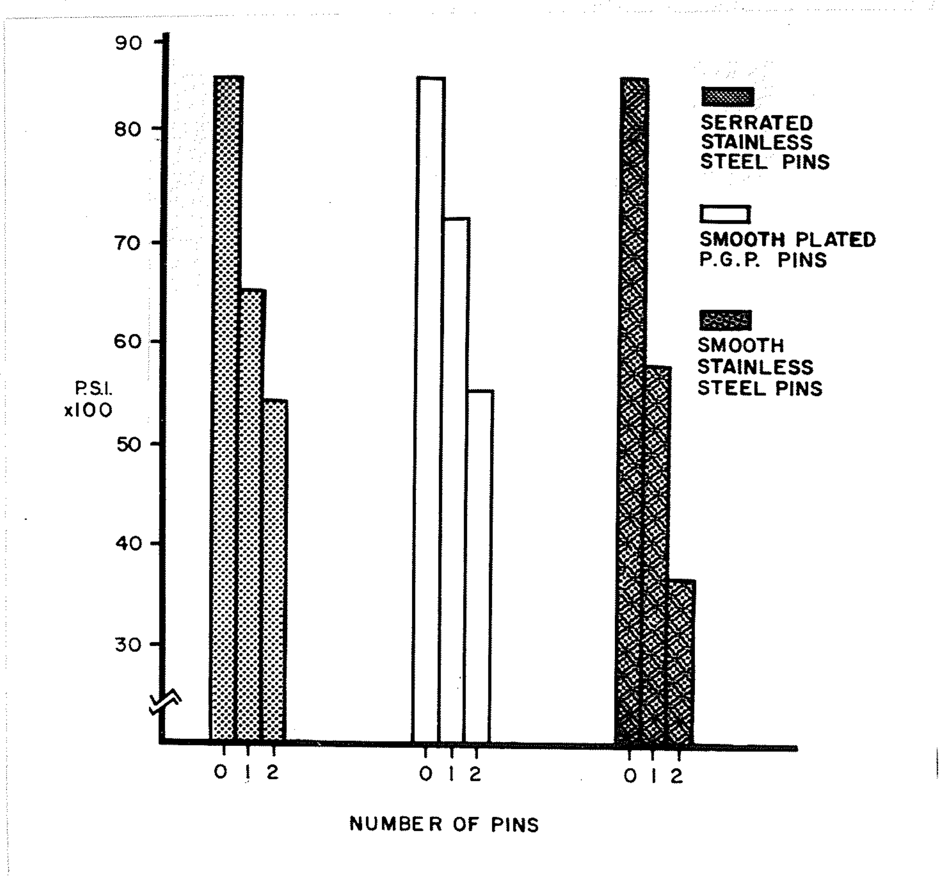

Fig. 41

TABLE XIX

	1-P	1-SS	1SSS	2-P	2-SS	2SSS
NOPN	**	**	**	**	**	**
1-P		NS	**	**	**	**
1-SS			NS	*	**	**
1SSS				NS	NS	**
2-P					NS	**
2-SS						**

SS - Serrated Stainless Steel

SSS- Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - P <.05

** - P <.01

Figure 42. The effect of pins on the twenty-four hour tensile strength of amalgam made using dispersion strengthened alloy. (Pins placed perpendicular to the tensile force)

TABLE XX. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 42

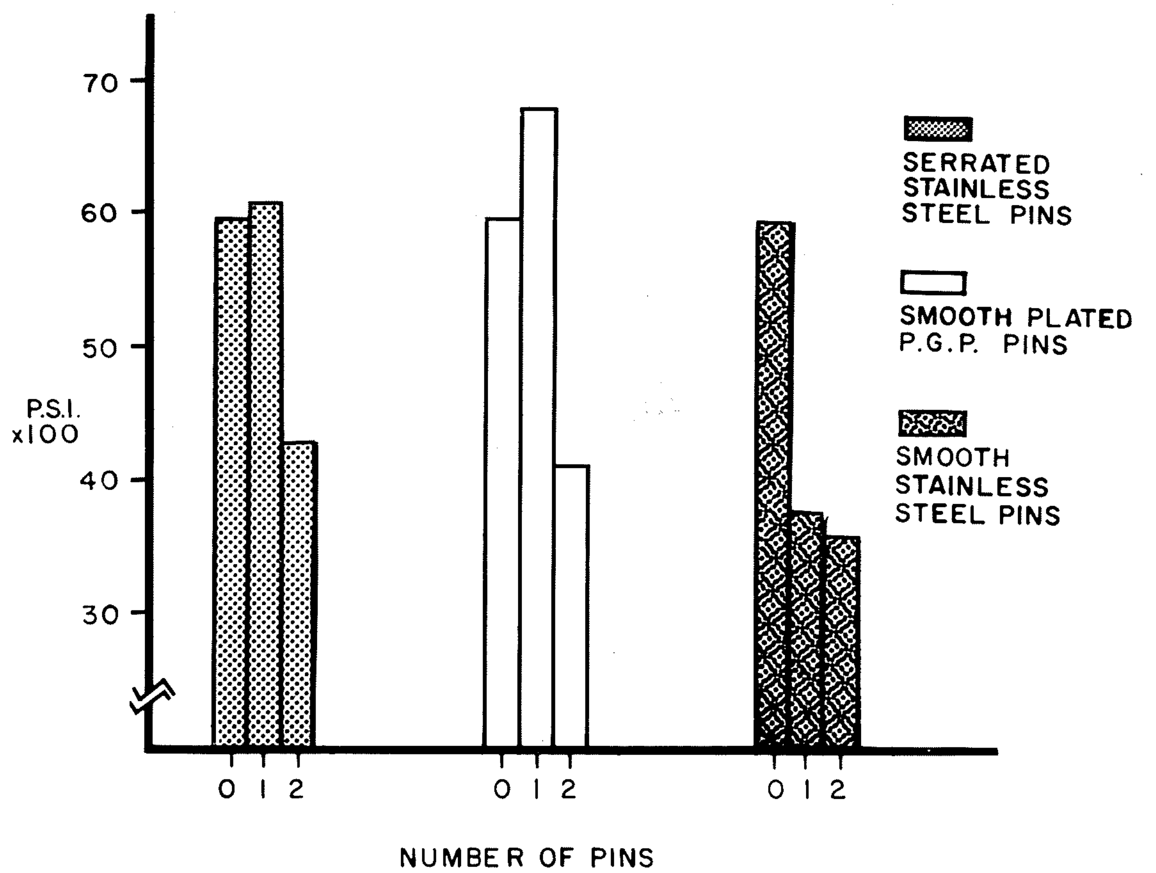

Fig. 42

TABLE XX

1-SS	NOPN	2-SS	2-P	1SSS	2SSS	
NS	NS	**	**	**	**	1-P
	NS	**	**	**	**	1-SS
		**	**	**	**	NOPN
			NS	NS	NS	2-SS
				NS	NS	2-P
					NS	1SSS

SS - Serrated Stainless Steel

SSS- Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - P <.05

** - P <.01

Figure 43. The effect of pins on the twenty-four hour tensile strength of amalgam made using spherical particle alloy. (Pins placed perpendicular to the tensile force)

TABLE XXI. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 43

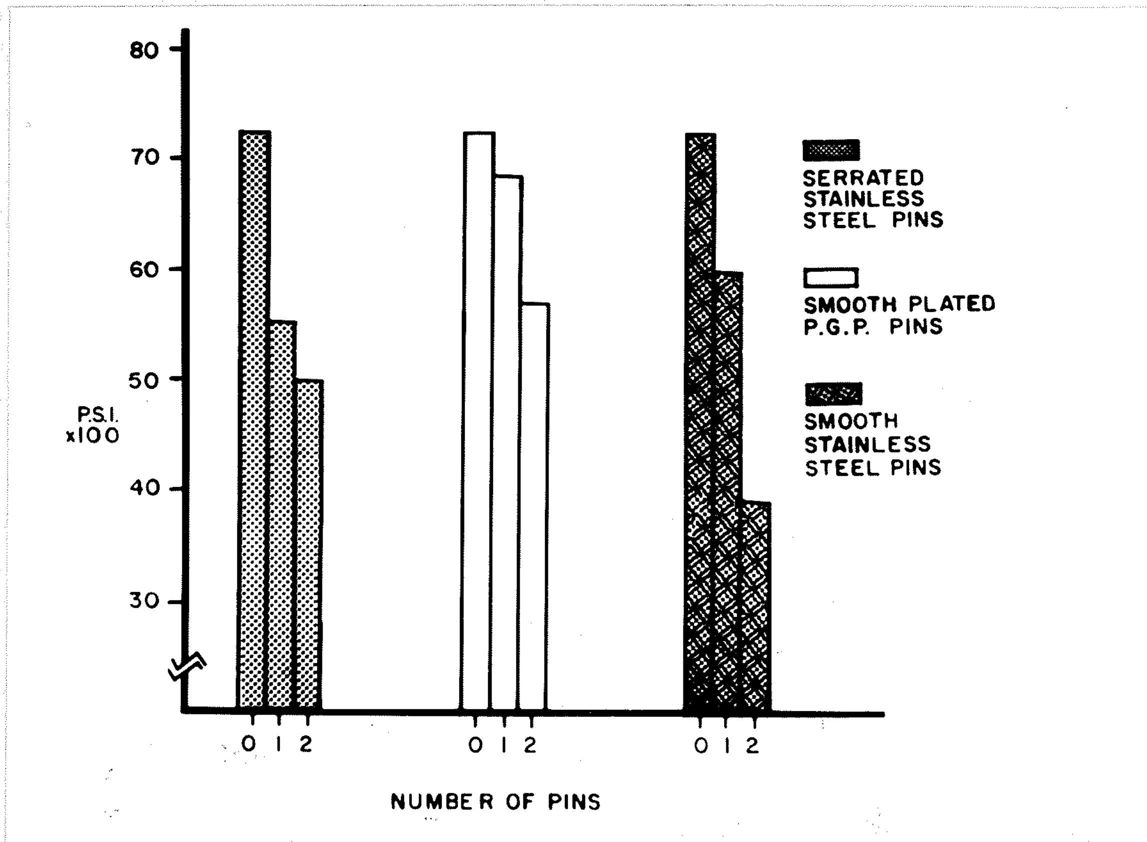

Fig. 43

TABLE XXI

1-P	1SSS	2-P	1-SS	2-SS	2SSS	
NS	**	**	**	**	**	NOPN
	*	**	**	**	**	1-P
		NS	NS	*	**	1SSS
			NS	NS	**	2-P
				NS	**	1-SS
					**	2-SS

SS - Serrated Stainless Steel

SSS- Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - P <.05

** - P <.01

PINS POSITIONED PARALLEL TO THE TENSILE FORCE

The residual mercury ranged from 44.37 per cent to 48.55 per cent considering all three types of amalgam alloy.

A covariance analysis, as previously described, yielded a pooled regression coefficient of 47.045 $\pm$ 86.16. This indicated an absence of any relationship between the tensile strength and the residual mercury content of the amalgam. Correction of the tensile strength values for residual mercury content was therefore unnecessary.

The mean tensile strength values for all combinations of number of pins and alloys, tested at one hour, are shown in Table XXII. Statistical analysis of these results was performed as previously described.

The effect of pins on the one hour tensile strength of amalgam, irrespective of type of alloy, is graphically illustrated in Figure 44. Table XXIII describes the corresponding statistical analysis.

Figures 45 to 47 illustrate the effect of pins on the one hour tensile strength of conventional, dispersion phase and spherical particle amalgam. Tables XXIV to XXVI describe the corresponding Duncan's analysis for each type of amalgam.

A similar analysis was conducted on the results obtained from tests on twenty-four hour specimens. Similar graphs and tables are illustrated in Figures 48 to 51, and Tables XXVII to XXXI.

At one hour, all three types of pins caused an increase in the tensile strength of dental amalgam. The increase in strength was greater when the number of pins increased from one to three. The specimens containing plated platinum-gold-palladium pins demonstrated the most substantial increase in tensile strength when two or three pins were used. An increase in tensile strength of lesser magnitude was also found when serrated stainless-steel pins were used.

When tensile tests were conducted at twenty-four hours after condensation, specimens containing serrated stainless-steel and plated platinum-gold-palladium pins demonstrated a slight increase in tensile strength. The conventional amalgam specimens, however, did not demonstrate a significant increase in strength with any type of number of pins. Overall, the greatest increase in strength was effected with the use of serrated stainless-steel pins.

RESISTANCE TO WITHDRAWAL OF PINS FROM AMALGAM

The results of the withdrawal tests were subjected to statistical analysis by means of an analysis of variance. Since no significant differences were found when comparing alloy types the mean values for each type of alloy were pooled in order that the effect of pins, irrespective of alloy type, could be determined.

It was found that an average force of 66.03 pounds was required to withdraw the serrated stainless-steel pin from the amalgam samples. An average force of 40.14 pounds was required to remove the plated platinum-gold-palladium pins. The smooth stainless-steel pins required a withdrawal force of 0.52 pounds. These values proved to be significantly different at the one per cent level of confidence.

TABLE XXII

THE EFFECT OF VARIOUS PIN MATERIALS ON THE ONE HOUR TENSILE STRENGTH OF THREE DENTAL AMALGAMS. (PINS PLACED PARALLEL TO THE TENSILE FORCE)

PIN	ULTIMATE TENSILE STRENGTH (P.S.I. x 100)			
	ALLOY			
Type and No.	Conventional	Dispersion	Spherical	Mean
Control (no pin)	19.64	21.44	26.13	22.40
1 SS	24.38	24.23	26.19	24.93
1 P	23.06	19.55	24.68	22.43
1 SSS	22.11	20.49	23.17	21.93
2 SS	24.77	22.67	26.82	24.75
2 P	27.43	22.9	30.17	26.83
2 SSS	21.21	19.59	26.33	24.75
3 SS	24.55	21.82	34.20	26.86
3 P	31.20	30.10	34.58	31.96
3 SSS	23.55	21.89	27.41	24.28

SS - Serrated Stainless Steel
P - Smooth Plated P.G.P.
SSS - Smooth Stainless Steel

Figure 44. The effect of pins on the one hour tensile strength of amalgam, irrespective of alloy type. (Pins placed parallel to the tensile force)

TABLE XXIII. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 44

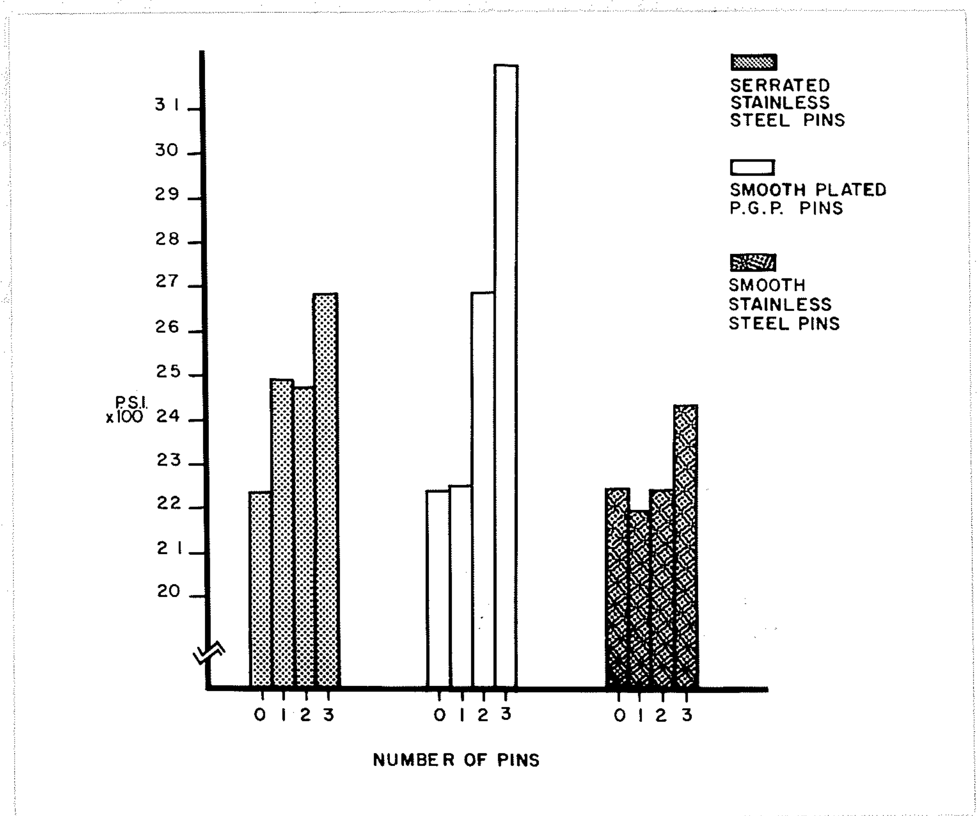

Fig. 44

TABLE XXIII

3-SS	2-P	1-SS	2-SS	3SSS	1-P	NOPN	2SSS	1SSS	
**	**	**	**	**	**	**	**	**	3-P
	NS	*	**	**	**	**	**	**	3-SS
		*	**	**	**	**	**	**	2-P
			NS	NS	**	**	**	**	1-SS
				NS	**	**	**	**	2-SS
					*	*	*	**	3SSS
						NS	NS	NS	1-P
							NS	NS	NOPN
								NS	2SSS

SS - Serrated Stainless Steel

SSS - Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - $P < .05$

** - $P < .01$

Figure 45. The effect of pins on the one hour tensile strength of amalgam made using conventional alloy. (Pins placed parallel to the tensile force)

TABLE XXIV. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 45

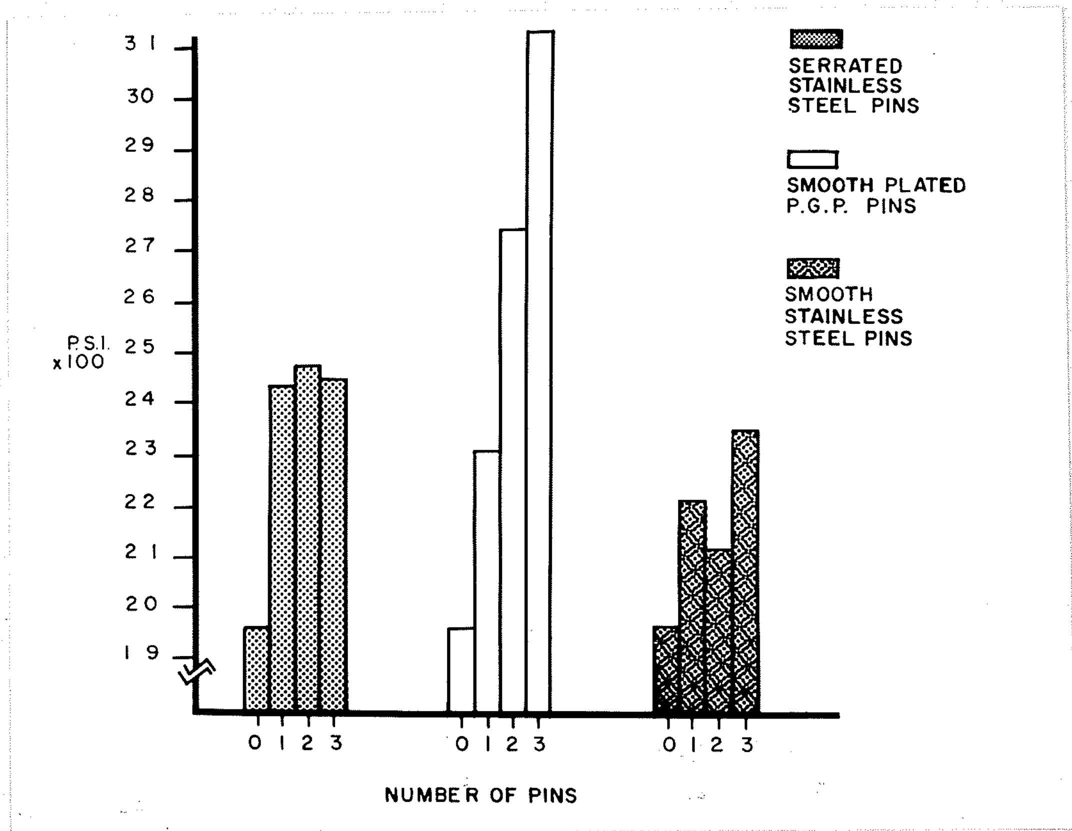

Fig. 45

TABLE XXIV

2-P	2-SS	3-SS	1-SS	3SSS	1-P	1SSS	2SSS	NOPN	
**	**	**	**	**	**	**	**	**	3-P
	*	*	*	**	**	**	**	**	2-P
		NS	NS	NS	NS	NS	*	**	2-SS
			NS	NS	NS	NS	*	**	3-SS
				NS	NS	NS	*	**	1-SS
					NS	NS	NS	**	3SSS
						NS	NS	*	1-P
							NS	NS	1SSS
								NS	2SSS

SS - Serrated Stainless Steel

SSS - Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - P <.05

** - P <.01

Figure 46. The effect of pins on the one hour tensile strength of amalgam made using dispersion strengthened alloy. (Pins placed parallel to the tensile force)

TABLE XXV. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 46

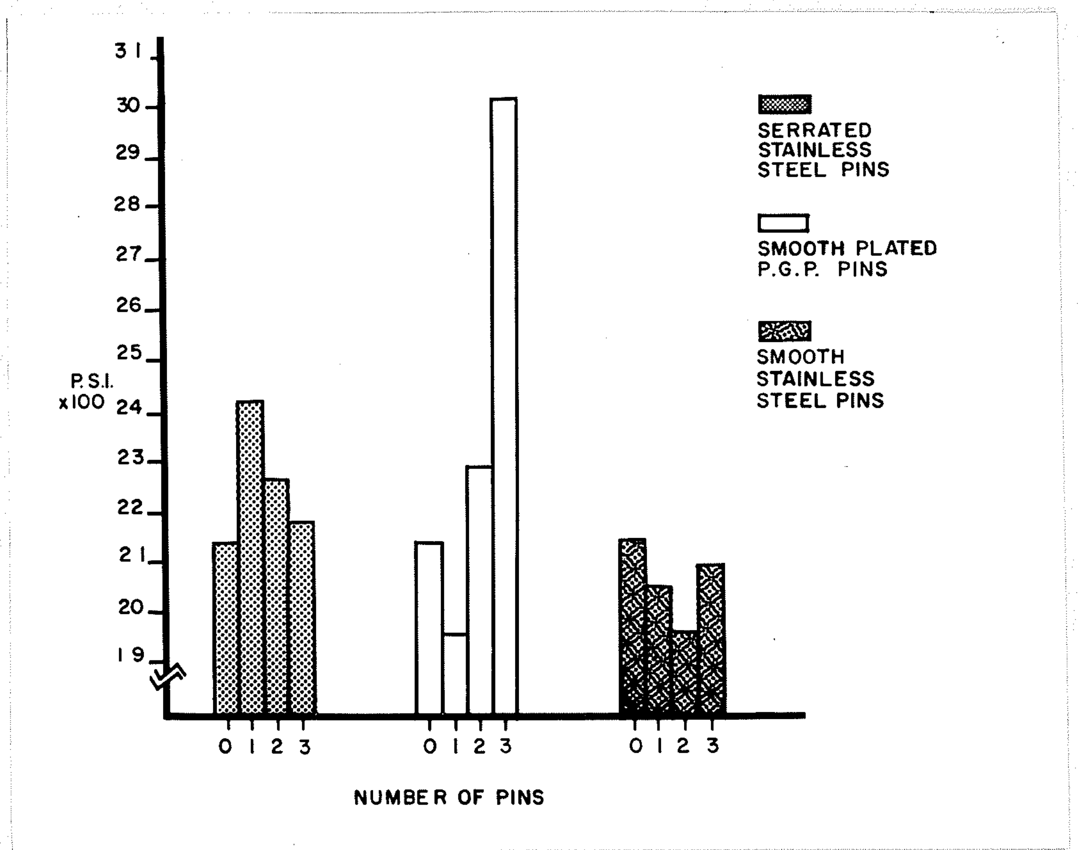

Fig. 46

TABLE XXV

	1-SS	2-P	2-SS	3SSS	3-SS	NOPN	1SSS	2SSS	1-P
3-P	**	**	**	**	**	**	**	**	**
1-SS		NS	NS	NS	NS	NS	*	**	**
2-P			NS	NS	NS	NS	NS	*	*
2-SS				NS	NS	NS	NS	*	*
3SSS					NS	NS	NS	NS	NS
3-SS						NS	NS	NS	NS
NOPN							NS	NS	NS
1SSS								NS	NS
2SSS									NS

SS - Serrated Stainless Steel

SSS - Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - $P < .05$

** - $P < .01$

Figure 47. The effect of pins on the one hour tensile strength of amalgam made using spherical particle alloy. (Pins placed parallel to the tensile force)

TABLE XXVI. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 47

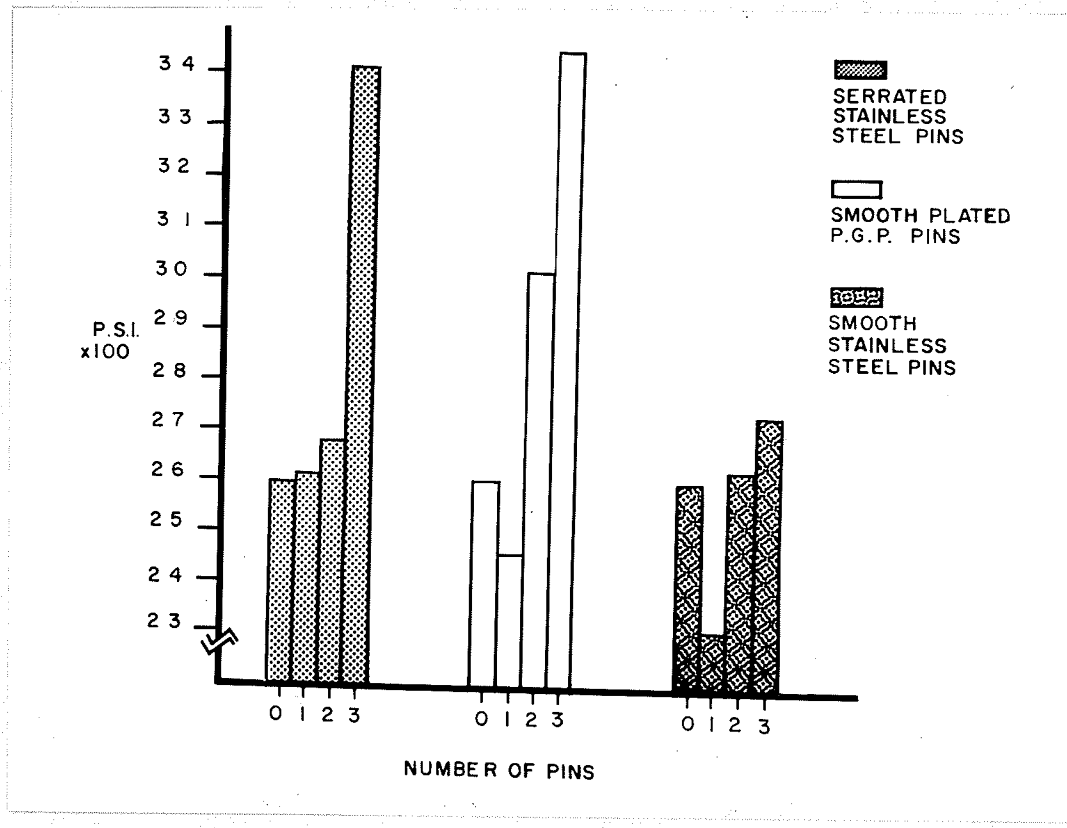

Fig. 47

TABLE XXVI

	3-SS	2-P	3SSS	2-SS	2SSS	1-SS	NOPN	1-P	1SSS
3-P	NS	**	**	**	**	**	**	**	**
3-SS		**	**	**	**	**	**	**	**
2-P			*	*	**	**	**	**	**
3SSS				NS	NS	NS	NS	NS	**
2-SS					NS	NS	NS	NS	*
2SSS						NS	NS	NS	*
1-SS							NS	NS	*
NOPN								NS	*
1-P									NS

SS - Serrated Stainless Steel

SSS - Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - P <.05

** - P <.01

TABLE XXVII

THE EFFECT OF VARIOUS PIN MATERIALS ON THE TWENTY-FOUR HOUR TENSILE STRENGTH OF THREE DENTAL AMALGAMS. (PINS PLACED PARALLEL TO THE TENSILE FORCE)

PIN	ULTIMATE TENSILE STRENGTH (P.S.I. x 100) ALLOY			
Type and No.	Conventional	Dispersion	Spherical	Mean
Control (no pin)	86.68	59.54	72.33	83.26
1 SS	86.90	71.27	85.66	81.28
1 P	83.85	62.89	82.74	76.50
1 SSS	80.32	60.51	75.73	72.19
2 SS	88.73	73.22	78.65	80.20
2 P	80.32	61.57	80.19	74.03
2 SSS	86.23	67.08	83.19	78.84
3 SS	89.37	73.35	85.27	83.26
3 P	82.45	71.01	81.23	78.23
3 SSS	86.28	55.12	85.27	75.56

SS - Serrated Stainless Steel
P - Smooth Plated P.G.P.
SSS - Smooth Stainless Steel

Figure 48. The effect of pins on the twenty-four hour tensile strength of amalgam irrespective of alloy type. (Pins placed parallel to the tensile force)

TABLE XXVIII. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 48

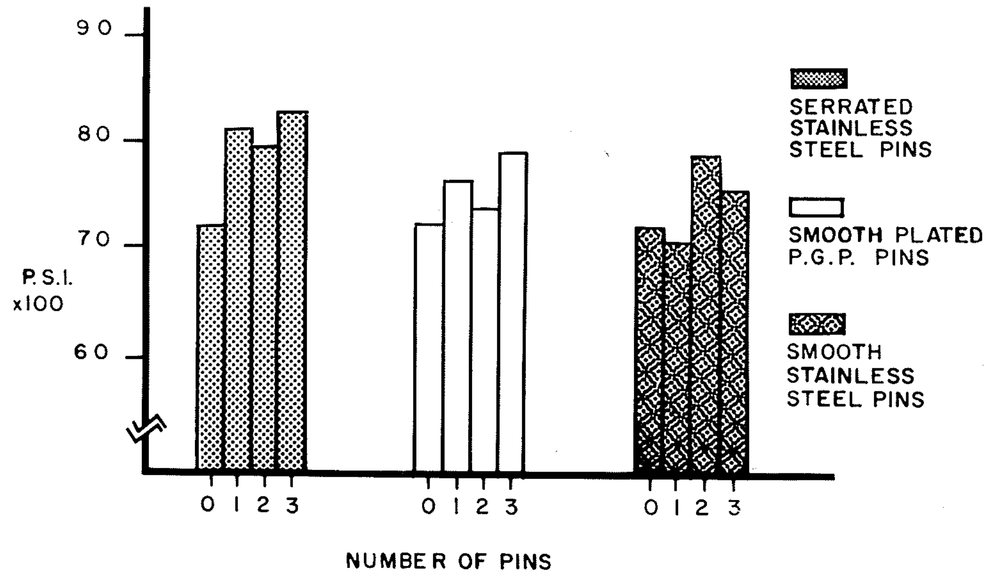

Fig. 48

TABLE XXVIII

1-SS	2-SS	2SSS	3-P	1-P	3SSS	2-P	NOPN	1SSS	
NS	NS	NS	*	**	**	**	**	**	3-SS
	NS	NS	NS	NS	*	**	**	**	1-SS
		NS	NS	NS	NS	*	**	**	2-SS
			NS	NS	NS	NS	*	**	2SSS
				NS	NS	NS	*	*	3-P
					NS	NS	NS	NS	1-P
						NS	NS	NS	3SSS
							NS	NS	2-P
								NS	NOPN

SS - Serrated Stainless Steel

SSS - Smooth Stainless Steel

P - Plated

NOPN - Control (no pins)

* - P <.05

** - P <.01

Figure 49. The effect of pins on the twenty-four hour tensile strength of amalgam made using conventional alloy. (Pins placed parallel to the tensile force)

TABLE XXIX. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 49

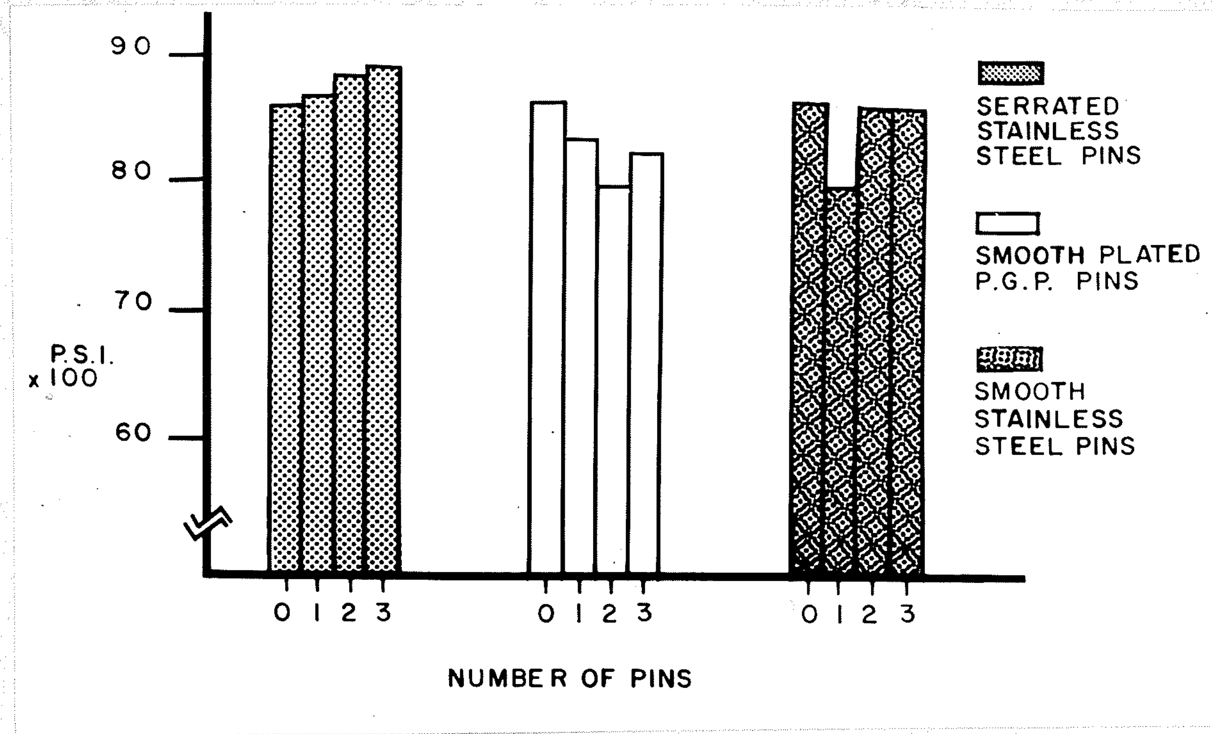

Fig. 49

TABLE XXIX

2-SS	1-SS	NOPN	3SSS	2SSS	1-P	3-P	1SSS	2-P	
NS	NS	NS	NS	NS	NS	NS	NS	NS	3-SS
	NS	NS	NS	NS	NS	NS	NS	NS	2-SS
		NS	NS	NS	NS	NS	NS	NS	1-SS
			NS	NS	NS	NS	NS	NS	NOPN
				NS	NS	NS	NS	NS	3SSS
					NS	NS	NS	NS	2SSS
						NS	NS	NS	1-P
							NS	NS	3-P
								NS	1SSS

SS - Serrated Stainless Steel

SSS - Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - P <.05

** - P <.01

Figure 50. The effect of pins on the twenty-four hour tensile strength of amalgam made using dispersion strengthened alloy. (Pins placed parallel to the tensile force)

TABLE XXX. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 50

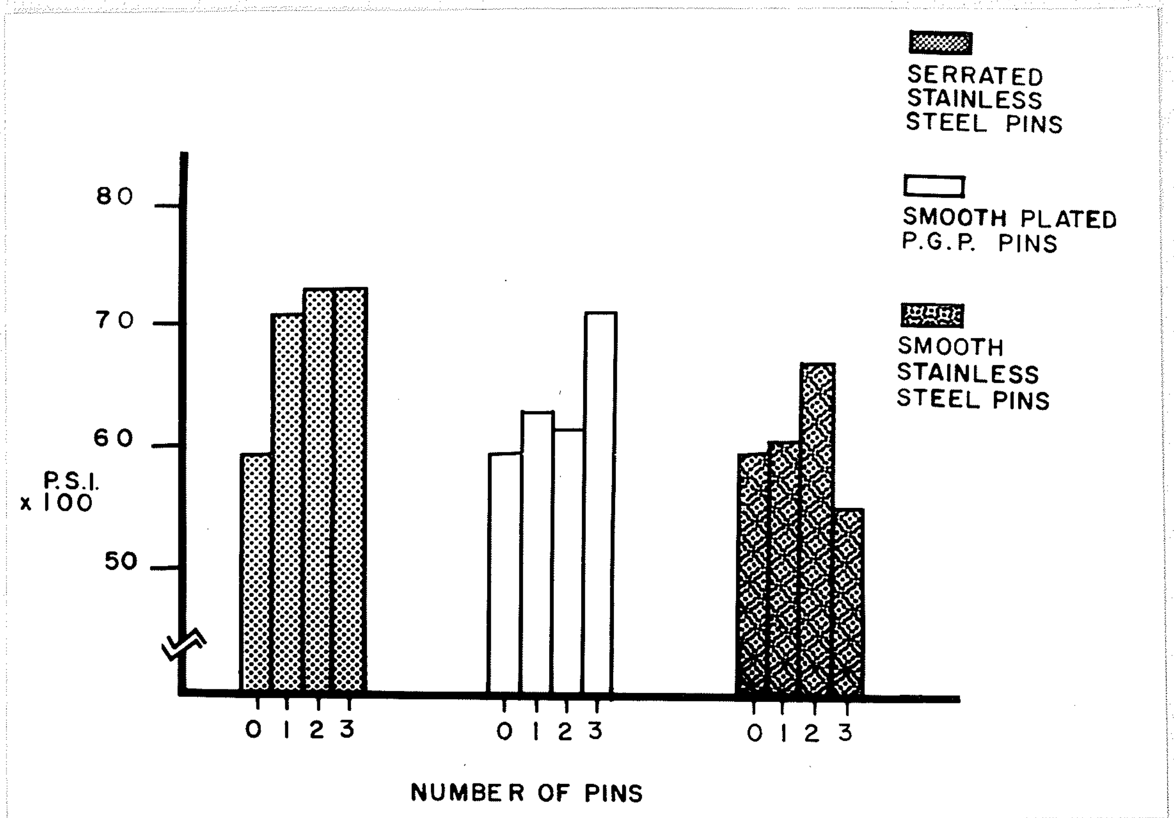

Fig. 50

TABLE XXX

	2-SS	1-SS	3-P	2SSS	1-P	2-P	1SSS	NOPN	3SSS
3-SS	NS	NS	NS	NS	*	**	**	**	**
2-SS		NS	NS	NS	*	**	**	**	**
1-SS			NS	NS	NS	*	*	**	**
3-P				NS	NS	*	*	**	**
2SSS					NS	NS	NS	NS	**
1-P						NS	NS	NS	NS
2-P							NS	NS	NS
1SSS								NS	NS
NOPN									NS

SS - Serrated Stainless Steel

SSS- Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - P <.05

** - P <.01

Figure 51. The effects of pins on the twenty-four hour tensile strength of amalgam made using spherical particle alloy. (Pins placed parallel to the tensile force)

TABLE XXXI. DUNCAN'S MULTIPLE RANGE TEST OF RESULTS ILLUSTRATED IN FIGURE 51

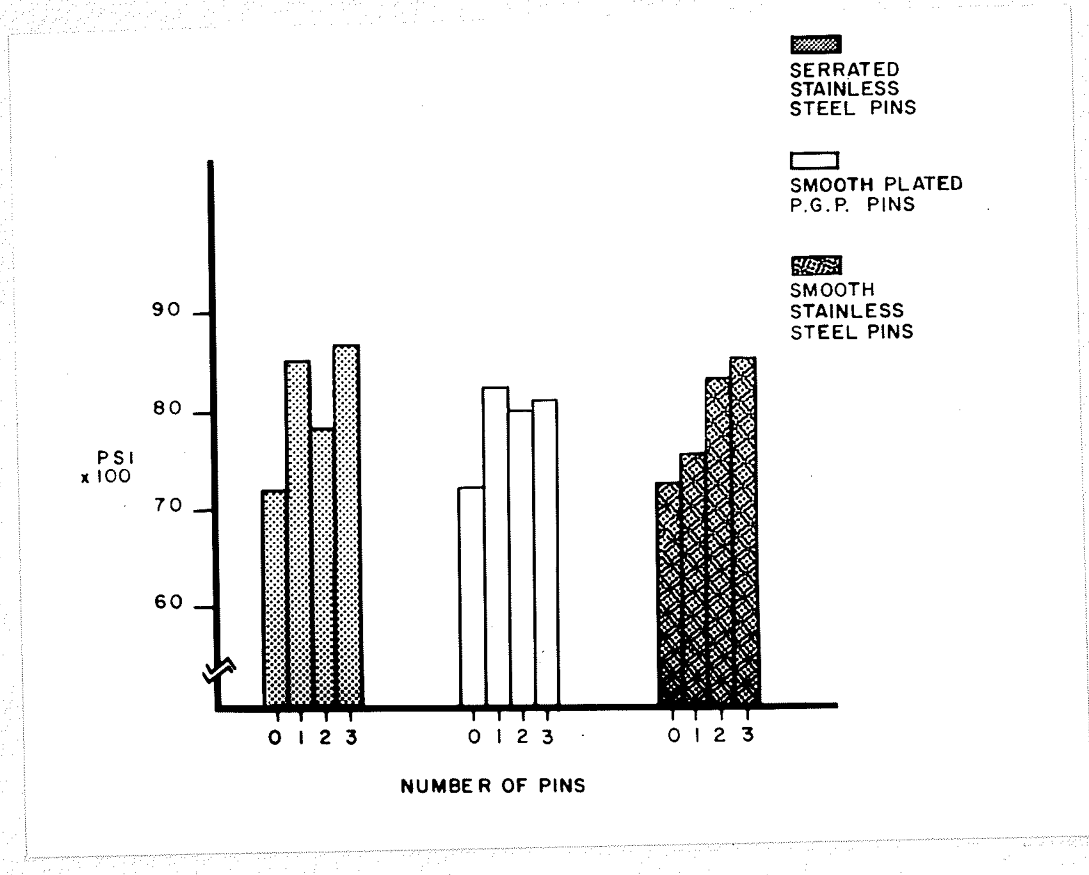

Fig. 51

TABLE XXXI

	1-SS	3SSS	2SSS	1-P	3-P	2-P	2-SS	1SSS	NOPN
3-SS	NS	NS	NS	NS	NS	NS	NS	*	**
1-SS		NS	NS	NS	NS	NS	NS	*	**
3SSS			NS	NS	NS	NS	NS	*	**
2SSS				NS	NS	NS	NS	NS	*
1-P					NS	NS	NS	NS	*
3-P						NS	NS	NS	*
2-P							NS	NS	NS
2-SS								NS	NS
1SSS									NS

SS - Serrated Stainless Steel

SSS - Smooth Stainless Steel

P - Plated

NOPN - Control (no pin)

* - P <.05

** - P <.01

DISCUSSION

COMPRESSIVE STRENGTH

Generally, a decrease in compressive strength was observed when specimens containing pins were compared to control specimens. The significance of the decrease in strength increased with the number of pins used. This loss of strength is contrary to that found by Charlick[20] who stated that no reduction in ultimate compressive strength was evident when testing amalgams containing various types and numbers of pins. Charlick, however, used pins which extended almost the entire length of his specimens, which is not the case when pins are used in vivo. The results of his tests therefore may have been influenced by the heads of the testing device bearing on the stainless steel wire, rather than on the amalgam specimen itself. These findings are also contrary to Markley's[7,8,9] statements on increased strength values for pin-retained amalgam. His statements, however, were based entirely on clinical observation, and not on laboratory findings. Reduction of compressive strength values with increasing number of pins was evident at both the one hour and the twenty-four hour test period. The lowering of compressive strength values in one hour is at variance with that found by Going[18] who stated that there appeared to be no significant decrease in ultimate compressive strength of pin containing amalgam specimens when testing such specimens at one-half hour and two hours after the completion of condensation. His test methods varied from that used in the present investigation. Prior to testing, the protruding ends of the pins were cut off flush with the bottom of the specimen, and then ground so that they were short of the specimen base. This did not therefore truly simulate the use of pins for retentive purpose in tooth structure. The effect of the cutting and grinding procedure on the pin-amalgam interface was unknown and may have been a contributing source of error.

With one pin embedded in the amalgam specimens there was a significant decrease in compressive strength only with the use of plated pins at the one hour test period. After twenty-four hours, there was a significant reduction in compressive strength with both serrated stainless-steel pins and plated pins. With the remaining combinations, there was a significant decrease in compressive strength when compared to the control specimens.

The decreased compressive strength values found in the specimens containing pins could be explained as being the result of the following contributing factors, namely, stress concentrations developed around the pins, relief of stresses from plastic deformation of the amalgam subjected to a compressive load, and cleavage planes which may be formed in the material by the serrated stainless-steel pins.

It is suggested that compressive loads applied to amalgam specimens, produced stress concentrations around all types of pins. Because of these areas of high stress concentration, failure of amalgam specimens occurred at a lower level of compressive stress. Some relief of stress concentrations could result from the creep or flow property which amalgam normally exhibits under stress. This creep tends to decrease the effect of stress concentration around the embedded pins. The ability of creep to reduce stress concentration can be seen when comparing the values obtained for dispersion-phase alloys to those of the spherical particle or the conventional alloys at the twenty-four hour test period. Inness and Youdelis[29] have demonstrated that the dispersion-phase alloy exhibits considerably less creep or flow, compared to conventional alloy. It can be seen from the graph, shown in Figure 34, and the statistical analysis in Table X, that the reduction in compressive strength of dispersion-phase amalgam alloy containing pins is more marked than that of the conventional or spherical particle amalgam alloys. The greater reduction in ultimate compressive strength may be due to the inability of this particular amalgam to flow and relieve the stress concentration around the pins.

It was thought that a fusion of pins with the amalgam matrix might reduce the flow of the amalgam in the area around the pins. No evidence from the results exists to support this hypothesis and the amalgam alloys containing plated pins behave similarly to those containing smooth stainless-steel pins.

It is possible that, in amalgam specimens containing two pins, under stress, a cleavage effect is established within the specimen in a plane along a line connecting the two pins. The void which is seen to occur around the stainless steel pin could possibly magnify the cleavage-plane effect when the material is placed under stress. No difference, however, was found between the two-pin specimens containing plated pins and those containing smooth stainless-steel pins. The effect of the void, therefore, must be considered to be a secondary factor in causing a noticeable reduction in compressive strength.

The results of the compressive strength tests, at one hour and twenty-four hours indicate that plated platinum-gold-paladium and smooth stainless-steel pins influenced the compressive strength of amalgam in the same manner. With all types of amalgam alloys, a progressive decrease in compressive strength resulted as the number of pins was increased from one to four. A different trend was evident, however, when serrated stainless-steel pins were used. When two pins were used, reduction in compressive strength was significantly greater with serrated stainless-steel pins than with the plated or the smooth stainless-steel pins. This trend, however, appeared to reverse itself when specimens with four pins were compared, and a significant difference was evident between the specimens with serrated stainless-steel pins and those with smooth plated or smooth stainless-steel pins. It is postulated that this apparent difference may be attributed to the serrations in the stainless-steel pins. The cleavage-plane potential previously described is probably present with all types of pins. In the case of a specimen with serrated pins, when a compressive load is applied, the amalgam may exhibit a sliding effect along the pin, and in an effort to move past the serrations a lateral force develops in an attempt to disengage the amalgam from it. This latter force is produced at right angles to the pin, and tends to enhance the effect of the cleavage plane. In specimens containing four serrated pins, however, six different cleavage planes are established in the specimen, with accompanying stresses acting in different directions, some at right angles to one another. A condition is created whereby the force exerted on the six cleavage planes in all directions may tend to counteract one another, therefore the specimen resists fracture to a significantly greater degree than those specimens containing two serrated pins.

Welk and Dilts[24] found that there was no proportional decrease in compressive strength as the number of pins were increased. The results of the present investigation, however, would tend to indicate that with the use of smooth-surface pins, there is a tendency towards progressively decreased compressive strength values as the number of pins are increased. A trend is also noticeable with the use of serrated pin materials when evaluating the compressive strength results, which could be attributed to the serrations in the pins. This difference in observation may be due to the larger number of samples tested in the present investigation.

The decrease observed in twenty-four hour compressive strength tests, although substantial, is not believed to be clinically significant. None of the specimens tested in this study recorded compressive strength values lower than those found for enamel and dentin by Stanford, et al.[41]

ULTIMATE TENSILE STRENGTH

PINS PLACED PERPENDICULAR TO THE TENSILE STRESS

The overall effect of placing pins with the long axis of the pin perpendicular to tensile stresses on amalgam was to reduce the ultimate tensile strength of the amalgam. This is in agreement with the results reported by Going, Nostrant and Johnson,[17] and Cecconi and Asgar.[22] The reduction of strength was evident at both the one hour and the twenty-four hour test interval. Each type of pin material produced a significantly different effect on the amalgam samples. The electroplated pins appeared to have the least effect on reducing the tensile strength. The serrated stainless-steel pins caused a greater reduction in strength, and the smooth stainless-steel pins produced the severest effect.

The difference in the effect produced by the three types of pins at one hour was more evident when specimens contained two pins. When two pins were used, the plated pins caused significantly less weakening than did either serrated or smooth stainless-steel pins. When one pin was used, there was no difference between samples containing plated and serrated pins. Samples containing smooth stainless-steel pins were significantly weaker. The trend was toward a reduced loss of strength when plated pins were used, as compared to serrated or smooth stainless-steel pins.

At twenty-four hours, specimens containing one plated pin affected reduction in tensile strength less than did serrated or smooth stainless-steel pins. With two pins, however, there was no difference between the plated and the serrated stainless-steel pins. The smooth stainless-steel pins did cause a significantly greater decrease in tensile strength than the plated or the serrated pins.

It is felt by this investigator that under tensile stress the pins behave like voids in amalgam specimens. The assumption could then be made that the larger the void or pin, the greater the weakening effect of the pin on the amalgam. The pins could also set up potential for a line of cleavage within the amalgam which could cause earlier propagation of tensile failure. It was obvious that the smooth stainless-steel pins created the largest void. These pins have a constant diameter which may form a straight line of cleavage through the specimen. The largest diameter of the serrated stainless-steel pins was the same as that of the smooth stainless-steel pins, however, the serrations in the pin had the effect of reducing the average diameter. Because the matrix of amalgam adapts very closely to the serrations, the volume of the void in the amalgam specimen could be effectively reduced. This could account for the greater effect of the smooth stainless-steel pins on the reduction of tensile strength of amalgam when compared to the serrated pin material. The plated pin, by virtue of its ability to fuse with the amalgam matrix, appears to eliminate the effect of the void at the interface of the pin and the amalgam produced when stainless steel pins are used. The fusion of the plated pin to the amalgam could also reduce the effect of the pin acting like a void within the amalgam specimen.

When the ultimate tensile strength of specimens containing two pins was determined using the diametral tensile strength test, a definite cleavage plane was established in the specimen along the long axis of the pins. This effect is thought to be the result of the pin material behaving like a void in the amalgam, even with the plated pins. This was most evident at the twenty-four hour test period. In all three types of amalgams tested, however, the plated pins caused less of a reduction in strength than did the serrated or smooth stainless-steel pins. This decreased effect was not statistically significant when comparing plated platinum-gold-palladium and serrated stainless-steel pins.

PINS PLACED PARALLEL TO THE TENSILE STRESS

At one hour all three types of pins caused an increase in the tensile strength of dental amalgam. In general, the increase in strength was greater as the number of pins within the specimens increased from one to three. These findings are at variance with those of Cecconi and Asgar[22] who found no significant difference in strength, although some suggestion of a trend toward increased strengths could be observed in their results. The specimens containing plated platinum-gold-palladium pins demonstrated the most substantial increase in strength when two or three pins were used. A significant increase in tensile strength was also found when serrated stainless-steel pins were used, however, the increase in strength was not as great as was the case with the plated pins, however, this increase was not thought to be of a significant magnitude to have any clinical importance.

When tensile tests were conducted at twenty-four hours after condensation, it was found that specimens containing serrated stainless-steel and plated platinum-gold-palladium pins demonstrated a slight increase in tensile strength. In no instance, however, was the increase in strength of the magnitude of the one hour test results.

Of the three alloys tested, only the conventional amalgam specimens failed to demonstrate a significant increase in tensile strength with any type of number of pins, although a trend toward increasing strength values was evident with the use of serrated stainless-steel pins. The remaining types of alloy revealed significant increases in strength with the use of pins, notably, when two or three pins were used.

The greatest increase in strength was effected with the use of serrated stainless-steel pins. The plated and smooth stainless-steel pins had similar but smaller effects on the tensile strength of the amalgam specimens.

The strengthening effect of the embedded pins on the amalgam specimens appeared to be a function of the retention of the pins within the amalgam. The pins tend to increase the resistance of the amalgam to the splitting tensile force by stapling the two halves of the specimen together.

One hour tensile values of specimens containing pins seem to indicate that the metallurgical bond formed between the matrix and the plated platinum-gold-palladium pin is stronger than the mechanical interlocking of the matrix in the serrations of the threaded pin. This would cause the plated pins to influence the strength of the specimen to a greater degree than would the serrated pins. This difference could be caused by the accumulation of mercury around the serrated and plated pins during condensation. Because both the silverplated layer of the pin and the unreacted alloy particles contain the mercury layer, a rapid reaction and solidification of this area should occur. In the case of the serrated pin materials, the reaction can only proceed from the amalgam toward the pin by crystal growth of the Gamma I and Gamma II phases of the amalgam matrix. The mechanical lock could thus require a longer period of time to form. This could result in a greater reinforcing effect by the plated pins during the early setting period.

At the twenty-four hour test period the mechanical locking effect of the serrated stainless-steel pins caused the specimens to offer more resistance to the splitting tensile force than did the plated pins. Tests to determine the twenty-four hour withdrawal resistance of the three types of pin materials from amalgam confirmed the premise that the serrated stainless-steel pins would be more resistant than plated pins. Smooth stainless-steel pins offered extremely little resistance to withdrawal from amalgam.

Of interest is the fact that serrated pins proved to be as effective as plated pins for increasing the one hour tensile strength values of spherical particle amalgam specimens. This might be attributed to the more rapid setting reaction of this particular alloy which would be more effective in achieving a mechanical lock, as compared to the other types of alloys, which have slower setting characteristics.

SUMMARY

The effects of three types of pin material on the compressive and tensile strength of three different amalgams were determined by mechanical tests conducted on a total of nine hundred and ninety specimens. These were divided into groups of six or more, each containing a specific combination of type and number of pins, and type of alloy. Sets of specimens, with pins embedded to simulate their use for retentive purposes, were subjected to compressive and tensile loads to determine their ultimate strength properties. Similar tensile tests were performed on specimens with pins placed parallel to the tensile stress, to simulate pins used for reinforcement of amalgam. Standardization of specimen preparation was assured by residual mercury determinations performed on every second specimen tested.

The withdrawal resistance of the various pins from amalgam was determined in order to acertain whether a relationship existed between this property, and the effect of the pins on the ultimate tensile strength of the amalgam when pins were used as reinforcing agents.

Statistical analysis of the results was accomplished utilizing an analysis of variance, followed by the Duncan's multiple range test. The results of the compressive strength tests indicated that all types and numbers of pins caused a decrease in the strength of the specimens with increasing numbers of pins. The serrated stainless-steel pins demonstrated a different trend than the smooth-surfaced pins. With pins placed perpendicular to the tensile force the platinum-gold-palladium pins proved superior in maintaining the tensile strength of the specimens. Both plated platinum-gold-palladium and serrated pins increased the tensile strength of amalgam specimens, when they were placed parallel to the tensile force. A relationship was found to exist between this phenomenon and the withdrawal resistance of pins from amalgam.

CONCLUSIONS

1. The use of pin materials for purposes of retention resulted in a decrease in the ultimate compressive strength of dental amalgam.
2. The use of pin materials for purposes of retention resulted in a decrease in the ultimate tensile strength of the dental amalgam. Platinum-gold-palladium pins caused less of a decrease in strength than did the stainless steel materials.
3. When pin placement in amalgam was such that the long axis of the pin was parallel with the tensile force, both the plated and serrated pins appeared to increase the tensile strength of the amalgam.
4. The serrated stainless-steel pins offered a greater resistance to withdrawal than did the electroplated pins. The smooth stainless-steel pins were the least resistant to withdrawal.
5. Within the range of residual mercury content of the amalgam tested in this study, there was no correlation between strength and residual mercury content.

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