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Fracture Resistance of Extensive Amalgam Restorations Retained by Pins, Amalgapins and Amalgam Bonding Agents

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Clinical Relevance

Amalgam bonding agents provided as much retention and resistance for extensive amalgam restorations as traditional mechanical methods of retention.

SUMMARY

This *in-vitro* study compared the resistance of extensive amalgam restorations retained by either four Regular TMS Link Plus pins, four amalgapins, Amalgambond Plus, Amalgambond Plus with HPA, Scotchbond Multi-Purpose Plus, PQ Amalgam, Panavia F 2.0, All-Bond 2 or Resinomer. Ninety caries-free third molars were embedded in acrylic resin and their occlusal surfaces reduced to within 2 mm of their CEJ. Tytin amalgam alloy was hand-condensed into copper band matrices reinforced with modeling compound after placement of mechanical retention or application of the amalgam bonding agents. Modeling compound and copper bands were removed after 24 hours, and the restorations were adjusted to produce specimens 5 mm in height with a 1 mm bevel on the occlusal-axial surface. The specimens were stored in 100% humidity for one month followed by immersion in de-ionized water for 24 hours at 37°C. The specimens were loaded in compression at a 45° angle in an Instron Universal Testing Machine at a crosshead speed of 0.02 inches/minute. The mean failure loads and standard deviations recorded in Newtons were as follows: Amalgambond Plus with HPA 2160N (380), Scotchbond Multi-Purpose Plus 1900N (380), four Amalgapins 1770N (340), PQ Amalgam 1660N (270), Panavia F 2.0 1620N (440), Amalgambond Plus 1570N (390), four Regular TMS Link Plus Pins 1325N (406), All-Bond 2 1300N (390) and Resinomer 1245N (310). A one-way ANOVA and Tukey post hoc analysis indicated all amalgam bonding agents were statistically equal to either four Regular TMS Link Plus pins or four amalgapins.

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INTRODUCTION

A well-placed extensive amalgam restoration, replacing one or more cusps, may provide a long-term successful alternative to a cast restoration. Clinical success rates for extensive amalgam restorations have been reported to be 50% at 11.5 years and as high as 73% at 15 years.[1-2] Historically, extensive amalgam restorations have been retained with pins. *In-vitro* studies and clinical experience have demonstrated favorable results with the use of self-threading pins.[1-4] The most widely used self-threading pin system is the Thread Mate System or TMS (Coltene/Whaledent, Cuyahoga Falls, OH, USA). TMS offers a variety of pin sizes, color-coding, gold plating to reduce corrosion and a self-limiting collar to decrease stress in the adjacent dentin. Generally, larger pins provide more retention than smaller pins.[3] Determining the number of pins per restoration remains subjective. A conservative guide of one pin per missing cusp is usually more than adequate. Despite clinical success, pin placement may cause pulpal inflammation,[5] crazing of dentin[6] and decreased tensile, compressive and transverse strength of amalgam.[7-8] Additionally, self-threading pin placement errors may result in pulpal or periodontal perforation.

Amalgam inserts in the form of amalgapins and slots have been a successful alternative to pin retention. Typically, amalgapins are placed 1.0 mm within the dentin-enamel junction with a pear-shaped bur to a depth of 1 to 3 mm, whereas slots are placed with an inverted cone bur. *In-vitro* research and clinical experience have demonstrated amalgapins and slots to be as effective as pin retention.[4,9-16] Certosimo demonstrated extensive restorations retained with more numerous and smaller amalgapins have greater resistance than those retained with fewer and larger amalgapins.[17] Amalgam inserts are easier to place than mechanical pins, reduce the risk of pin placement errors and do not adversely affect the mechanical properties of the amalgam alloy. Although slightly larger than mechanical pins, amalgapins do not induce dentinal crazing. A more conservative alternative to mechanical pin and amalgam insert retention techniques is amalgam bonding.

Terminology among amalgam bonding manufacturers is not standardized; however, most contain an acid conditioner, primer and a chemically- or dual-cured resin. The amalgam bonding agents must be unpolymerized, while the amalgam is condensed into the preparation. During condensation, the resin polymerizes and forms a micro-mechanical bond with amalgam, while simultaneously bonding to dentin via formation of a hybrid layer. In 1989, the first product marketed in the United States for amalgam bonding was Amalgambond (Parkell, Edgewood, NY, USA). Amalgambond is an unfilled 4-Methacryloyloxyethyl trimellitate anhydride (4-META)/methyl methacrylate resin whose polymerization is initiated by Tri-N-butyl borane. *In-vitro* studies demonstrated extensive amalgam restorations retained by Amalgambond to be more retentive than four regular TMS pins and as effective as four amalgapins.[18] In 1991, Parkell introduced an improved product known as Amalgambond Plus, with the addition of a polymethyl methacrylate particulate filler or High Performance Additive (HPA). This essentially transformed the unfilled Amalgambond into a filled resin by the addition of HPA. The manufacturer recommends the use of HPA when maximum retention is necessary. Laboratory studies have demonstrated greater bond strength with Amalgambond Plus when compared to Amalgambond.[19-21] The higher strength is thought to be the result of greater entrapment between the filler and amalgam alloy particles.

Several dental manufacturers have modified their light-cured dental bonding agents to include a chemically-cured reaction allowing for their use in amalgam bonding. These products include Scotchbond Multi-Purpose Plus (3M ESPE, St Paul, MN, USA), All-Bond 2 (BISCO, Schaumburg, IL, USA) and PQ Amalgam (Ultradent, South Jordan, UT, USA). Scotchbond Multi-Purpose Plus was modified by the addition of an activator to the primer and a catalyst to the adhesive agent, thus allowing it to be chemically cured. All-Bond 2 consists of alcohol and ethanol-based primers and a dual cured unfilled resin formed by mixing D/E resin and Pre-Bond (BISCO). For maximum bonding, BISCO recommends the use Resinomer (BISCO) in lieu of D/E resin and Pre-Bond. Resinomer is a dual-cured, fluoride-releasing resin that is 57% filled. PQ Amalgam is a bis-GMA resin that is 40% filled with fumed silica and glass. It is the result of Ultradent reducing the amount of camphorquinone in its dentin bonding agent, PQ1 (Ultradent), and replacing it with chemical initiators and activators.

In addition to dentin bonding agents, resin cements have been advocated for amalgam bonding. One such cement, Panavia 2.0 F (Kuraray America, New York, NY, USA), is a bis-GMA resin cement primarily marketed for the cementation of resin-bonded fixed-partial dentures. Since it is chemically cured in an anaerobic environment, formulation modifications were not necessary for amalgam bonding. The original Panavia (Kuraray America), initially introduced in the mid-1980s as a powder and liquid, has since undergone several improvements and today is marketed in a two-paste metered-dosed system with a self-etching primer. Unlike the majority of amalgam bonding agents, Panavia 2.0 F is claimed to bond to tooth structure via micromechanical interlocking and ionic bonding between its negatively charged phosphate ester group 10-methacryloyloxy decyl dihydrogen phosphate (MDP) and the cations in dentin and enamel.[22]

The current study compared the resistance of complex amalgam restorations retained by either four regular TMS Link Plus pins, four amalgapins 2 mm deep and 1 mm in diameter, Amalgambond Plus, Amalgambond Plus with HPA, Scotchbond Multi-Purpose Plus, PQ Amalgam, Panavia F 2.0, All-Bond 2 and Resinomer. Table 1 illustrates the amalgam bonding agents and their main components used in this study.

Table 1

Product	Conditioner	Primer	Resin	Other
Amalgambond Plus	10% Citric Acid 3% Ferric Chloride	HEMA	**Base-** 4-META MMA **Catalyst** Tri-N-Butyl Borane	**HPA** Poly MMA
Panavia F 2.0		**ED Primer A** MDP 5-NMSA Accelerators/Initiators HEMA **ED Primer B** 5-NMSA Accelerators/ Initiators	**Paste A** MDP DMA Fillers Camphor quinone **Paste B** Sodium fluoride DMA Fillers Accelerators/Initiators	**Oxyguard** Polyethylene glycol
PQ Amalgam	35% Phosphoric Acid		Bis–GMA HEMA Camphor quinone Benzoyl peroxides Phosphate methacrylates Filler–fumed silica	
Scotchbond Multi-Purpose Plus	35% Phosphoric Acid	**Primer 1.5** Water HEMA Coploymers of acrylic and itaconic acids **Activator 2.0** Ethyl Alcohol Sodium Benzene Sulfinate	**Activator 3.0** Bisphenol A Diglycidyl Ether DMA HEMA Blend of amines **Catalyst 3.5** Bisphenol A Diglycidyl Ether DMA HEMA Benzoyl peroxide	
All Bond 2	10% or 32% Phosphoric Acid	**Primer A** Acetone/Ethanol NTG-GMA **Primer B** Acetone/Ethanol BPDM	**D/E Resin** Bis-di-GMA HEMA UDMA **Prebond** Bis-GMA TGDMA Benzoyl peroxide	
Resinomer	10% or 32% Phosphoric Acid	**Primer A** Acetone/Ethanol NTG-GMA **Primer B** Acetone/Ethanol BPDM	**Base** Bis-di-GMA HEMA Sodium fluoride Glass filler/silica **Catalyst** Glass filler DSDMA TGDMA	

Abbreviations:
HEMA *2-hydroxyethyl methacrylate;* ***4-META*** *4-methacryloxyethyl trimellitate anhydride;* ***MMA*** *methyl methacrylate;* ***5-MNSA*** *N-methacryloyl-5aminosalicylic acid;* ***MDP*** *10-methacryloyloxy decyl dihydrogen phosphate;* ***DMA*** *dimethacrylate;* ***Bis-GMA*** *bisphenol A gylcidyl methacrylate;* ***NTG-GMA*** *N-tolylgylcine gylcidyl methacrylate;* ***UDMA*** *urethane dimethacylate;* ***BPDM*** *biphenyl dimethacrylate;* ***DSDMA*** *diphenylsulfone dimethacrylate;* ***TEGDMA*** *triethylene glycol dimethacrylate*

Figure 1: *Copper band matrix reinforced with modeling compound.*

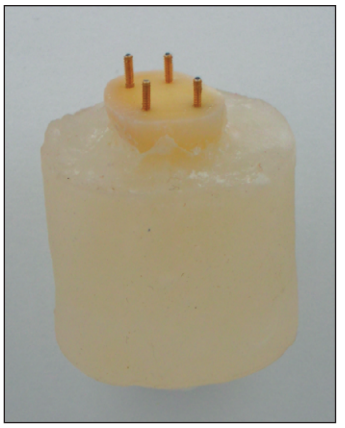

Figure 2: *Four Regular Link Plus TMS pins.*

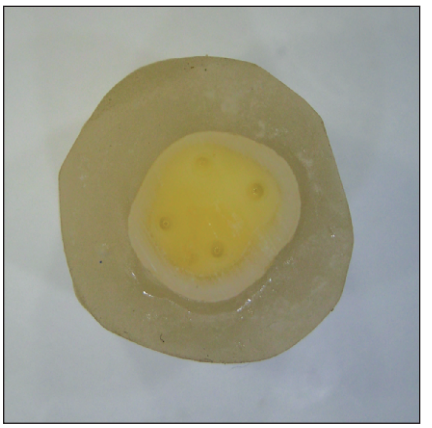

Figure 3: *Four amalgapins.*

METHODS AND MATERIALS

Ninety caries-free third molars of similar size were cleaned of debris and disinfected in a 10% solution of sodium hypochlorite and sterile water for 30 minutes. The teeth were embedded in Orthodontic Resin (LD Caulk/Dentsply, Milford, DE, USA) 2 mm apical to their cemento-enamel junction (CEJ). The 90 teeth were randomly assigned to nine groups of 10 teeth each. The occulsal surface of each tooth was reduced to within 2 mm of its CEJ using an Isomet saw (Buehler Ltd, Lake Bluff, IL, USA) to produce a flat, non-retentive surface. After placement of mechanical retention but before placement of amalgam bonding agents, copper bands (Moyco Industries, Philadelphia, PA, USA) were adapted to the prepared teeth and supported with impression compound (Sybron/Kerr, Romulus, MI, USA) (Figure 1). To prevent bonding of the amalgam to the matrices, Copalite (Cooley & Cooley Ltd, Houston, TX, USA) was carefully applied to the internal surfaces of the copper bands.

Teeth receiving four Regular TMS Link Plus pins had pin channels prepared at the four line angles of the tooth 1 mm from their dentin-enamel junctions (DEJ) and parallel to their long axis. This was accomplished using a 2 mm Kodex self-limiting twist drill (Coltene/Whaledent) in a slow-speed handpiece (A-dec Newberg, OR, USA). The pins were mechanically placed with a slow-speed handpiece (A-dec Newberg) until they self-sheared (Figure 2).

Amalgapins were prepared with a #330 friction grip bur (SS White, Lakewood, NJ, USA) in a high-speed handpiece to a depth of 2 mm and a width of 1 mm. A round No 4 bur (SS White) in a slow-speed handpiece was used to place a bevel at the entrance of each amalgapin. Similar to TMS Link Plus pins, the four amalgapins were placed at the four line angles of the tooth (Figure 3).

Amalgambond Plus was placed according to the manufacturer's protocol. The dentin surface was treated for 10 seconds with Amalgambond Activator (Parkell, Edgewood, NY, USA) and rinsed with an air/water aerosol for 30 seconds. The Adhesive Agent (Parkell) was applied for 30 seconds, then carefully blotted dry. Two drops of Base (Parkell) were mixed with one drop of Catalyst (Parkell) and applied to the prepared tooth surface. Amalgambond Plus with HPA was placed following the same protocol as described for Amalgambond Plus except three drops of Base were mixed with one drop of Catalyst and one level scoop (0.05 grams) of HPA.

The dentin surfaces for the PQ Amalgam specimens were etched with Ultra-Etch (Ultradent) for 15 seconds and rinsed with an air/water aerosol for 30 seconds. A uniform layer of PQ Amalgam was applied and thinned with a light air stream until it lost its milky appearance. The dentin services were then light cured for 20 seconds using LE Demetron II (Sybron/Kerr) but remained only partially polymerized.

The following protocol was used for specimens retained by Panavia 2.0 F. One drop each of ED Primer A and B (Kuraray America) were mixed for five seconds and applied to dentin with a small sponge pledget. After 60 seconds, the volatiles were evaporated with a gentle stream of air. Equal amounts of Catalyst and Universal pastes (Kuraray America) were mixed for 30 seconds to create a uniform paste and applied to the dentin surface.

The dentin surfaces of the All-Bond 2 specimens were etched with All-Etch (BISCO) for 15 seconds with agitation and thoroughly rinsed with an air/water aerosol for 30 seconds. Two drops of Primer A and Primer B (BISCO) were mixed and applied to the moist dentin five consecutive times. After the last application, the primer was thoroughly dried and light cured for 20 seconds with LE Demetron II. Equal volumes of D/E Resin and Pre-Bond Resin were mixed and applied to the dentin surface. The Resinomer group was treated by

following the same protocol as described for All-Bond 2. However, after five applications of the primer, Resinomer Base and Catalyst (BISCO) were substituted for D/E Resin and Pre-bond. Equal amounts of Resinomer Base and Catalyst were mixed for 15 seconds and applied to the dentin surface.

The dentin surfaces of the Scotchbond Multi-Purpose Plus samples were treated with Scotchbond Etchant (3M ESPE) for 15 seconds and rinsed with an air/water aerosol for 30 seconds. The dentin surface was carefully dried to remove excess water, but remained slightly moist. One drop each of Activator 1.5 (3M ESPE) and Primer 2.0 (3M ESPE) were mixed and applied to the cavity preparation and allowed to remain for 15 seconds before gently drying for five seconds. One drop each of Catalyst 3.0 (3M ESPE) and Adhesive 3.5 (3M ESPE) were mixed and brushed onto the primed surface.

Table 2: *Fracture Resistance of Extensive Amalgam Restorations*

Group	Mean (N)	SD	Fractures
Amalgambond Plus with HPA	2160	(380)	1
Scotchbond Multipurpose Plus	1900	(380)	1
4 Amalgapins	1770	(340)	7
PQ Amalgam	1660	(270)	1
Panavia F 2.0	1620	(440)	2
Amalgambond Plus	1570	(390)	0
4 Regular TMS Link Plus Pins	1325	(406)	2
All Bond 2	1300	(390)	0
Resinomer	1250	(310)	0

Groups connected by vertical bars are not statistically different (p>0.05).

Figure 4: *Extensive amalgam specimen.*

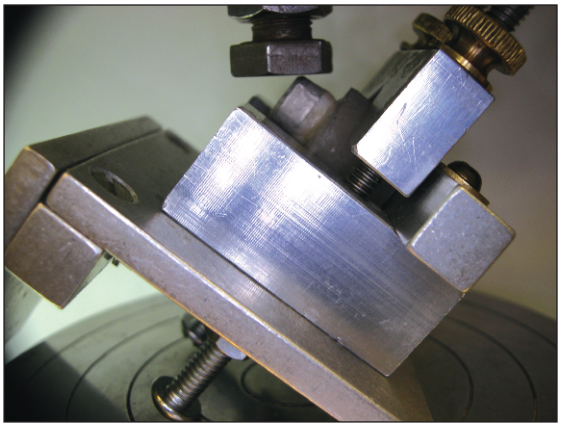

Figure 5: *Specimen in an Instron Universal Testing Machine.*

Tytin (Sybron/Kerr), a high copper spherical alloy, was triturated in a Touch Pad amalgamator (Henry Schein, Port Washington, NY, USA) for eight seconds and hand condensed to restore all specimens. The copper band matrices were removed 24 hours after amalgam condensation. For the group retained with Panavia F 2.0, Oxyguard (Kuraray America) was applied to all margins for three minutes after removal of the copper band matrices, then rinsed with an air/water aerosol. All specimens were adjusted using a high-speed handpiece to produce amalgam restorations 5 mm in height with a 1 mm bevel at the axial-occulsal surface (Figure 4). All groups were stored in 100% humidity for four weeks, followed by immersion in de-ionized water for 24 hours at 37°C. The specimens were loaded in compression at a 45° angle to the long axis of the tooth in an Instron Universal Testing Machine (Model #TTC, Instron Corporation, Canton, MA, USA) at a crosshead speed of 0.02 inches/minute. The load required for failure was recorded in Newtons (Figure 5). The parametric data was analyzed with a one-way analysis of variance (ANOVA). A Tukey's test was used to assess significant intergroup differences.

Figure 6: *Root fracture of a restoration retained by Amalgambond Plus with HPA. The amalgam restoration remained intact.*

Figure 7: *Non-restorable fracture with pulp exposure using four amalgapins.*

RESULTS

The mean fracture resistance, standard deviations and non-restorable tooth fractures are illustrated in Table 2. The greatest fracture resistance was obtained with Amalgambond Plus with HPA, although it was not statistically different from restorations retained by Scotchbond Multi-Purpose Plus, four amalgapins or PQ Amalgam. One specimen of Amalgambond Plus with HPA experienced a

catastrophic root fracture deep in the acrylic resin base, but the restoration did not fail (Figure 6). Four amalgapins and PQ Amalgam were statistically similar to all other groups. However, 70% of the teeth restored with amalgapins experienced non-restorable fractures (Figure 7). Four Regular TMS Link Plus pins were statistically similar to all other groups except Amalgambond Plus with HPA and Scotchbond Multipurpose Plus. All amalgam-bonding agents were statistically equal to either four Regular TMS Link Plus pins or four amalgapins.

DISCUSSION

The load-displacement curve on the Instron was carefully observed during testing of all specimens. Alteration in the linear pattern occurred for several specimens within the group retained by four Regular TMS Link Plus pins. This suggested slippage of either the TMS Link Plus pins within dentin or slippage of amalgam adjacent to the pins. When this occurred, the specimens were carefully examined to determine if the slippage would result in a clinical failure. In all cases, it did result in clinical failure, and the force was recorded as its maximum fracture resistance. Outhwaite and others reported early failure of pin-retained restorations may occur at 75%-85% of its peak load.[10] Thus, pin-retained restorations may fail clinically prior to their maximum resistance or retention strength. The fracture resistance of restorations retained by four Regular TMS Link Plus pins was nearly identical to other studies.[18-19] To standardize the pin-retained group, TMS pins were placed parallel to the long axis of the teeth to reduce differences in pin orientation among the specimens. Clinically, pins should be placed parallel to the external surface of the tooth to reduce the risk of periodontal perforation. Pin placement near the DEJ and parallel to the long axis of the teeth may have been a contributing factor for two non-restorable tooth fractures (Figure 8). The use of TMS Plus Link pins with a self-limiting shoulder that lessens crazing in the adjacent dentin may have helped reduce the number of non-restorable fractures. A similar study using TMS Regular pins without a self-limiting shoulder reported five non-restorable fractures.[18] Although this study did not evaluate the amount of crazing during pin placement, it was clearly evident in several samples using 2.5x magnification. Larger pins produce more crazing than smaller pins, especially when placed in proximity to the DEJ.[23] For this reason, Durkowski and others do not recommend the use of Regular TMS pins.[23] It may be more appropriate to use the smaller Minim TMS pin (Coltene/Whaledent) and, if the Minim pin does seat completely or strips out of the pin channel, the larger Regular TMS pin may be substituted.

The majority of restorations retained by the amalgam bonding agents failed via a simple shearing-off of the amalgam at the tooth/resin interface (Figure 9). This would suggest that the bond between the resin and tooth may be further improved. However, there were a combined five non-restorable tooth fractures with Amalgambond Plus with HPA, Scotchbond Multi-Purpose Plus, PQ Amalgam and Panavia 2.0, which would suggest that configuration of the bonded amalgam exceeded the supporting capacity of the tooth (Figure 10). There were fewer non-restorable tooth fractures when the filled resins were used compared to mechanical retention, which had a total of nine non-restorable tooth fractures. There were not any fractures when the unfilled dentin bonding agents of Amalgambond Plus and All-bond 2 were used.

The bond of the amalgam alloy to the bonding agent is purely micromechanical, with filled resins generally providing greater bond strength than unfilled resins.[24] This study generally demonstrated greater fracture resistance using filled resins (Amalgambond Plus with HPA, PQ Amalgam and Panavia 2.0 F) compared to unfilled resins (Amalgambond Plus and All Bond 2). This is supported by other studies that have also demonstrated greater retention and resistance with

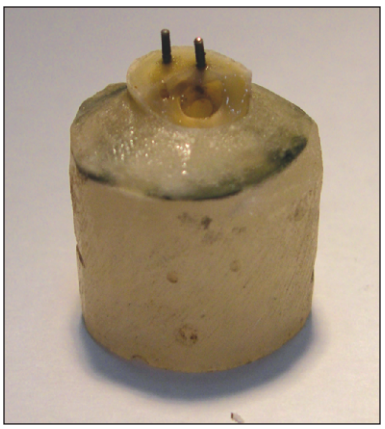

Figure 8: *Non-restorable fracture using four TMS Link Plus pins.*

Figure 9: *Typical fracture with an amalgam bonding agent.*

Figure 10: *Non-restorable fracture and pulp exposure using Panavia F 2.0.*

filled resins compared to unfilled amalgam bonding agents.[19-21] However, there were two exceptions in the current study. Scotchbond Multi-Purpose Plus, an unfilled resin, produced the second strongest bond strength and Resinomer, a filled resin, provided the least resistance. The authors of the current study noticed that Scotchbond Multi-Purpose Plus, when mixed, is more viscous than the other unfilled agents. They theorized that this may be due to dimethacrylates in the adhesive and catalyst. The instructions accompanying Resinomer state using it in lieu of D/E Resin and Pre-Bond. However, the instructions on BISCO's website recommend using a bonding agent such as All-Bond 2 with Resinomer. It is possible that the manufacturer intends the clinician to use D/E Resin and Pre-Bond along with Resinomer. If this is BISCO's intention, Resinomer may provide greater strength than All-Bond 2.

Flash consisting of bonding agent and amalgam was evident despite the use of well-adapted and compounded matrices. In a clinical application, this flash, if not removed, may result in an overhang restoration leading to recurrent caries, gingival inflammation or periodontal attachment loss. Additionally, the resins were noticeably present in several specimens at the cavosurface margins. The effects of incorporation of amalgam bonding agents upon the physical properties of amalgam have not been fully investigated. A study by Charlton and others revealed Amalgambond Plus without HPA did not significantly affect the compressive strength or creep values of Tytin.[25] However, Panavia, in the same study, significantly reduced the compressive strength of Tytin.[25] When used in excessive amounts, both Amalgambond and Panavia reduced the diametral tensile strength of amalgam.[26] Bonding agents used in excess would appear to decrease the physical properties of amalgam, especially if used in small, conservative Class II restorations. However, an *in-vitro* study demonstrated a significant increase in bulk fracture strength in smaller restorations using Amalgambond Plus with HPA compared to unbonded restorations.[27] The seven amalgam bonding agents used in this study may adversely affect the physical properties of amalgam and, until research can prove otherwise, they should be applied as thinly as possible and the amalgam condensed in a manner so as to reduce the resin's incorporation into the alloy. The amalgam should be simultaneously condensed on the pulpal and gingival floors of the preparation and pushed laterally against the axial walls to help reduce its incorporation into the body of the restoration. It is likely that the physical properties of the bonded amalgam alloy may be dependent upon the alloy type (spherical versus dispersed alloy), viscosity of the agent (filled versus unfilled) and the bonding agent itself. Unfilled amalgam bonding agents are easier to confine to the dentin interface, whereas the more filled and viscous agents tend to adhere to the condenser and become incorporated into the alloy.

The current study only compared mechanically retained extensive restorations to bonded restorations; other studies demonstrated greater resistance when bonding is combined with pins or amalgapins.[18-19,28] In fact, one study did not recommend combining mechanical retention with amalgam bonding in the fear that, if failures do occur, the result would be an unrestorable tooth fracture.[29]

The use of retentive grooves in Class II amalgam restorations continues to be debated. The routine use of proximal retention grooves may be an unnecessary hazard in small restorations but may be required for larger restorations.[30] However, other research demonstrated a significant increase in resistance when conventional groove retentive features are placed in proximal slot preparations compared to restorations without additional retention.[31-32] If amalgam bonding can provide adequate retention and resistance for non-retentive flat amalgam preparations, its use may eliminate the necessity of proximal retentive grooves in both small and large Class II restorations. Several *in-vitro* studies demonstrated that conservative Class II bonded amalgam restorations were as retentive as those retained by retentive grooves extending from the gingival floor to the occlusal surface.[33-34]

Most *in-vitro* studies include storage in water in addition to thermocycling prior to testing the specimens. Imbery and others demonstrated no difference in fracture strength of bonded restorations immersed in water for three months compared to those immersed for six months.[19] Similarly, Hasawaga and Retief did not demonstrate any difference in bond strengths for either Amalgambond Plus with HPA or All-Bond 2 when immersed in water for up to 48 weeks.[35] However, other studies have shown significant degradation after aging, thermocycling or cyclic loading.[36-37]

In-vitro studies do not accurately replicate intraoral conditions. Studies have shown a significant decrease in the retention of extensive amalgam restorations when they are loaded at a 90° angle to their long axis as opposed to a 45° angle.[16,38] Loads occurring intraorally at 90° are not very common. The 45° angle used in this study best represents what may occur intraorally. The totally flat surface in this study does not represent what commonly occurs clinically. Most extensive amalgam restorations will have proximal boxes and opposing walls to provide additional resistance and retention. The authors of the current study duplicated the worst scenario in terms of preparation, but they designed the study to provide the best possible results (spherical alloy and load application at a 45° angle). Additionally, the load was applied at a very slow and constant rate.

Intraorally, most loads will occur suddenly and be of a shorter duration. Therefore, the results of fatigue loading may be more indicative of clinical performance.

Clinical trials remain the only conclusive and predictive performance of dental materials. A six-year clinical evaluation by Summitt and others, comparing Amalgambond Plus with HPA to TMS pin-retained restorations, did not demonstrate any significant difference in failure rate, marginal adaptation, marginal discoloration, secondary caries or tooth vitality.[39] Thus, at the end of six years, there was not any statistical difference in the performance of extensive amalgam restorations retained by TMS pins or Amalgambond Plus with HPA. A note of interest is that several of the molars restored in Summitt's clinical study resembled specimens in the current study in that the occlusal surface was essentially flat without any additional retentive or resistance features, and yet they did not fail. The bonded extensive amalgam restorations that did fail were not due to loss of retention, but rather from root fracture or secondary caries.[39]

A once purported disadvantage of amalgam bonding was the additional cost and time. Table 3 illustrates the approximate additional cost per restoration and time required in the current study to apply the bonding agent or mechanical retention. On average, amalgam bonding adds several dollars to the cost of a restoration and, in all cases, requires less time than placing four pins, which cost approximately $18. The amalgam-bonding agent that produced the highest resistance, was the easiest to use and cost the least was PQ Amalgam. The correct placement of pins was more technically demanding than using amalgam-bonding agents. The authors of the current study required 16 samples to obtain 10 specimens with four properly placed TMS pins. In the rejected samples, the pins either did not seat completely, seated beyond the shoulder or stripped out of the pin channel. The authors of the current study's experience is confirmed by a study by Harris and Lund that demonstrated differences in the ability of different pin systems to seat completely.[40]

Table 3: *Product Comparison*

Product	Estimated Cost	Approximate Time
All-Bond 2	$1.20	2:20
Amalgambond Plus	$2.50	1:45
Amalgambond Plus (HPA)	$2.75	2:00
Panavia 2.0 F	$1.50	4:30
PQ Amalgam	$1.00	1:00
Resinomer	$2.80	2:20
Scotchbond Multi-Purpose Plus	$2.60	1:30
Four Regular TMS Link Plus Pins	$18.00	5:00
Four Amalgapins	$0.00	1:00

CONCLUSIONS

1. Amalgambond Plus with HPA, Scotchbond Multi-Purpose Plus, PQ Amalgam and four amalgapins provided statistically stronger fracture resistance than the other groups.
2. All the amalgam bonding agents evaluated produced fracture resistance for extensive amalgam restorations statistically equivalent to either four Regular TMS Plus Link pins or four amalgams.

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