AN EVALUATION OF CURRENT ORTHODONTIC BONDING MATERIALS AND A COMPARISON OF THE DIRECT AND INDIRECT TECHNIQUES

by

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Abstract

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The objective of this study was to determine and compare the accuracy of placement of bonded metal orthodontic brackets by the direct and indirect methods. Also, bond strengths in the shear mode were determined for four bonding systems placed in vivo: Bond-Eze Light-Cure, Concise, Lee-Bond, and Nuva-Tach.

Fourteen orthodontic patients requiring extraction of the four first premolars were utilized in the study. The teeth were marked superficially before bonding for accuracy determinations. The bonding material used and the method of bracket application for each tooth was assigned, using a balanced incomplete block design. Teeth were extracted after approximately 28 days in vivo and measurements for bracket placement were made from photographic enlargements. Bond strengths in a shear mode were determined using an Instron Universal Testing Machine.

A separate experiment compared *in vitro* shear strengths of the same four materials plus three additional new bonding materials: Auto-Tach, Endur, and Solo-Tach. These bond strengths were determined following three months immersion in isotonic saline.

Analyses of variance were performed and means were compared with Duncan's New Multiple-Range Test. The results of this study may be summarized as follows:

1. There was no significant ($P > 0.05$) difference in accuracy of bracket placement between the two methods. This may be attributed to the fact that the design eliminated factors of operator perception.

2. There were significant ($P < 0.05$) differences in the bond strengths among materials tested. Concise and Lee-Bond were both significantly stronger than Nuva-Tach and Bond-Eze *in vivo*. Auto-Tach and Solo-Tach were both significantly stronger than all other materials except Nuva-Tach *in vitro*.

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DEDICATED

TO

My Wife Celeste,

My Children Christine and Brett, and

My best friends, Shannon and Deacon,

For their love, devotion, and encouragement.

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INTRODUCTION

The indirect technique, a relatively new method for bonding orthodontic attachments to teeth, (first described by Silverman et al, 1972) is becoming increasingly popular. Two stated advantages over direct bonding are reduced chair time and increased accuracy of bracket placement, but there has been some disagreement over the validity of the latter advantage.

The growth in popularity of orthodontic bonding procedures has resulted in an increasing number of commercially available materials, one of which was specifically designed for indirect bonding.

The purpose of this present study is to test the accuracy of bracket placement with indirect bonding and to compare bond strengths of some of the newer bonding materials in the shear mode, both in vivo and in vitro.

LITERATURE REVIEW

A study of orthodontic bonding methods and materials requires a background in some basic concepts of adhesion and mechanical properties. Bonding considerations are covered thoroughly by Schmoll (1974), while recent findings concerning bonding, factors affecting bond strength, indirect bonding, and comparisons with direct bonding will be considered here.

Direct Bonding - Recent Findings

The most valuable testing method for bond strength is a shear test using an Instron Universal Testing Machine. A summary of bond strength tests and materials is presented in Table 1. Fracture of plastic brackets during testing has been reported as a problem by Cohl et al, (1972); Nagel, (1973); Schmoll (1974); Khowassah (1975); and Bishara (1975). Lee, et al, (1974) found bond strengths to be high with polycarbonate discs, but minimal with stainless steel bar stock. Keizer, et al, (1976) found that the bond between a smooth plastic bracket base and the adhesive was unsatisfactory. Testing Nuva-Seal with plastic brackets, Cohl et al, (1972) found bond failures occured at the bracket-adhesive interface. Eighty-eight percent of the metal brackets bonded by Lee et al, (1974) to human enamel exhibited failure of the bonding material at the bracket base.

TABLE 1 - BOND STRENGTH TESTS OF ORTHODONTIC DIRECT BONDING SYSTEMS (using Instron Testing Machine)

INVESTIGATOR	MODE	BRACKET	MATERIALS	ENAMEL SOURCE
Newman 1965	Shear	Plastic	Experimental materials	Human
Mizrahi and Smith 1969	Tensile, shear, peel	Button-metal	Zinc polycarboxylate cement, silico phosphate, zinc phosphate, and copper phosphate	Human
Cohl et al. 1972	Tensile, shear	Plastic	Nuva-Seal	Human
Hunter et al. 1973	Shear	Plastic	Durelon, Bracket Bond, OIS, and Nuva-Seal	Bovine
Nagel 1973	Tensile, shear, peel	Plastic	Enamelite, Nuvafil, Sevriton, Nuva-Seal, Nuva-Seal Bracket Bond, Unitek, Directon, Orthomite, OIS	Human
Lee et al. 1974	Tensile	Metal	Genie and two undisclosed materials	Human
*Schmoll 1974	Shear	Plastic	Nuva-Seal, Bracket Bond, Orthomite, Unibond, Directon	Human

* Schmoll bonded brackets to premolars in vivo and later extracted them prior to testing.

TABLE 1 (Continued)

INVESTIGATOR	MODE	BRACKET	MATERIALS	ENAMEL SOURCE
Bishara et al 1975	Tensile, shear	Plastic	Nuva-Seal, Bracket Bond, Unitek direct bonding system	Human
Johnson 1976	Shear	Metal	Nuva-Tach, Orobond, Orthomite II, Directon, Unitek, Genie, Strata-Dent	Bovine
Khowassah 1975	Tensile, shear	Plastic	Rocky Mountain DBS, Unitek DBS	Human
Retief 1975	Tensile	None	Epoxy resin (testing different acid strengths for etching)	Human
Keizer et al. 1976	Shear	Plastic	Lightwire Adhesive, Directon, and three experimental materials	Bovine
Moser et al. 1976	Tensile	None	Nuva-Seal, Bracket Bond, Unitek, Lee, Orthomite, Durelon	Human
Reynolds et al. 1976a	Tensile	Metal mesh-backed buttons	Concise, Delphic, Protecto	Human

TABLE 1 (Continued)

INVESTIGATOR	MODE	BRACKET	MATERIALS	ENAMEL SOURCE
Reynolds et al. 1976b	Tensile	Metal mesh-backed buttons	Genie, Once, Concise, Delphic, Nuva-Seal, Poly F, Protecto, Unitek bonding kit	Human
Svitzer 1976	Shear	Metal mesh and perforated backed	Nuva-Tach, Bond-Eze, Protecto	Not stated

Reynolds and von Fraunhofer (1976a) found insignificant correlation between bond strength and the area of the adhesive-enamel interface. Schmoll (1974) reported that in vivo bond strengths (bonded in vivo, and tested following extraction) were significantly less than in vitro bond strengths. He also determined that the duration of the bond, either in vivo or in vitro, had no significant effect upon the bond strength up to five months. Reynolds, et al, (1976b) discovered a significant decrease in bond strength after six months immersion in water, and that the use of Nuva-Seal as a promoter of adhesion or interfacial agent had no significant effect on bond strength. Hunter et al, (1975), however, determined that pretreatment with Nuva-Seal substantially increased the bond strength of the materials tested, (Durelon, Bracket Bond, and OIS). Prolonged exposure to heat, moisture, and severe thermal changes were found to decrease the shear strength of the bond by Bishara et al, (1975). Johnson et al, (1975) reported disparity in results following three months immersion in saline. One material, (Nuva-Tach) was slightly stronger with time, while others, (Orthomite II, Directon, Orobond) were significantly weaker. Khowassah et al, (1975) noted an increase in tensile and shear strength after 15, 22, and 30 days incubation at room temperature and 100 percent humidity. They also found that it took longer than 30

minutes to obtain complete polymerization of the bonding materials (Rocky Mountain and Unitek). Moser et al, (1976) indicated that 30-day storage in artificial saliva at room temperature decreases the bond strengths of most adhesives tested with or without use of a silane primer. Lee Experimental, a composite resin, was significantly stronger than other materials, and its strength was enhanced by the silane primer. Lee et al, (1976) reported that significant quantities of ultra-violet (UV) bonding material are obscured under the bracket and remain uncured and potentially available for dissolution and transport to the oral mucosa or as irritants to the pulpal tissue.

Retief (1975) found no significant difference in bond strengths using phosphoric acid concentrations from 10 to 50 percent by weight for etching. The most severe etching resulted from use of 10 to 45 percent solutions and the depth of etch was fairly constant for these concentrations. At higher concentrations, the depth of etch and tensile bond strength were reduced while the surface roughness was dramatically increased. A 50 percent solution had less depth of etch and greater surface roughness than weaker solutions. Therefore, he advocated the use of a 50 percent solution for etching.

Svitzer (1976) determined that Nuva-Tach was not as strong as Bond-Eze and Protecto, especially when used

with a bracket backing of coarse mesh. Failure of the bond usually occured at the bracket-adhesive interface; also Nuva-Tach polymerization was incomplete under the bracket. Johnson et al, (1976) found Nuva-Tach to be stronger than several other materials. Reynolds and von Fraunhofer, (1976a and b) drew no conclusions comparing materials, but decided that coarse mesh backings were better than fine mesh backings, and that filled diacrylate resins function as satisfactory adhesives for direct bonding. They also decided Nuva-Seal provides no advantage as an adhesion promoter for acrylics, and that prolonged immersion in water (six months) significantly decreased the strength of acrylic but had no significant effect on diacrylate and filled poly-acrylic materials.

Disadvantages of Direct Bonding

Throughout the literature on laboratory and clinical evaluations of direct bonding techniques, several disadvantages may be inferred:

1. Moisture control throughout the procedure is difficult due to the length of time required for bonding.

2. Bracket placement is inaccurate due to bracket float that occurs after placement and prior to set of the bonding material. This tends to introduce stress for the operator who must maintain the bracket in position while the bonding material hardens without the benefit of a

guide.

3. Significant time is required for tooth preparation and bonding teeth individually.

Isolation and Moisture Control

Barnard (1976) reported on a modified photographic lip retractor held in place by an aluminum neck bow. This retractor was also described by Borges and Prucha (1977). They added buccinator muscle retraction blades to the cheek retractors and used a plexiglas bow behind the head to provide a lateral expansive force.

Newman (1974) and Brandt et al, (1975) used lip retractors to isolate the anterior teeth. Silverman and Cohen (1975) used triangular, foil-backed Dri-Angles in the buccal vestibule to cover the parotid ducts, and to isolate the mandibular teeth from the tongue. In 1976, these authors used the Dri-Angles with McSpreader cheek retractors. Silverman and Cohen (1976) administered Banthine (antisialogogue) tablets 30 minutes prior to the bonding procedure. However, this medication was discontinued from their procedure in 1976. Borges and Prucha (1977) also use Banthine, Newman (1974), Borges and Prucha (1977), and Slodov et al, (1974) all use a warm-air hair dryer.

Indirect Bonding

Silverman et al, (1972) advanced a method of

indirect bracket placement for bonding for which precision of bracket location was emphasized as an advantage. Work models are constructed, and attachments are bonded using the adhesive. A plastic tray is fabricated over the brackets, and adaptation is facilitated by hand pressure. The tray is then removed from the model with the brackets retained in their exact positions in the plastic. These trays are stored until the patient's bonding appointment. At the appointment, the labial and buccal surfaces are cleaned with a rubber cup and pumice. The teeth are isolated with cotton rolls and dried with an air syringe that has been checked for the absence of oil and water. Dryness is maintained with a saliva ejector or evacuator.

All the teeth in one arch are then etched with the tooth conditioner for 60 to 70 seconds. The etchant is applied with a stroking motion, since rubbing the tooth tends to burnish the surface irregularities that are the desired end product of pretreatment. The teeth are then rinsed and fresh cotton rolls placed. Following a second drying, a sealant is painted on the labial and buccal surfaces and polymerized with the UV light. A dampened cotton roll is lightly wiped over the teeth to remove excess material and the teeth are dried once more. Adhesive is mixed to a syrupy consistency and placed on each bracket in the plastic tray, which is then seated in the mouth and held for five minutes to ensure set of the

bonding cement. Upon removal of the tray the brackets are in exactly the same position that they occupied on the work model. Excess material and "bridging" between teeth are eliminated with an Ellman scaler and the teeth are ready for archwires.

The technique has been updated and modified several times. Silverman and Cohen (1974) introduced a new and superior adhesive (Nuva-Tach) which is catalyzed by the UV light. This allows unlimited time to seat the tray in the mouth before starting the setting reaction. A mouth prop was also suggested to help maintain dryness. Newman (1974) reported his version of the technique using Duco cement to attach brackets to the plaster teeth. If metal brackets are used, the tray and brackets are cleaned in acetone in an ultra-sonic cleaner. A tray containing plastic brackets is prepared by roughening the backs of the brackets with a #557 fissure bur. The EPAC adhesive system is used with plastic, and Bond Mor with metal brackets. After seating the tray in the mouth, a warm air dryer is applied for ten minutes to accelerate the cure of the adhesive. Cohen and Silverman (1974) reported the use of a separating medium on the model before attaching brackets. They also began administering Banthine 30 minutes before bonding to control salivation. Silverman and Cohen (1975) again updated the technique by intro-

ducing the new Clev-dent Quick-Lite which permits curing in a whole quadrant at once. Indirecto (1975) recommends polymerization of both sealant and adhesive at the same time through the bracket tray. Brant et al, (1975) reported their modification using a lip retractor for isolation, double-sided tape to attach brackets to the model, Optosil to fabricate the tray, and autopolymerizing Protecto as an adhesive applied to both the teeth and the backs of the brackets.

Silverman and Cohen (1976) again updated their technique introducing Auto-Tach, a self-curing thermoset material for the intraoral steps. It has a fluid consistency which eliminates the necessity of a sealant and has adequate working time but polymerizes rapidly (three minutes) at oral temperatures. They also used McSpreader cheek retractors and Dri-Angles for moisture control.

Kurz (1977) advocated the use of Genie, a self-curing adhesive which is refrigerated and mixed on a cold slab to gain working time. This material also requires no sealant or primer.

Advantages of Indirect Bonding

The advocates of this method (Silverman et al, 1972, 1976; Brandt et al, 1975; Kurz, 1977) cite as advantages more accurate bracket placement and reduced

chair time, providing better moisture control. Additional benefits, according to Cohen et al. (1974) are ease of restoration of fractured teeth during bonding and reduced inventory since the set-up can be performed by a commercial laboratory which would maintain the inventory.

The accuracy of the indirect bonding method has not been determined, nor has it been compared to that of the direct method. There are also no reported bond strength results for Bond-Eze Light-Cure, Lee-Bond, Concise, Auto-Tach, Solo-Tach or Endur.

MATERIALS AND METHODS

In Vivo Procedures

Fourteen patients of the Case Western Reserve University Orthodontic Clinic, requiring extraction of the four first premolars for treatment, were selected for the study. The only qualifications required were: a) all four first premolars must be sufficiently erupted to facilitate bonding procedures, and b) the premolars must be amenable to forceps extraction procedures under local anesthetic. A parent or guardian of each subject completed a consent form for the research project (Appendix 1).

Four commercially available direct-bonding adhesives suitable for both direct and indirect bonding procedures were selected; 1) Bond-Eze Light-Cure[1]; 2) Concise Composite-Enamel Bond Combination[2]; 3) Lee-Bond[3]; and 4) Nuva-Tach[4] (Plate 1).

Metal siamese edgewise brackets[5] (#22BC22) with perforated bicuspid contour backs were attached to the subjects' teeth using the bonding materials in both the direct and indirect methods. The subjects were assigned randomly to treatment combinations (Table 2) according to

---

1 - Unitek Corporation, Monrovia, California 91016
2 - 3M Company, St. Paul, Minnesota 55101
3 - Lee Pharmaceuticals, South El Monte, California 91733
4 - L.D. Caulk Company, Milford, Delaware 19963
5 - GAC International, Inc., Farmington, New York 11735

PLATE I

Materials use *in vivo*: Nuva-Tach, Lee-Bond, Bond-Eze Light-Cure, and Concise.


DIRECTIONS FOR BONDING ORTHODONTIC BRACKETS
Caulk Nuva System
Nuva-Tach
Nuva-Seal
Nuva-Lite
Lee-Bond
UNITEK
BOND-EZE
Direct Bonding Adhesive Kit
LIGHT-CURE
Concise
Composite
3M

a balanced incomplete block design of Cochran and Cox (1968). (Table 3)

Initial Intra-Oral Procedure

For the determination of accuracy, (direct and indirect methods) the tip of the buccal cusp of the tooth was chosen as one reference point. A superficial mark for a second reference was placed in the enamel with a #½-round high-speed carbide bur at the gingival margin in the center of the buccal surface (Plate II). For the indirect procedures alginate impressions were then obtained which included the gingival marks. The subject was dismissed for a period of time ranging from two to ten days while brackets for indirect bonding were prepared.

Indirect Preparation

The orthodontic model was painted with two coats of separating medium (Al Cote)[6]. Brackets were attached to the model using the assigned material. The desired position for placement was halfway between the two reference points with the bracket slot at the right angle to a line joining the two reference points. Concise was diluted with Enamel Bond, following the manufacturer's directions for direct bonding. Sealant was not used on the model for any material. The model with brackets attached was sprayed with a silicone release agent

6 - L.D. Caulk Company, Milford Delaware 19963

TABLE 2 - COMBINATIONS OF MATERIALS AND TECHNIQUES

TREATMENT NUMBER	MATERIAL	TECHNIQUE
1	Nuva-Tach	Direct
2	Nuva-Tach	Indirect
3	Concise	Direct
4	Concise	Indirect
5	Lee Bond	Direct
6	Lee Bond	Indirect
7	Bond-Eze Light Cure	Direct
8	Bond-Eze Light Cure	Indirect

TABLE 3 - BALANCED INCOMPLETE BLOCK DESIGN

Block	Rep. I	Rep. II	Rep. III
(1)	1 2 3 4	1 2 7 8	1 3 6 8
(2)	5 6 7 8	3 4 5 6	2 4 5 7

	Rep. IV	Rep. V	Rep. VI
(7)	1 4 6 7	1 2 5 6	1 3 5 7
(8)	2 3 5 8	3 4 7 8	2 4 6 8

	Rep. VII
(13)	1 4 5 8
(14)	2 3 6 7

PLATE II

Preparation of tooth for direct bonding

A. Tooth with gingival reference mark (arrow) etched and dried.

B. Same tooth partly coated with sealant.





(Omnidental) and placed in a Buffalo Dental Omnivac for bracket tray fabrication. Buffalo Dental Omnivac Rigid Positioner Material was used and adaptation was assisted with finger pressure on an overlying damp towel. The brackets and trays were removed from the models and the trays were trimmed to approximately 1/8 of an inch from the gingival margin. All teeth present were included in the tray for stability. Any plaster adhering to the bonding material in the bracket tray was removed with a bur. The bracket trays were then stored awaiting the bonding appointment.

Bonding Procedures (Intra-Oral)

Brackets bonded indirectly were always placed before those applied directly and the mandibular brackets were always placed prior to the maxillary with either technique of application. This sequence of procedures was necessary to facilitate indirect bonding. Manufacturers' instructions were followed explicitly for brackets bonded directly (Plate III). These directions are referenced in Appendix 2. The only modifications for brackets attached indirectly (Plate IV) were a) for all UV-cure materials, an increase in UV light exposure of 30 seconds above recommendations for direct bonding was used to compensate for the thickness of bracket tray material, and b) for Nuva-Tach, the UV light was applied

PLATE III

Bracket placement for direct bonding

A. Placement of bracket on tooth.

B. Clearing material from under the bracket tie wings.

C. Final positioning of the bracket.

PLATE IV

Bracket placement for indirect bonding

A. Bracket-Tray seated holding bracket in position.

B. UV light applied.

to the sealant and adhesive at the same time as advocated by Indirecto (1975). Etchants and Sealants (or primer) were used only with the adhesives as specified.

Flour of pumice mixed with tap water was applied with a low speed prophy brush to the four first premolars. The teeth were rinsed and McSpreaders and Dri-angles were placed. Dri-angles were used in the buccal vestibule and lingual to the mandibular teeth. No antisialogogue (Banthine) was used.

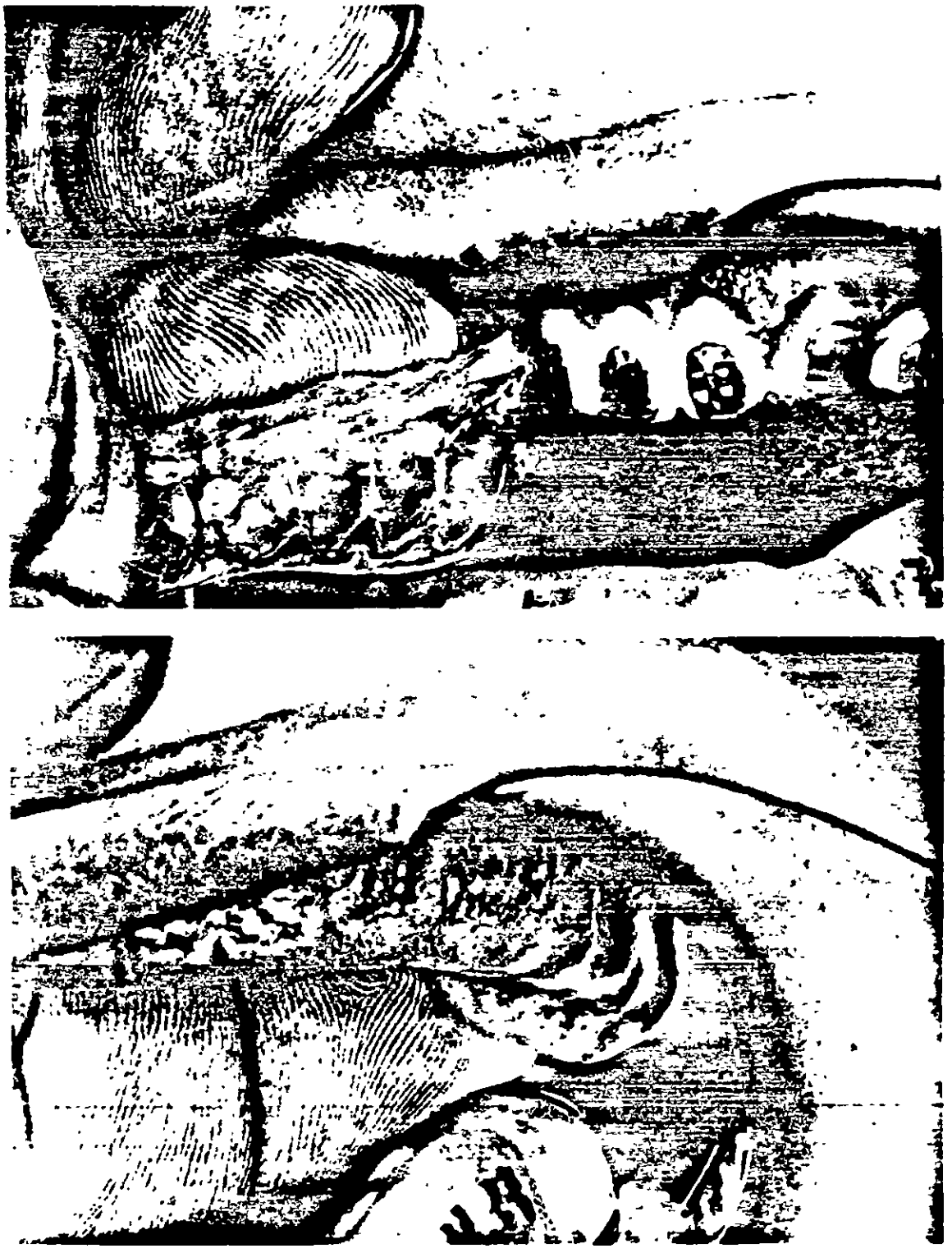
The tray was removed by grasping the disto-lingual flange, pulling it up and over the occlusal surfaces and working around to the opposite side, while turning it inside out (Plate V). Any bridging present was removed with a sickle scaler while the bracket was pressed against the tooth with finger pressure. If interferences with any brackets were present, a bite plate was seated to clear the occlusion. The patient was then dismissed for approximately 28 days with instructions to a) continue oral hygiene procedures, b) be careful when chewing and avoid hard foods, and c) save any lost brackets, if possible. At the appointed time the patient reported to the Case Western Reserve University Oral Surgery Clinic for extraction of the four first premolars. Extractions were accomplished under local anesthetic using forceps (#150 and #151) which were modified by hollow grinding to provide

PLATE V

Removal of bracket tray

A. Grasping disto-lingual flange of tray.

B. Removing tray by turning it inside out.



more clearance for the brackets (Plate VI). All teeth were labeled and stored in isotonic saline at room temperature until the entire sample was collected (an average of six weeks storage).

Accuracy Determination

First, any gingival bur marks with overlying adhesive were uncovered with a low-speed #4-round bur (Example Plate X). Care was taken to avoid contact with the bracket base. Next, the teeth were photographed with the face of the bracket perpendicular to the long axis of the camera lens.[7] Where brackets were lost intra-orally, new brackets were set on the teeth indexed in the retained adhesive for photography. (One bracket could not be indexed reliably due to insufficient adhesive). The image was then printed at 10X enlargement. The reference points (the tip of the buccal cusp and the center of the gingival mark) were then marked on each photograph in India ink, while observing the extracted natural tooth. Following this procedure the innermost corners of the bracket, in the depths of the slot, were connected diagonally forming an 'X' which market the center of the bracket. A photographic grid measuring 0.5 millimeters from center to center was used with an overgrid depicting every five millimeters. This composite grid was

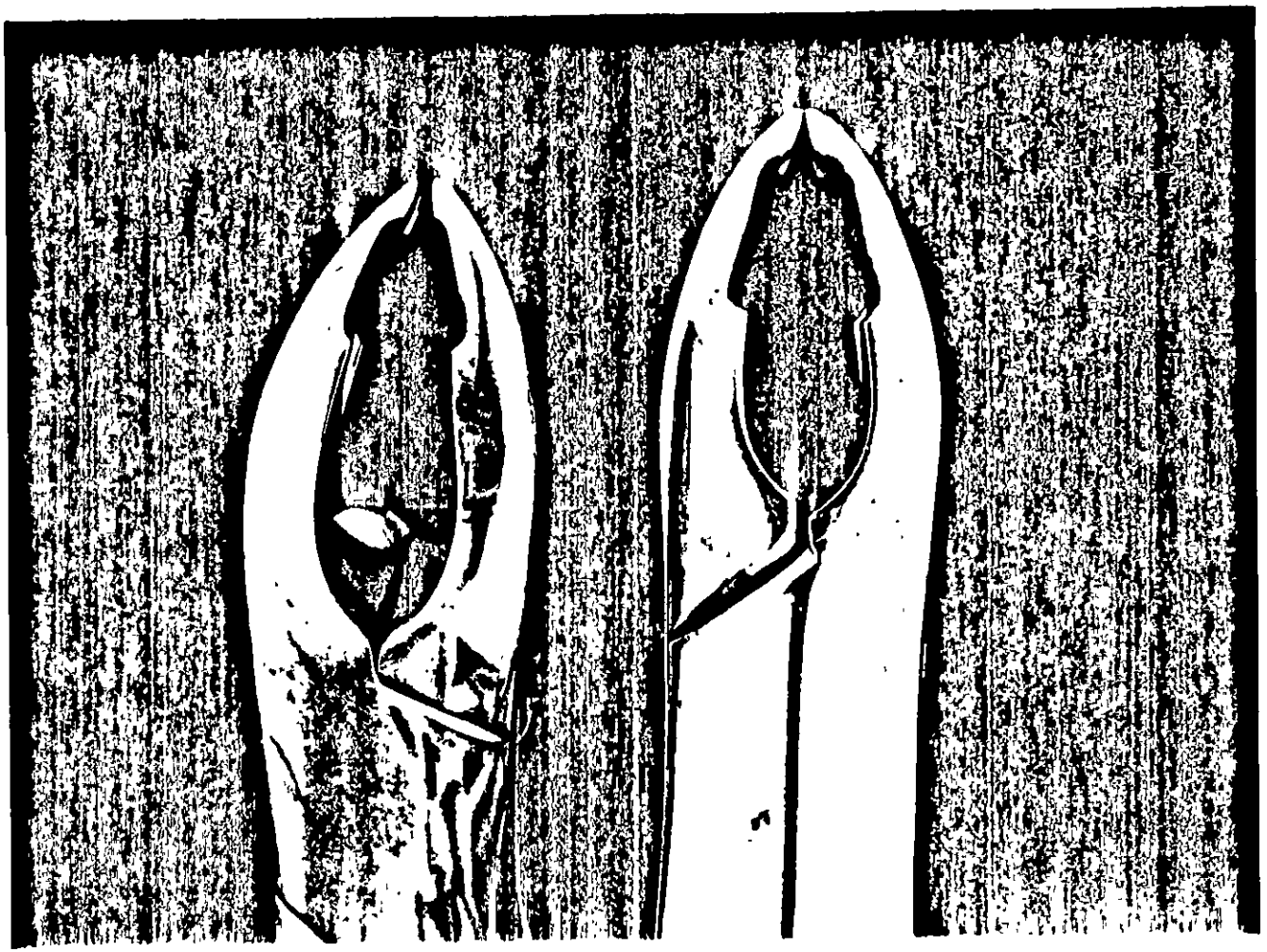
7 - A Nikon F2 was employed coupled with a bellows mounted 55mm Micro-Nikkor lens; the entire assembly was mounted on a copy stand.

PLATE VI

Forceps modified by hollow grinding tips

A. #150 Maxillary forceps.

B. #151 Mandibular forceps.



then superimposed on the two reference points and the accuracy of placement in vertical and horizontal directions was determined by recording the distance of the center of the bracket to the center of the grid (Plates VII and VIII). This gave two variables, an abscissa $^{(x)}$ and an ordinate$^{(y)}$, indicating the position of the bracket center relative to the center of the two reference points. The total magnitude of linear error was determined for each point by the formula:

Total Linear Error (in mm) $\varepsilon = \sqrt{x^2 + y^2}$

The angular error (in degrees) was determined by measuring the angle formed by the axis of the two reference points and the line of the slot edge of the gingival tie wings (Plate IX and X).

Materials Evaluation

The testing apparatus was modified from that of Schmoll (1974) to allow free rotation of the tooth in a bucco-lingual direction. The device was mounted on the cross-head of an Instron Universal Testing Machine[8]. A stepwedge was used to adjust the bucco-lingual position of the tooth-holding apparatus, so that the bracket base was parallel to the jig (.022 inch stainless-steel orthodontic wire) attached to the upper member of the testing

8 - Model No. TTCML, Serial No. 1130, Instrong Engineering Corporation, Canton, Massachusetts

PLATE IX

Photographic enlargement (10X) prepared for angular measurement. NOTE: Bracket tie wings (occlusal) are worn and distorted.

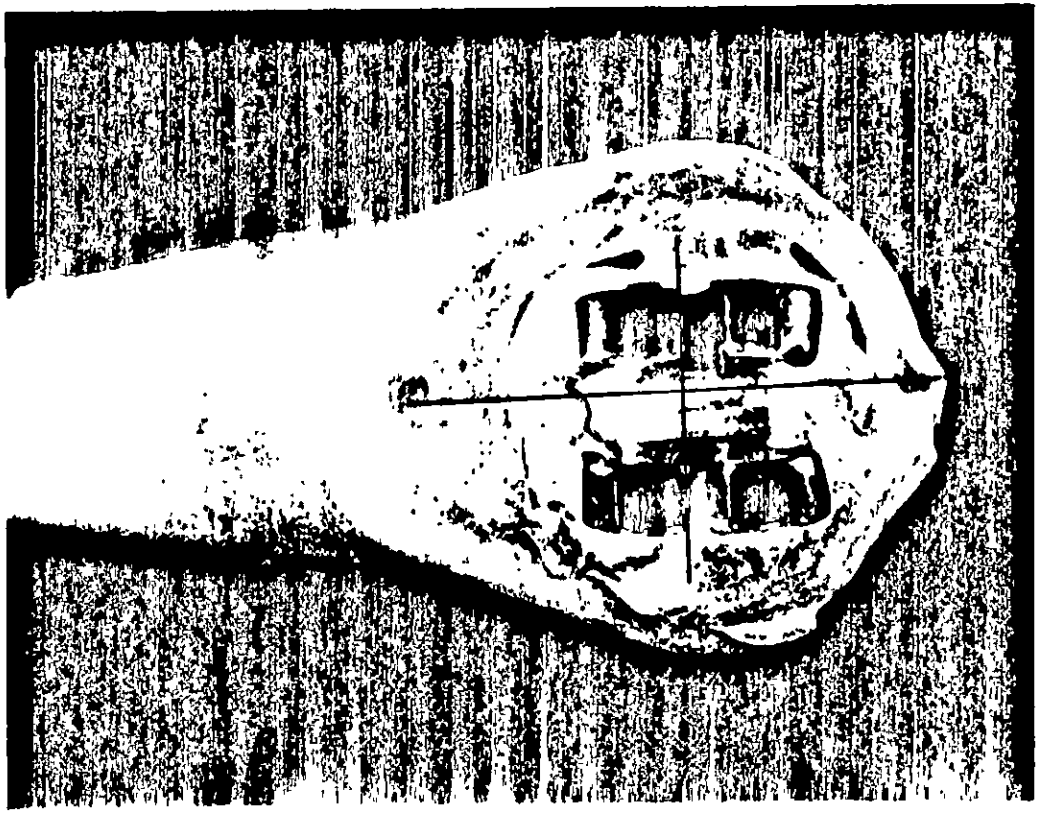
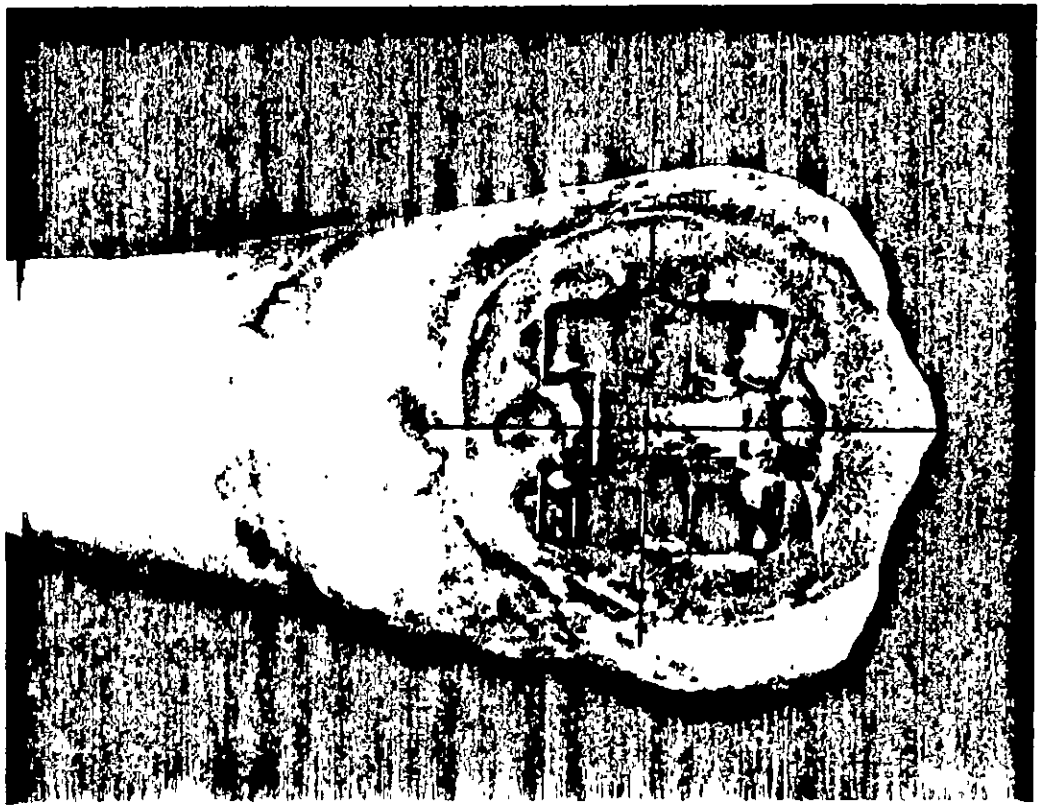


PLATE X

Photographic enlargement (10X) prepared for angular measurement. NOTE: Bracket tie wings (occlusal) are worn and distorted. This gingival reference mark was uncovered with a low-speed #4-round bur.



machine (Plate XI). The jig was placed under the occlusal tie wing of the bracket and the cross-head speed was set at 0.05 cm/per minute using a 50kg load cell. The ultimate shear force was recorded automatically on the chart recorder.

The area of the bracket base for bond strength calculations was determined by tracing one bracket base outline from a 10X photograph on a piece of acetate tracing paper. This was cut and weighed along with a standard cutout ($16cm^2$) from the same piece of acetate. The bracket base area was calculated according to the following formula:

$$\text{Enlarged Bracket Base Area} = \frac{16cm^2 \times \text{wt. of bracket base cutout}}{\text{wt. of standard cutout}}$$

$$= 16 \times \frac{160}{150} = 17.067cm^2$$

$$\text{Actual Bracket Base Area} = \frac{17.067cm^2}{100} = .17067cm^2$$

The force measurement for each shear test was converted to bond strength using the following formula:

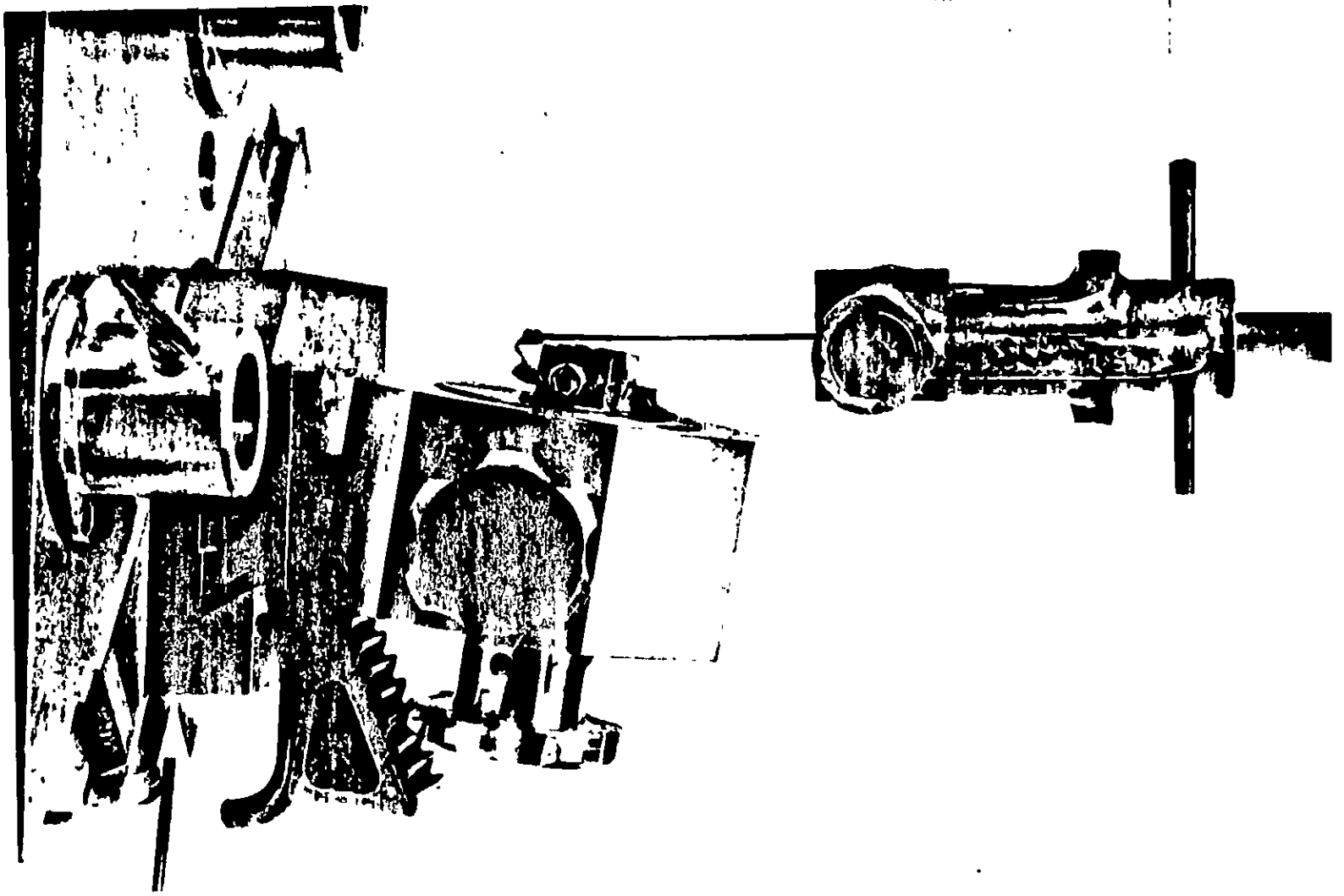
$$\text{Bond Strength } (Kg/cm^2) = \frac{\text{Shear Force}}{\text{Bracket Base Area}}$$

Bond strengths in Kg/cm^2 were converted to Bond Strengths in PSI by the following formula:

$$\text{Bond Strength PSI} = 14.2247 \frac{PSI}{Kg/cm^2} \times \text{Bond Strength } kg/cm^2$$

PLATE XI

Bond strength testing device. NOTE: Step wedge behind device holds the pre-selected angle.



A two-way analysis of variance with interaction, and Duncan's New Multiple-Range Test were performed on the bond strength data in Kg/cm^2. The formula for Duncan's New Multiple Range Test (Steel and Torrie, 1960) is:

$$Q\sqrt{\frac{MS}{n_n}}$$ where MS = Error mean square and n_n is effective number of repetitions

$$n_n = \frac{1}{\frac{1}{\#\ cells}\left(\frac{1}{n_1} + \frac{1}{n_2} + \ldots \frac{1}{n_{last}}\right)}$$ (Snedecor and Cochran 1967)

Each tooth and bracket (except those lost intra-orally) were examined under a dissecting microscope in an attempt to determine the location and character of the bond failure.

In Vitro Procedures

Samples of Auto-Tach, Solo-Tach, and Endur were not available when the protocol was set, for the *in vivo* investigation. As a result a second investigation was undertaken using an *in vitro* sample to test the four materials used *in vivo* plus Auto-Tach[9], Solo-Tach[10], and Endur[11] for bond strength only.

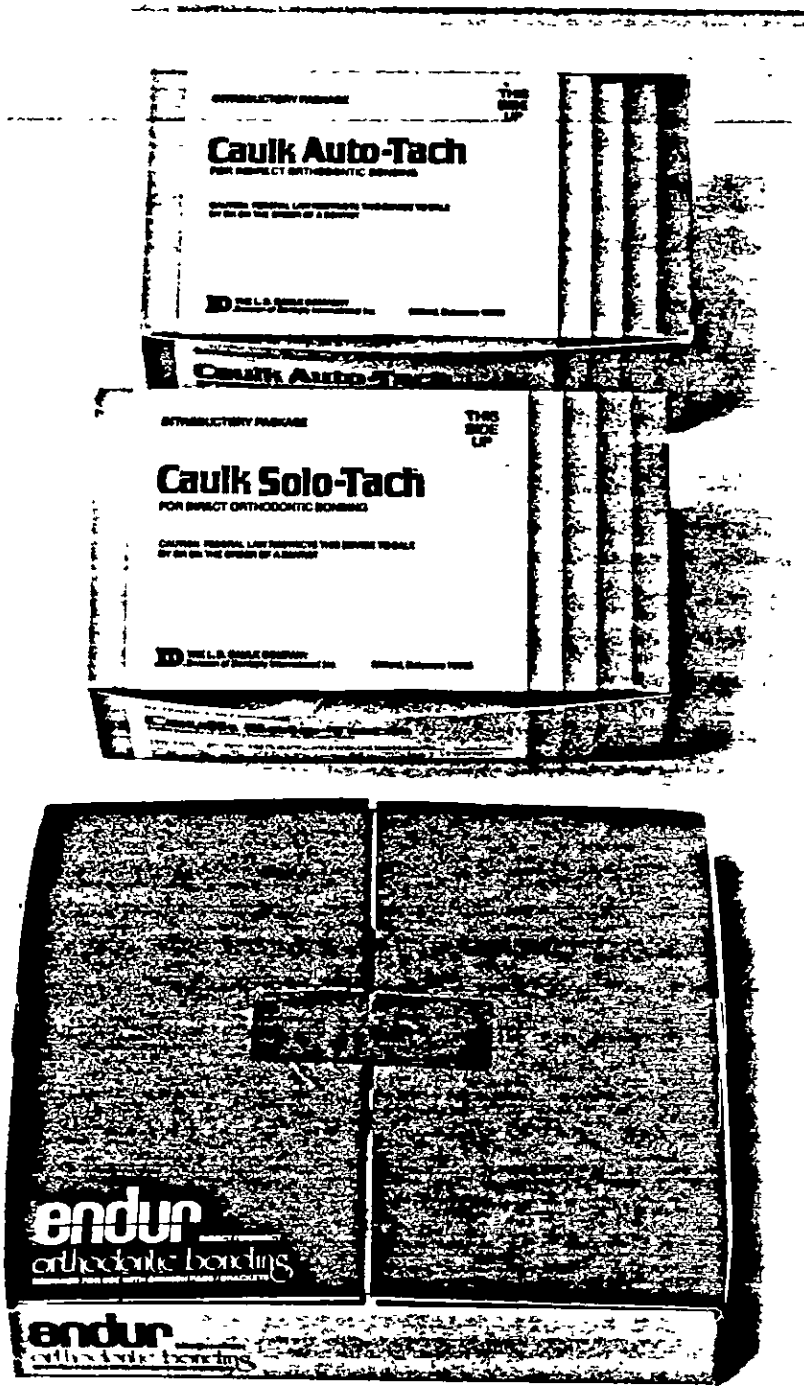
Extracted human premolars were collected and stored at room temperature in isotonic saline. They were divided randomly into seven groups of three. (Plate XII)

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9 - L.D. Caulk Company, Milford, Delaware 19963
10 - L.D. Caulk Company, Milford, Delaware 19963
11 - Ormco Corporation, Glendora, California 91740

PLATE XII

Materials used *in vitro*: Auto-Tach, Solo-Tach, and Endur.


Caulk Auto-Tach
Caulk Solo-Tach
endur
orthodontic bonding

The same bracket with perforated metal base was used throughout (although directions for Endur specifically state "Endur is not intended for use with plastic brackets or perforated metal bases.") All materials were used directly on the extracted teeth (although Auto-Tach is specifically formulated for "indirect placement methods".) Bond strength determinations and conversions to PSI followed the same methods as described for the in vivo study. Testing was performed following three months immersion in isotonic saline at room temperature.

Statistical analysis utilized a standard one-way analysis of variance and Duncan's New Multiple-Range Test.

RESULTS

Raw data for the error study to determine accuracy of bracket placement appear in Appendices 3, 4 and 5. The number of bonds that failed intraorally are noted in these appendices. None of these brackets were returned to the investigator. Means and Standard Errors for vertical, horizontal, total linear, and angular error are listed in Table 4. Two-way analyses of variance for total linear error and angular error (Tables 5 and 6) revealed no interaction and no significant differences between methods.

In vivo bond strengths in Kg/cm^2 and PSI are exhibited in Tables 7 and 8.* Table 9 presents the two-way analysis of variance with interaction for material and method. Only differences in materials were significant. Duncan's New Multiple-Range Test is shown in Table 10, which demonstrates that Concise and Lee-Bond are significantly stronger than Nuva-Tach and Bond-Eze Light-Cure.

Tables 11 and 12 contain the in vitro bond strengths in Kg/cm^2 and PSI respectively. Results of the one-way analysis of variance are provided in Table 13, and of Duncan's New Multiple-Range Test in Table 14.

---

* The bonds that failed intraorally or during testing procedures are denoted in these tables. Descriptions of these failures are included in the Discussion.

TABLE 4 - ACCURACY OF BRACKET PLACEMENT. MEANS AND STANDARD ERRORS

Vertical Error in Millimeters

	Direct	Indirect
$\bar{y}$	0.0176	0.0198
S.E.	0.0231	0.0236

Horizontal Error in Millimeters

	Direct	Indirect
$\bar{x}$	0.0139	0.0145
S.E.	0.0225	0.0227

Total Linear Error in Millimeters

	Direct	Indirect
$\bar{\epsilon}$	0.0252	0.0270
S.E.	0.0227	0.0248

Angular Error in Degrees

	Direct	Indirect
$\bar{\theta}$	2.3333	1.5714
S.E.	0.4713	0.2147

TABLE 5 - ACCURACY OF BRACKET PLACEMENT

ANOVA for Total Linear Error

Source	df	SSQ	MSQ	F	P
Material	3	0.085	0.028	1.867	NS
Method	1	0.005	0.005	0.333	NS
Interaction	3	0.017	0.006	0.400	NS
Subtotal	7	0.107			
Error	47	0.723	0.015		
TOTAL	54	0.830			

$F_{(3,47)}^{0.05} = 2.82$

$F_{(1,47)}^{0.05} = 4.06$

TABLE 6 - ACCURACY OF BRACKET PLACEMENT

ANOVA for Angular Error

Source	df	SS	MS	F	P
Material	3	1.07	0.357	0.0906	NS
Method	1	7.98	7.98	2.025	NS
Interaction	3	4.45	1.48	0.376	NS
Subtotal	7	13.50			
Error	47	185.336	3.94		
TOTAL	54	198.836			

$F_{(3,47)}0.05 = 2.82$

$F_{(1,47)}0.05 = 4.06$

Table 7 - Legend

a - bond failed intraorally

b - bond failed during preparation for testing

c - #4 round bur used to uncover gingival reference mark for accuracy study

d - bond failed at less than maximum recorded force. Tabled value is the strength corresponding to maximum recorded force.

TABLE 7 - IN VIVO BOND STRENGTHS (Kg/Cm^2)

	Nuva-Tach		Bond-Eze		Concise		Lee-Bond	
	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect
RH 1		96.1[c]		56.3[d]	106.1		131.3[c]	
DC 2		118.9	62.1		148.8			118.4[c]
AW 3	126.6	81.4[c]			137.1	135.4[c]		
PJ 4			35.2	69.1[c]			97.3	168.2
DM 5	68.6			72.1		188.1[c]	133.6	
RA 6					93.2	86.1[c]	110.7	121.9[c]
MS 7		172.3[c]	73.2			137.1[c]	a	
JB 8	70.9			72.7	107.8			209.2
LA 9	35.2	21.1					112.5	48.0
TJ 10		68.0[c]		68.6		206.3		62.1
JK 11			a,c	a,c	155.9	157.6[c]		
JC 12	90.8		a,c			128.9[c]		62.1[c]
CK 13	54.5[c]	36.3[d]	b	82.0				
LG 14	89.1		a,c		152.3		a	

Table 8 - Legend

a - bond failed intraorally

b - bond failed during preparation for testing

c - #4 round bur used to uncover gingival reference mark for accuracy study

d - bond failed at less than maximum recorded force. Tabled value is the strength corresponding to maximum recorded force.

TABLE 8 - IN VIVO BOND STRENGTHS (PSI)

	Nuva-Tach		Bond-Eze		Concise		Lee-Bond	
	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect
RH 1		1366.9[c]		800.1[d]	1508.6		1867.0[c]	
DC 2		1692.0	883.5		2117.0			1683.6[c]
AW 3	1800.3	1158.5			1950.3	1925.3[c]		
PJ 4			500.1	983.5[c]			1383.6	2392.1
DM 5	975.2			1025.2		2675.5	1900.3	
RA 6					1325.2[c]	1225.2[c]	1575.3	1733.6[c]
MS 7		2450.4[c]	1041.8			1950.3[c]	a	
JB 8	1008.5			1033.5[c]	1533.6			2975.5
LA 9	500.1	300.1					1600.3	683.5
TJ 10		966.8[c]		975.2		2933.8		883.5
JK 11			a,c	a,c	2219.1	2242.1		
JC 12	1291.9		a,c			1833.7		883.5
CK 13	775.1[c]	516.8[d]	b	1166.9				
LG 14	1266.9		a,c		2167.0		a	

TABLE 9 - ANOVA FOR IN VIVO BOND STRENGTHS (Kg/cm^2)

Source	df	SSQ	MSQ	F	P
Material	3	38866.91	12955.64	9.13	0.01
Method	1	390.37	390.37	0.28	NS
Interaction	3	1625.84	541.95	0.38	NS
Subtotal	7	40883.12			
Error	41	58191.01	1419.29		
TOTAL	48	99074.13			

$F_{(3,41)}{}^{0.05} = 2.84$

$F_{(3,41)}{}^{0.01} = 4.30$

TABLE 10 - DUNCAN'S NEW MULTIPLE-RANGE TEST FOR MATERIALS USED IN VIVO

	Concise	Lee-Bond	Nuva-Tach	Bond-Eze
$\bar{x}$	138.616	114.600	80.692	65.690

NS at 0.05 NS at 0.05

NS at 0.01

TABLE 11 - IN VITRO BOND STRENGTHS (Kg/cm^2)

Sample	Auto-Tach	Solo-Tach	Endur	Bond-Eze Light Cure	Con-cise	Lee-Bond	Nuva-Tach
1	146.5[a]	127.1	b	49.2	100.2	64.5	93.2
2	138.9	223.8	48.0	47.5	c	133.0	121.3
3	238.5	138.3	49.8	60.9	80.3	86.7	102.5

a - Enamel fractured at the dento-enamel junction. Bond to enamel did not fail.

b - Bond failed during preparation for testing.

c - Enamel with bracket still attached fractured at dento-enamel junction during preparation for testing.

TABLE 12 - IN VITRO BOND STRENGTH (PSI)

Sample	Auto-Tach	Solo-Tach	Endur	Bond-Eze Light Cure	Concise	Lee-Bond	Nuva-Tach
1	2083.7[a]	1808.6	b	700.1	1425.2	916.8	1325.2
2	1975.3	3183.9	683.5	675.1	c	1892.0	1725.3
3	3392.3	1967.0	708.5	866.8	1141.9	1233.5	1458.6

a - Enamel fractured at the dento-enamel junction. Bond did not fail.

b - Bond failed during preparation for testing.

c - Enamel with bracket still attached fractured at dento-enamel junction during preparation for testing.

TABLE 13 - ANOVA FOR BOND STRENGTH IN VITRO (Kg/cm^2)

Source	df	SSQ	MSQ	F	P
Treatment	6	39797.804	6632.967	5.340	0.01
Within	12	14906.366	1242.197		
TOTAL	18	54704.17			

$F_{(6,12)}^{0.05} = 3.00$

$F_{(6,12)}^{0.01} = 4.82$

TABLE 14 - DUNCAN'S NEW MULTIPLE-RANGE TEST

	Auto-Tach	Solo-Tach	Nuva-Tach	Lee-Bond	Concise	Bond-Eze	Endur
$\bar{x}$	174.609	163.086	105.664	94.727	90.234	52.539	48.929

NS at 0.05 (Nuva-Tach, Lee-Bond, Concise, Bond-Eze, Endur)

NS at 0.05 (Auto-Tach, Solo-Tach)

NS at 0.05 (Solo-Tach, Nuva-Tach)

NS at 0.01 (Auto-Tach, Nuva-Tach, Lee-Bond, Concise, Bond-Eze, Endur)

DISCUSSION

The objective of this study was to determine and compare the accuracy of bracket placement by the direct and indirect methods of orthodontic bonding, and to compare bond strengths obtained with some of the newer commercially available bonding materials.

All of the materials tested were BIS-GMA based materials. All of the etchants were phosphoric acid at varying concentrations (Table 15). Two etchants also contained a thixotropic additive to provide gel properties. The Unitek etching gel was easier to rinse than the Lee-Bond gel, but both required more vigorous flushing for removal than any of the liquid forms. Considering the results of Retief (1975) on effectiveness of various concentrations, a more cautious selection of 10 to 30 percent phosphoric acid for etching may be conducive to greater biocompatability with soft tissues. In the present study, perforated bracket backings were used. These backs require time to clear tie wings, so foil-covered mesh backs used with auto-cure materials might be more efficient if it can be domonstrated that they are capable of sufficiently strong bonds with the various materials currently in use.

There were six bond failures intraorally. Reasons given were: 1) eating, 2) during sleep, 3) while returning home from the bonding appointment. Examination

TABLE 15 - ETCHANTS

MATERIAL	CONCENTRATION	FORM
Auto-Tach	50%	liquid
Solo-Tach	50%	liquid
Nuva-Tach	50%	liquid
Bond-Eze Light Cure	60%	gel
Concise	37%	liquid
Endur	50%	liquid
Lee-Bond	35%	gel

of these brackets was not possible since none were returned. Several bonds also failed during the preparation for testing bond strengths. One bond of the in vivo sample failed during mounting. Two bonds failed at less than the recorded maximum force. This occured as the jig slipped under the bracket tie wings which were partly occluded by bonding materials. In these cases the maximum recorded force was used for bond strength calculations. In the in vitro sample, one bond failed during preparation for testing, and for two teeth the enamel detached at the dento-enamel junction with the bond and bracket intact. One of these failures occured during preparation for testing, when the enamel was inadvertently crushed in the vise. The other enamel failure occured during testing under a relatively heavy load. For a few brackets the occlusal tie wings were severly worn and distorted while in vivo (Plates VIII, IX, and X). Due to these cases the gingival tie wings were used for angular accuracy measurements, and the depths of the bracket slots were used to determine the center of the bracket for linear accuracy data.

In this study, the measurement of vertical, horizontal, total linear, and angular error revealed no significant ($\alpha = 0.05$) differences in bracket placement. However, in placing the gingival reference marks on the teeth intraorally, then examining the model, the extracted

teeth or the photographs, it was generally found that the marks were not in the anatomically correct location Plate VIII). This was especially true in cases where bicuspids were rotated or crowded and the gingival architecture was irregular. It would appear that accuracy of bracket placement is more dependent upon the perception of the operator than the method of application and that interference of oral soft tissues (i.e. lips and cheeks) is minimal. However, operator stress in maintaining bracket position during the set of the material may be reduced significantly by the indirect method. Use of an antisialogogue would help control moisture contamination for most patients and, therefore, help to reduce stress.

Difficulty in holding teeth firmly without fracture was encountered during testing while applying the shear force. This was due to the varying angle between the long axes of the crown and root. The device of Schmoll (1974) required modification to permit clamping of the tooth in the hollow-ground, serrated vise and then to allow application of the force in a shear mode. In the present study, approximately 30 degrees free range of rotation of the vise was provided in a bucco-lingual direction. The desired angle was selected and a step-wedge was inserted as a shim to hold the position during testing. This modification was necessary due to greater

magnitude of force required to cause bond failure with some of these newer materials. As an example, the greatest bond strengths in Schmoll's study were 1807 PSI *in vivo* and 1679 PSI *in vitro* compared with maxima in the present study of 2934 PSI *in vivo* and 3392 PSI *in vitro*. For shear strength testing, the apparatus should be designed to rotate about two axes so as to adjust the force application at an angle of 180 degrees to the enamel surface. The vise should be hollow ground on both sides to better hold the roots of the teeth.

Since the *in vivo* study was a comparison of the direct and indirect methods under clinical conditions it was not possible to control the area of the adhesive-enamel interface. Thus the bracket base area was used for bond strength calculations. In the *in vitro* study, no attempt was made to limit the area of enamel covered by adhesive since Reynolds and von Fraunhofer (1976a) showed the area of the bond does not influence its strength, and disturbing auto-cure materials during setting weakens them. Therefore, bond strengths were again calculated using the area of the bracket base. It should be noted that for one tooth, the enamel fractured at the dento-enamel junction at 2083 PSI (146.5 Kg/cm^2) although the bond did not fail.

Because of inconsistencies in methods of determining bracket base area, and the different brackets and

bases tested among studies in the literature, it may not be valid to compare the present bond strength values with those reported earlier. However, all materials in the present study were handled and analyzed uniformly so comparisons of these strengths are possible.

Of the materials tested in vivo, Concise and Lee-Bond were both significantly stronger than Nuva-Tach and Bond-Eze Light-Cure at $p = 0.05$. Of all the materials tested in vitro, Auto-Tach proved significantly superior to all others except its counterpart for direct bonding, Solo-Tach. However, only one bond in the entire study was below the 400 to 500 PSI Newman, et al, (1965) recommended as a minimum and all but one of the rest were well above that level. There were significant ($p = 0.01$) differences among the strengths of bonding systems employed in both sections of the study.

At the bond strengths demonstrated in this study it would seem that bonding materials available today are considerably stronger than their counterparts of three years ago (1974), and in general, are very acceptable clinically. Clinical observations concerning handling of materials used in this study are considered in Appendix 2.

Although instructions for Endur specifically recommend against using perforated metal bracket bases, none of the failures occured at the bracket base. There were a total of six purely cohesive failures of which five

occurred on indirectly placed brackets. Therefore, it would seem the separating medium used on the models might interfere with the reactivity of the surface of the first phase of material or else the materials do not as readily bond to previously set material. Both of these possibilities should be investigated further.

Brackets attached with Bond-Eze and Lee-Bond had respectively five and six brackets with unpolymerized material directly under the bracket. This would seem to indicate the setting reaction does not occur where exposure to the UV light is prevented. In vitro the UV cure materials were not so markedly porous as the auto-cure materials.

SUMMARY AND CONCLUSIONS

The objective of this study was to determine and compare the accuracy of placement of bonded metal orthodontic brackets by the direct and indirect methods, also, bond strengths in the shear mode were determined for four bonding systems placed *in vivo*: Bond-Eze Light-Cure, Concise, Lee-Bond, and Nuva-Tach.

Fourteen orthodontic patients requiring extraction of the four first premolars were utilized in the study. The teeth were marked superficially before bonding for accuracy determinations. The bonding material used and the method of bracket application for each tooth was assigned, using a balanced incomplete block design. Teeth were extracted after approximately 28 days *in vivo* and measurements for bracket placement were made from photographic enlargements. Bond strengths in a shear mode were determined using an Instron Universal Testing Machine.

A separate experiment compared *in vitro* shear strengths of the same four materials plus three additional new bonding materials: Auto-Tach, Endur, and Solo-Tach. These bond strengths were determined following three month's immersion in isotonic saline.

Analyses of variance were performed and means were compared with Duncan's New Multiple-Range Test. The results of this study may be summarized as follows:

1. There was no significant ($P > 0.05$) difference in accuracy of bracket placement of the two methods. This may be attributed to the fact that the design eliminated factors of operator perception.

2. There were significant ($P < 0.05$) differences in the bond strengths among materials tested. Concise and Lee-Bond were both significantly stronger than Nuva-Tach and Bond-Eze *in vivo*. Auto-Tach and Solo-Tach were both significantly stronger than all other materials except Nuva-Tach *in vitro*.

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APPENDIX I

CASE WESTERN RESERVE UNIVERSITY CONSENT FORM

After careful evaluation of your child's records by the orthodontic department instructors, it has been determined that there is inadequate space in your child's jaws to align all teeth. Orthodontic treatment of your child will require the removal of four bicuspid teeth in order to create enough room to align the rest of the teeth in proper position.

These extracted teeth would normally serve no useful purpose; however, a study is being conducted by Dr. Bates to use these teeth to gain valuable information about orthodontic treatment. This study requires that 30 days before the extraction of teeth, they be marked superficially and have the usual metal orthodontic brackets bonded to the enamel with adhesives which are commercially available and commonly used by many orthodontists.

The study concerns the strengths of different bonding materials and the accuracy of bracket placement. After this 30-day period, the extractions will be done in the Case Western Reserve Oral Surgery Clinic under local anesthetic with commonly used extraction techniques. The teeth will be kept for research purposes.

****

I have read the above statement and Dr. Bates has explained anything not clear in terms I understand. I hereby consent to allow my child to volunteer in this clinical investigation realizing that the study will in no conceivable way effect the results or increase the time of orthodontic treatment. I understand that all information will be kept confidential, and that I may withdraw my child from the study at any time.

Signature - Parent or Guardian _____

Witness _____ Date _____

APPENDIX II

Materials Utilized

I. UV Light Source

A. Nuva-Lite, L.D. Caulk Company, Milford, Delaware 19963

1. Model No. L101
2. Serial No. 2609

II. Bonding Materials

A. Auto-Tach, L.D. Caulk Company, Milford, Delaware 19963

1. Catalog No. 1264-849004
2. Lot Nos.

a. Catalyst 111676
b. Catalyst Activator 11876
c. Base 111776

3. Instructions: Form No. AT-100 (11/76)
4. Clinical Observations:

a. Auto-curing
b. No primer or sealant required
c. Fluid enough to easily coat bracket bases
d. Ample working time when mixed on a chilled slab

B. Bond-Eze Light-Cure, Unitek Corporation, Monrovia, California 91016

1. Catalog No. 712-007
2. Lot. No. 090876
3. Instructions: Form No. 11-216
4. Clinical Observations:

a. UV curing
b. Thickest of tested materials
c. Very little flow or bracket float
d. Settles to powder and liquid after packaging and is difficult to mix initially

C. Concise Combination Kit (Enamel Bond and Composite), 3M Company, St. Paul, Minnesota 55101

1. Catalog No 1925E
2. Lot No. 6296RR17
3. Instructions: Technique Sheet for Orthodontic Bonding of Metal Brackets (3M Company Dental Products)
4. Clinical Observations:

    a. Auto-curing
    b. If undiluted is too stiff and stands up under and occludes bracket tie wings
    c. Easily over diluted causing excessive bracket float (several brackets fell off the tooth after placement but prior to final positioning due to gravity)

D. Endur, Ormco, Glendora, California 91740

1. Catalog No. 740-0020
2. Lot Nos.

    a. Sealant Resin 6G050
    b. Sealant Catalyst 6G060
    c. Adhesive Resin 6E040
    d. Adhesive Catalyst 6E040

3. Instructions: In packaging of materials 1976
4. Clinical Observations:

    a. Auto-curing
    b. Two gels which mix readily and are easy to apply

E. Lee-Bond, Lee Pharmaceuticals, South El Monte, California 91733

1. Catalog No. 3030-100
2. Lot No. LB0005
3. Instructions: Technical Bulletin No. 3030
4. Clinical Observations:

    a. UV curing
    b. Consistance is more fluid than Nuva-Tach but not as fluid as the auto-curing materials.
    c. Uses a primer that does not require UV

light polymerization.

F. Nuva-Tach, L.D. Caulk Company, Milford, Delaware 19963

1. Catalog No. 1264-848006
2. Lot. No. 1264-848006
3. Instructions: Form No. NUVA-500 (R-6/76)
4. Clinical observations:

    a. UV curing
    b. More fluid than Bond-Eze
    c. Slightly more awkward to apply to backs of brackets than Lee-Bond

G. Solo-Tach, L.D. Caulk Company, Milford, Delaware 19963

1. Catalog No. 1264-850004
2. Lot Nos.

    a. Catalyst 111976
    b. Catalyst Activator 112076
    c. Base 112076

3. Instructions: Form No. ST-100 (11/76)
4. Clinical Observations:

    a. Slightly thicker than Auto-Tach
    b. Fluid enough to be easily applied to bracket bases
    c. Very little if any bracket float

APPENDIX III - LINEAR ERROR IN TENTHS OF A MILLIMETER

Material	Direct				Indirect			
	Measured Coordinates	Error Vert.	Error Horiz.	Total	Measured Coordinates	Error Vert.	Error Horiz.	Total
Nuva-Tach	1- (0.1,-2.2)	.22	.01	.2202	1- (0,7,0.5)	.05	.07	.0860
	2- (0.7,2.5)	.25	.07	.2596	2- (2.9,1.3)	.13	.29	.3178
	3- (-0.4,-2.2)	.22	.04	.2236	3- (-0.2,-1.3)	.13	.02	.1315
	4- (0.8,-1.8)	.18	.08	.1970	4- (1.9,1.4)	.14	.19	.2360
	5- (1,-1.7)	.17	.10	.1972	5- (0.7,0.1)	.01	.07	.0707
	6- (-0.3,-3.25)	.33	.03	.3264	6- (-0.3,-3)	.30	.03	.3015
	7- (0.1,-1.6)	.16	.01	.1603	7- (01,1.2)	.12	.10	.1562
Bond-Eze	*1- (0.7,-2.75)	.28	.07	.2838	*1- (-2.2,3.1)	.31	.22	.3801
	*2- (-2,-1.5)	.15	.20	.2500	2- (1.9,3.8)	.38	.19	.4248
	3- (1.8,0)	.00	.18	.1800	3- (0.7,1.7)	.17	.07	.1838
	*4- (1,1.6)	.16	.10	.1887	4- (0.2,1.8)	.18	.02	.1811
	5- (-0.5,0)	.00	.05	.0500	5- (-3,0.1)	.01	.30	.3002
	6- (0.5,-2.7)	.27	.05	.2746	6- (1.3,1.3)	.13	.13	.1838
	7- (-3,-2.75)	.28	..3	.4070	7- (0,-1.8)	.18	.00	.1800

* Brackets repositioned for error study after bond failure intraorally.

APPENDIX III (con't) LINEAR ERROR (0.1mm)

	Direct				Indirect			
		Error				Error		
Material	Measure	Vert.	Horiz.	Total Error	Measure	Vert.	Horiz.	Total
Concise	1- (0.5,3.5)	.35	.05	.3536	1- (-3.3,3.2)	.32	.33	.4597
	2- (-0.75,-0.25)	.025	.075	.0790	2- (-1.25,3.5)	.35	.125	.3716
	3- (1.4,-0.2)	.02	.14	.1414	3- (3.3,1.5)	.15	.33	.3625
	4- (-0.75,1.8)	.18	.075	.195	4- (-1.2,1.3)	.13	.12	.1769
	5- (2.8,-3.8)	.38	.28	.4720	5- (-1.7,3.5)	.35	.17	.3891
	6- (2.3,4.4)	.44	.23	.4965	6- (-0.8,-0.8)	.08	.08	.1131
	7- (2,-0.5)	.05	.2	.2062	7- (1.8,-0.8)	.08	.18	.1970
Lee-Bond	1- (4,-0.5)	.05	.4	.4031	1- (-2,4.75)	.475	.2	.5154
	2- (4.3,-1.75)	.175	.43	.4642	2- (1.1,1.1)	.11	.11	.1556
	*3- (-1.2,1.2)	.12	.12	.1697	3- (0.5,3)	.3	.05	.3041
	4- (1.6,2)	.2	.16	.2561	4- (5.1,1.3)	.13	.51	.5263
	5- (-0.2,-0.9)	.09	.02	.0922	5- (-0.75,4.3)	.43	.075	.4365
	6- (2.7,0.25)	.025	.27	.2712	6- (0.7,-2.1)	.21	.07	.2214
	**7-				7- (0.2,-2)	.2	.02	.2010

* Brackets repositioned for error study after bond failure intraorally.
** Bracket could not be indexed on tooth with reliability following intraoral bond failure.

APPENDIX IV

ANGULAR ERROR (Degrees)

Material	Direct		Indirect	
	Measure	Error	Measure	Error
Nuva-Tach	1- 90°	0	1- 93°	3
	2- 92°	2	2- 87°	3
	3- 92°	2	3- 91°	1
	4- 87°	3	4- 88°	2
	5- 88°	2	5- 90°	0
	6- 92°	2	6- 93°	3
	7- 91°	1	7- 91°	1
Bond-Eze	*1-100°	10	*1- 90°	0
	*2- 90°	0	2- 89°	1
	3- 91°	1	3- 89°	1
	*4- 91°	1	4- 89°	1
	5- 89°	1	5- 93°	3
	6- 93°	3	6- 89°	1
	7- 86°	4	7- 93°	3
Concise	1- 97°	7	1- 91°	1
	2- 89°	1	2- 92°	2
	3- 89°	1	3- 90°	0
	4- 90°	0	4- 89°	1
	5- 93°	3	5- 88°	2
	6- 88°	2	6- 91°	1
	7- 93°	3	7- 94°	4

Material	Direct		Indirect	
	Measure	Error	Measure	Error
Lee-Bond	1- 90°	0	1- 87°	3
	2- 93°	3	2- 90°	0
	*3- 82°	8	3- 88°	2
	4- 89°	1	4- 90°	0
	5- 91°	1	5- 92°	2
	6- 91°	1	6- 91°	1
	7- --	-	7- 92°	2

* Brackets repositioned for error study after bond failure intraorally.
** Bracket could not be indexed on tooth with reliability following intraoral failure.