Improved orthodontic bonding to silver amalgam. Part 2. Lathe-cut, admixed, and spherical amalgams with different intermediate resins

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Adult patients in need of orthodontic treatment often have amalgam restorations on the buccal surfaces of their posterior teeth. Sometimes these restorations are small and cover only pits and/or fissures, but in other instances the amalgam alloy may include most, if not all, of the buccal surface (Figure 1). Since an increasing number of adult patients are receiving orthodontic treatment, satisfactory bonding of attachments to amalgam represents an interesting clinical problem.

In a previous study,[1] we showed that a 4-META/MMA-TBB resin (Superbond C&B, a.k.a. C&B Metabond in the United States) created significantly stronger bonds in vitro to sandblasted amalgam than either a 10-MDP BisGMA resin (Panavia Ex) or a conventional orthodontic bonding adhesive (Concise, No. 1994 A and B). However, when coupled with an intermediate application of All-Bond 2 Primers A + B, the bond strength of Concise to sandblasted amalgam was comparable to the Superbond C&B

Abstract

Flat rectangular tabs (n=270) prepared from spherical (Tytin), admixed (Dispersalloy) or lathe-cut amalgam (ANA 2000) were subjected to aluminum oxide sandblasting with either 50-µ or 90-µ abrasive powder. Mandibular incisor edgewise brackets were bonded to these tabs. An intermediate resin was used, either All-Bond 2 Primers A + B or a 4-META product—Amalgambond Plus (AP) or Reliance Metal Primer (RMP)—followed by Concise. All specimens were stored in water at 37°C for 24 hours and thermocycled 1000 times from 5°C to 55°C and back before tensile bond strength testing. The bond strength of Concise to etched enamel of extracted, caries-free premolars was used as a control. Bond failure sites were classified using a modified adhesive remnant index (ARI) system. Results were expressed as mean bond strength with SD, and as a function relating the probability of bond failure to stress by means of Weibull analysis. Mean tensile bond strength in the experimental groups ranged from 2.9 to 11.0 MPa—significantly weaker than the control sample (16.0 MPa). Bond failure invariably occurred at the amalgam/adhesive interface. The strongest bonds were created to the spherical and lathe-cut amalgams (range 6.8 to 11.0 MPa). Bonds to the spherical amalgam were probably more reliable. The intermediate application of the 4-META resins AP and RMP generally created significantly stronger bonds to all three basic types of amalgam products than the bonds obtained with the All-Bond 2 primers. The effect of abrasive-particle size on bond strength to different amalgam surfaces was not usually significant ($p > 0.05$). The implications of these findings are discussed in relationship to clinical experience bonding orthodontic attachments to large amalgam restorations in posterior teeth.

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Key words

Adhesives • Amalgam • Bonding • Bond strength • Debonding

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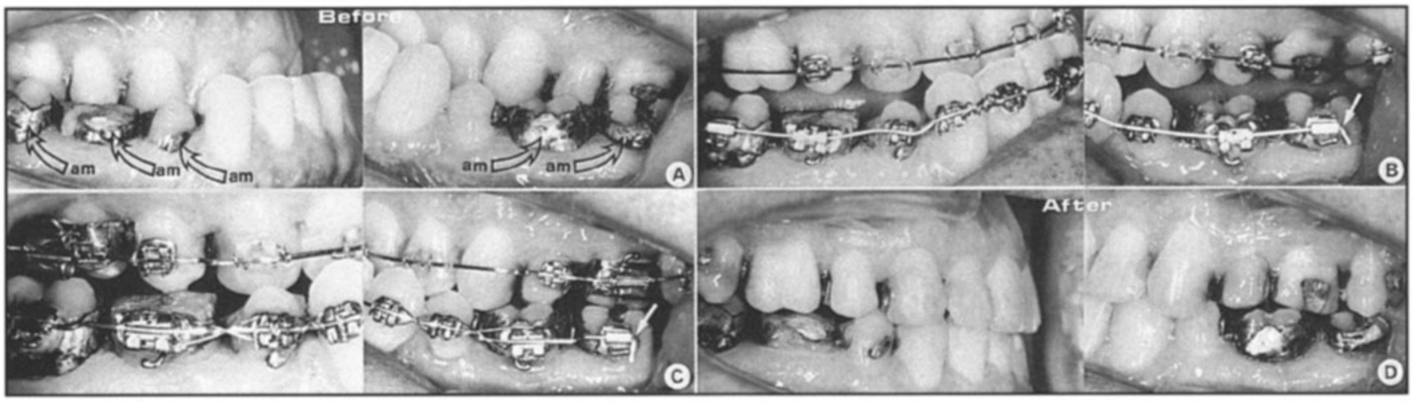

Figure 1

Figure 1A-D
Adult Class III patient with several large amalgam restorations (am) before (A), during (B-C), and after (D) orthodontic treatment.

bonds. Mean tensile bond strengths were around 6.5 MPa, which was significantly lower than the bond strength of Concise to etched enamel.

Our clinical tests on the success rate of orthodontic brackets and tubes bonded to sandblasted amalgam fillings with the All-Bond 2 primers + Concise have been encouraging.[2,3] In the period between March 1992 and March 1996, 83 buccal attachments were bonded to large amalgam restorations (amalgam only, or at least 75% amalgam under the bracket base) mainly in mandibular molars in 49 adult orthodontic patients (Figure 1). All attachments were placed out of contact with maxillary teeth, or, where this was not possible, the specific bracket tie-wings in contact were ground out of occlusion. To date (March 1997), with a minimum observation time of 12 months, only 13 failures have been observed (15.7%). Seven losses occurred in mandibular first molars, five in mandibular second molars, and one was a nonmolar failure. In 103 teeth with small amalgam fillings (etched enamel in at least 50% of the area under the bracket base), only 2 failures (2.0 %) occurred during the same observation period.

Although these results may be considered satisfactory, further experiments and improvements seemed desirable for several reasons. First, it would be interesting to test other 4-META (methacryloxyethyl trimellitic anhydride) resins besides Superbond C&B. This is because a clinical drawback with Superbond C&B is its curing time of 10 minutes or more. The liner version (Superbond-D liner), which in the US is marketed as Amalgambond Plus, is fast to auto-cure (60 seconds), and is increasingly being used in restorative dentistry for amalgam bonding to dentin and previously placed amalgam restorations.[4-7] Another 4-META intermediate resin that will enhance bond strength to artificial tooth surfaces[8] and has a short polymerization time (30 seconds) is Reliance Metal Primer. Therefore, the coating of a sandblasted amalgam surface with Amalgambond Plus or Reliance Metal Primer as an intermediate application before bonding with a composite resin would be interesting to study in vitro.

Second, our previous study included only lathe-cut dental amalgam. Spherical and admixed (mixture of lathe-cut and spherical) types of amalgams are used in restorative dentistry. It is not possible for an orthodontist to differentiate between these types of amalgams in old restorations. In studies by others, higher bond strengths are usually experienced when bonding composite resin to spherical amalgam alloys compared with lathe-cut and admixed amalgams.[4,9-11] Third, it would also be of interest to compare the effectiveness in surface preparation by sandblasting with different size aluminum oxide abrasive powders. Caughman et al.[10] recently found indications of higher mean bond strengths with 60-μ aluminum oxide sandblasting than when 50-μ abrasive powder was used on both spherical (Tytin) and admixed (Dispersalloy) amalgams, although the differences were not statistically significant. Finally, the effects of thermocycling on the composite resin-amalgam bond were not examined in the previous study. Extensive thermocycling might provide information on differences between various amalgam-bonding systems in temperature-dependent degradation of the bonds and on differences in coefficient of thermal expansion. Thermal cycling has been shown to be of significant importance in evaluating composite resin bonds to porcelain.[12-14]

Hence, the purpose of the present study was to investigate and compare the in vitro tensile bond strengths of orthodontic brackets bonded to three different amalgam alloys (lathe-cut, admixed, and spherical) after sandblasting with two different-sized abrasive particles (50 μ and 90 μ) and using three different intermediate resins (All-Bond 2 Primers A and B, Amalgambond Plus, and Reliance Metal Primer).

Material and methods

Flat, rectangular amalgam tabs, 45 x 10 x 1 mm, were prepared by condensing silver amalgam alloy into recesses made in classic Blu-Mousse (Parkell Biomaterials Division, Farmingdale, NY), a vinyl polysiloxane impression material that sets almost as hard as impression plaster (sets to a durometer of 85 vs. 100 for plaster). The amalgam was allowed to harden for 24 hours. The amalgam materials tested represented the three basic types: a pure lathe-cut nongamma 2 material (ANA 2000, Nordiska Dental AB, Helsingborg, Sweden), an admixed product (Dispersalloy, Caulk/Dentsply, Milford, Del), and an all-spherical amalgam (Tytin, Kerr USA, Romulus, Mich). After removal from the impression material, the amalgam tabs were polished with 600- then 1200-grit waterproof silicone carbide paper (Struers A/S, Rodovre, Denmark), green rubber points (Dedeco green "midgets" no. 4572, Dedeco International Inc, Long Eddy, NY) and a polishing paste (Universal polishing paste, Ivoclar AG, Switzerland).

Surface treatment

The polished amalgam specimens were rinsed ultrasonically in distilled water for 10 minutes and dried. Two kinds of surface treatment were used: (1) aluminum oxide sandblasting with 50-μ abrasive powder in a Microetcher erc (Danville Engineering, San Ramon, Calif) at approximately 7 kg/cm^2 of air pressure for 3 seconds from a distance of 10 mm, or (2) sandblasting with 90-μ abrasive powder. The surfaces were then washed and dried thoroughly.

Bracket

The bracket type used was microarch mandibular incisor edgewise brackets (Microarch # 72-612-00, GAC International Inc, Central Islip, NY) with a base area of 9.4 mm^2. Before the bonding procedure, a circular steel ring was soldered onto the bracket slot[14] in order to control the type of stress and reduce the risk of load misalignment.[15,16] One operator (TB) bonded 270 brackets onto the tabs according to routine procedures.[17]

Resins

As shown in Table 1, one of three intermediate resins—All-Bond 2 Primers A and B (Bisco Dental Products, Itasca, Ill), Reliance Metal Primer (Reliance Orthodontic Products, Itasca, Ill), and Amalgambond Plus (Parkell, Biomaterials Division, Farmingdale, NY)—was used according to the manufacturer's instructions before the brackets were bonded using a modified Concise composite resin (Concise, No. 1994 A and B, 3M/Unitek, Monrovia, Calif). Bonding resin was not used. With All-Bond 2 (AB2), one drop each of Primers A and B were mixed, and three coats were applied to the sandblasted amalgam surface. The primer layers were gently blown with oil-free, water-free air and allowed to dry for 10 seconds before the bonding procedure. With Reliance Metal Primer (RMP) the single-component product was applied to the sandblasted amalgam and allowed to dry for 30 seconds. The Amalgambond Plus (AP) was applied by mixing 2 drops of base with 1 drop of catalyst and allowed to dry for 60 seconds. The high performance additive (HPA) powder was not used, since it is not recommended when the system is used as a bonding agent for composite resins.[18]

In all cases, the excess bonding adhesive outside the bracket base was removed with a small, round TC bur (Komet no. H1 008, Gebr. Brasseler GmbH & Co Kb, Lemy, Germany). This procedure was executed in all 270 cases following the curing of the composite resin for 5 minutes at room temperature. The assemblies were then placed in water and stored at 37°C for 24 hours. Thereafter, they were thermocycled 1000 times from 5°C to 55°C and back, with an immersion period in each bath of 40 seconds.

Table 1
Test design and number of samples

Amalgam type	Abrasive particle size (μm)	Intermediate resin	n
Tytin (spherical)	50	RMP	15
		AP	15
		AB2	15
	90	RMP	15
		AP	15
		AB2	15
Dispersalloy (admixed)	50	RMP	15
		AP	15
		AB2	15
	90	RMP	15
		AP	15
		AB2	15
ANA 2000 (lathe-cut)	50	RMP	15
		AP	15
		AB2	15
	90	RMP	15
		AP	15
		AB2	15

RMP: Reliance Metal Primer; AP: Amalgambond Plus, AB2: All-Bond 2 Primers A+B.

Table 2
Tensile bond strengths for Tytin, a spherical amalgam. Orthodontic brackets were bonded to amalgam tabs after different surface treatments with intermediate resin.

Intermediate resin	Abrasive particle size (μm)	Tensile bond strength (MPa) Mean	SD
RMP	90	11.0	2.4
RMP	50	9.8	3.0
AP	90	9.1	1.4
AP	50	8.9	1.7
AB2	50	8.3	2.2
AB2	90	6.6	1.8

Vertical lines connect mean values, which do not differ significantly according to Duncan's multiple-range test.

Table 3
Tensile bond strengths for ANA 2000, a lathe-cut amalgam. Orthodontic brackets were bonded to amalgam tabs after different surface treatments with intermediate resins.

Intermediate resin	Abrasive particle size (μm)	Tensile bond strength (MPa) Mean	SD
RMP	50	10.9	3.5
AP	90	8.9	2.7
AP	50	8.8	3.4
RMP	90	8.3	2.9
AB2	50	6.8	2.5
AB2	90	6.8	2.4

Vertical lines connect mean values, which do not differ significantly according to Duncan's multiple-range test.

Bond strength testing

When removed from the water container, the amalgam tabs were securely mounted in a special holding device[1,2] on a Lloyd 1000 R testing machine (Lloyd Instruments Ltd, Fareham, Hants, England). The tensile load was applied via a stainless steel hook (0.8 mm thick) engaging the circular ring of the bracket. The crosshead speed was 1 mm/min. The force required to dislodge the bracket was recorded electronically on a graph and measured in Newtons. The force-per-unit area required for breakage was calculated and reported as the tensile bond strength in Megapascals (MPa).

After debonding, failure sites were recorded and classified according to the modified Adhesive Remnant Index (ARI) of Årtun and Bergland.[20]

Fifteen premolars without demineralization or other visible defects, extracted for orthodontic reasons, were used as a control sample. The control teeth were embedded in acrylic blocks and prepared for bracket placement.[2] Following conventional conditioning of the buccal surfaces with 37% phosphoric acid for 60 seconds, maxillary premolar twin edgewise brackets (Microarch # 74-542-22, GAC International Inc, Central Islip, NY), with a base area of 9.8 mm^2 and provided with soldered rings identical to those in the experimental groups, were bonded to the enamel surface with Concise. After water storage at 37°C for 24 hours, tensile bond strength testing was carried out as above.

Statistical analysis

Bond strength results were evaluated both in terms of means with standard deviations and assessment of reliability. The significance of the differences between the means presented in Tables 2 to 4 was estimated by analysis of variance (ANOVA) and by Duncan's Multiple-Range test at a 5% level of significance.[21] To assess reliability, the data on bonding to the different types of amalgam were subjected to a Weibull analysis.[22-24] This analysis expresses bond strength as a function relating probability of bond failure at any chosen level of stress (see Figure 3). The test also generates a Weibull modulus, which has practical implications when comparing material strengths. A high value indicates a close grouping of failures, while a low value indicates a large spread of failures with a long tail in low stress values and a low reliability.[22-25] The statistical analysis and graphic demonstrations were carried out using SPSS/PC (SPSS Incorporated, Chicago, Ill) and Harvard Graphics software packages (Harvard Graphics Software Publishing Corporation, Mountain View, Calif).

Results

Surface treatment

There was no statistically significant difference in bond strengths between the 50-μ and 90-μ abrasives for the spherical and admixed amalgams (Tables 2 and 4). However, for the lathe-cut alloy (Table 3), sandblasting with 50-μ particles provided higher mean bond strengths than blasting with the 90-μ particles ($p < 0.05$) when RMP was used as an intermediate resin.

Bond strength measurements

The mean bond strengths and standard deviations for the different types of amalgam with 50-μ and 90-μ abrasives and different intermediate resins are presented in Tables 2 to 4. Figure 2 represents the mean bond strength values to each type of amalgam using different primers when the 50-μ and 90-μ abrasives were grouped together. Table 5 shows the results of the Weibull analysis (modulus and stress required for 1% and 5% probabilities of failure), and Figure 3 illustrates the shape of the Weibull curves, when applied to the various test systems.

Significantly higher mean bond strengths ($p < 0.05$) were observed for the spherical and lathe-cut alloys (8.9 and 8.4 MPa, respectively) than for the admixed amalgam (4.9 MPa, Tables 2 to 4). Although mean bond strengths were not significantly different between the spherical and the lathe-cut amalgams, both the higher Weibull modulus (4.82 vs. 3.02, Table 5) and the shape of the Weibull curve indicated better reliability for the spherical amalgam compared with the lathe-cut amalgam (Figure 3). Irrespective of the type of amalgam, higher bond strengths were observed when either of the two 4-META intermediate resins (RMP or AP) were used than when AB2 was used (Tables 2 to 4). The difference was statistically significant ($p < 0.05$) for all combinations except one (Table 2).

Bond failure site

Bond failures invariably occurred at the amalgam/adhesive interface, with no adhesive left on the metal. In four instances, the amalgam piece broke during testing with the lathe-cut alloy. There were no bond failures in the adhesive or in the adhesive/bracket interface.

Table 4
Tensile bond strengths for Dispersalloy, an admixed amalgam. Orthodontic brackets were bonded to amalgam tabs after different surface treatments with intermediate resins.

Intermediate resin	Abrasive particle size (μm)	Tensile bond strength (MPa) Mean	SD
AP	50	6.9	3.1
AP	90	5.9	2.4
RMP	50	5.2	1.7
RMP	90	4.6	0.9
AB2	90	3.5	1.1
AB2	50	2.9	0.9

Vertical lines connect mean values, which do not differ significantly according to Duncan's multiple-range test.

Discussion

The bond strengths to the different amalgam types (spherical, admixed, lathe-cut) recorded in this study were generally in agreement with those found in comparative studies by other investigators.[1,4,8-11,26] Several studies have indicated higher tensile and shear bond strengths with a spherical alloy (Tytin) compared with an admixed amalgam (Dispersalloy).[4,9-11,19] The exact mechanism for the variation in bonding is not known. The alloy portion of Dispersalloy is an admixture of particles with two-thirds lathe-cut and one-third spherical configuration.[10] Since the bond between amalgam and resin cement was of similar strength for the spherical (Tytin) and lathe-cut (ANA 2000) alloys in this study, it is unlikely that bonding strength is related solely to particle configuration. Other investigators have speculated that it may be attributed to differences in the prepared amalgam surface topography, differences in surface wetability, concentration and distribution of tin within the amalgam, etc.[10] Additional research is needed to fully understand the mechanism of the resin bond to different amalgam alloys and its longevity following fatigue and thermocycling.

Thermocycling apparently affected the bond strength of composite resin to amalgam only marginally in this study. This finding is in accordance with observations by other investigators for adhesive bonds to amalgam,[6,11,26,27] gold,[28] and etched enamel.[29] In contrast, thermocycling appears necessary for adequate testing of silane-coupled bonds to porcelain. If thermal cycling of such specimens is not performed, high laboratory bond strength values, which probably misrepresent clinical reality, will be observed.[12-14] The reduction in bond strength after thermocycling is remarkable for most porcelain bonding systems.[12,13,30]

With regard to surface pretreatment, the present findings demonstrated no obvious differences between the 50-μ and 90-μ abrasives on the three amalgam types tested (Tables 3 to 5). As mentioned, Caughman et al.[10] claimed that when spherical and dispersed amalgams were sprayed with 60-μ aluminum oxide, the mean bond strengths were somewhat higher than

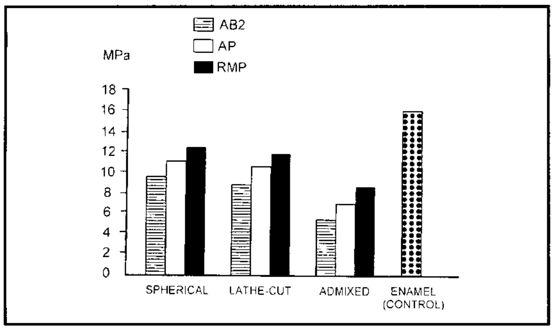

Figure 2

Figure 2
Mean tensile bond strengths of the three types of amalgam tested with different intermediate resins when the 50-μ and 90-μ abrasives were grouped together. AB2: All-Bond 2 Primers A+B; AP: Amalgambond Plus; RMP: Reliance Metal Primer.

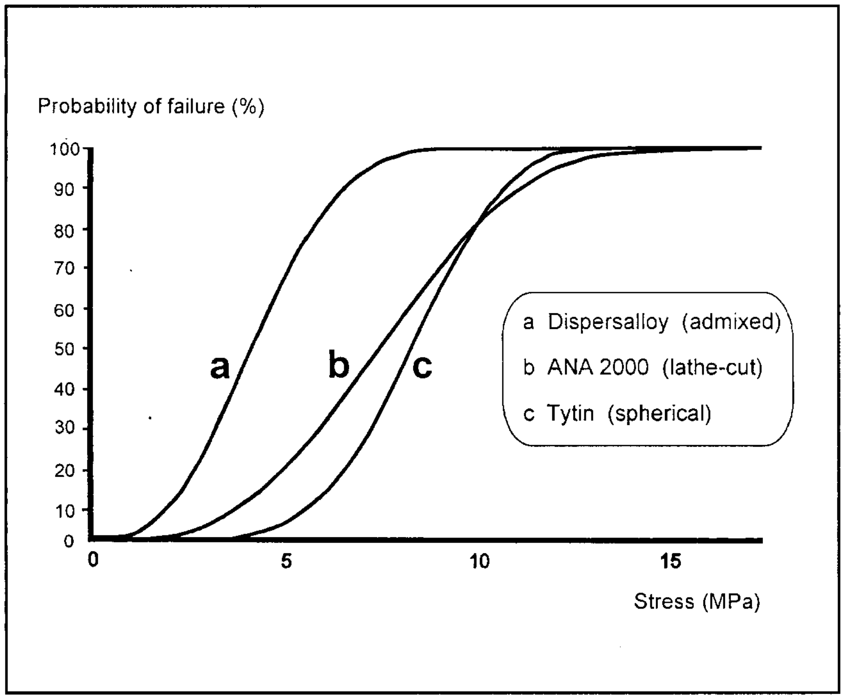

Figure 3
Weibull curves for the three types of amalgam demonstrate the probability of bond failure at any chosen level of stress. Note the difference in reliability (steeper slope of curve) between spherical (c) and lathe-cut (b) amalgams.

when abraded with 50-μ abrasive. These differences were most likely related not only to aluminum oxide particle size, but also to variations between two manufacturers' aluminum oxide formulations. Comparing the effect after air-abrasion of precious and nonprecious metals with 250-μ and 50-μ diameter aluminum oxide particles, Suh and Lamerand[31] showed increasing contact angles (decreasing surface energy) when the larger particle sand was used. They also reported a statistically significant decrease in shear bond strength when the metals were exposed to room conditions for several hours after sandblasting. This study indicated that in order to achieve the highest possible bond strengths and maximum wetting of metals, surface preparation prior to adhesive bonding should be done immediately before the bonding procedure with a small diameter sand.

The present findings demonstrate the efficiency of using an intermediate primer when bonding orthodontic brackets with a standard orthodontic adhesive like Concise to sandblasted amalgam. The bond strengths to amalgam obtained with the best combinations in this study were high and approached the values between Concise and etched enamel (Figure 2). In agreement with the findings in our previous study,[1] the mean in vitro tensile bond strength to the lathe-cut amalgam specimens when AB2 was used with Concise was around 6 to 7 MPa. It is of interest, therefore, that both 4-META resin primers used in this study (Amalgambond Plus and Reliance Metal Primer) apparently provided even better bond strengths than AB2 to all three basic types of amalgam (Figure 3, Tables 2 to 4). This could be particularly significant when bonding to Dispersalloy restorations (Table 4). The effectiveness of the 4-META primers confirms previous observations on composite resin bonding to amalgam and other nonprecious metals, both with AP[4,11,19,27] and RMP.[8] It is believed that the polarity of the 4-META molecule is the key to its metal-bonding mechanism. The adhesive molecule orients toward the metal surface and forms hydrogen bonds with the oxygen and hydroxyl groups in the metal oxide layer.

In the statistical evaluation, the present bond strength data were evaluated both with regard to mean value, variation around the mean, and reliability. Since a mean value of strength may be influenced by a few high values, the merits of the Weibull analysis for bond strength testing in orthodontics has recently been stressed by several authors.[22-25] Consideration of Tables 2 and 3 and Figure 2 suggests little difference in mean bond strengths between the spherical and lathe-cut amalgams. However, the data in Table 5 and Figure 3 indicates a greater variation in the stress required for debonding at both the 1% and 5% levels for the lathe-cut than for the spherical amalgam, demonstrating the greater reliability of bonds with the spherical amalgam. This pattern also demonstrates the relevance of the Weibull analysis compared with consideration of mean values only.

The true level of mechanical stress for a bracket system in vivo still requires a clinical evaluation. Although the present in vitro results look promising, the limitations of laboratory studies must be recognized. One reason for the difficulty in determining the mean in vitro tensile bond strength, which is required for successful clinical bonding of orthodontic attachments to teeth, is the complexity of the oral environment with variations in temperature, stresses, humidity, acidity, and plaque. This is not reproducible in

Table 5
Reliability of the bonds to three amalgam alloys according to the Weibull analysis. The correlation coeffficient describes how closely the actual data fit the curve produced by the Weibull equation.

Intermediate resin	Mean tensile bond strength	Weibull modulus	Correlation coefficient	Stress (MPa) for 1% chance of failure	Stress (MPa) for 5% chance of failure
Tytin (spherical)	9.1	4.82	0.995	7.1	9.9
ANA 2000 (lathe-cut)	8.4	3.02	0.993	3.8	6.5
Dispersalloy (admixed)	4.8	2.69	0.997	1.8	3.3

the laboratory. Moreover, a continually increasing tensile (or shear) force applied to the teeth is not typical of the type of loading that occurs clinically, and does not adequately represent the effects of masticatory stresses. Bonded brackets in the mouth are subjected to tensile, shear, and torsional forces, and to combinations of all these. Except for traumatic incidents, brackets coming loose in the mouth probably do so as a result of repeated stress producing micro cracks that propagate until bond failure occurs. Thus, load fatigue testing, in which a sample is repeatedly subjected to a load well below the level that causes fracture in static tensile and shear tests, and eventually fails, may provide an alternative way to test the durability of resin bonds in vitro.[32] The results from laboratory studies should be used only to indicate which products and materials seems most valuable to include in supplementary clinical testing.

In summary, the present laboratory observations on bonding to different types of amalgam indicate that the clinical use of either of the 4-META products, RMP or AP, as an intermediate primer when bonding brackets to large amalgam restorations may have the potential to produce even better success rates than the numbers mentioned for AB2 in the introduction. Preliminary studies with RMP since February 1996 in our clinic would seem to support this assumption.

Conclusions

In conclusion, the results of the present in vitro study demonstrated that:

1. The mean tensile bond strength to sandblasted amalgam in this study, regardless of preparation and resin combination used, approached but was significantly lower than the bond strength of Concise to etched enamel. Bond failures typically occurred at the amalgam/adhesive interface.

2. The mean bond strength of Concise to sandblasted amalgam was considerably higher for the spherical (Tytin) and lathe-cut amalgams (ANA 2000) than for the dispersed product (Dispersalloy). The difference was statistically significant ($p < 0.05$).

3. Significantly stronger bonds to all three basic types of amalgam were obtained with an intermediate application of the 4-META primers Amalgambond Plus and Reliance Metal Primer compared with the All-Bond 2 primers.

4. There was generally no statistically significant difference between sandblasting with 50-μ or 90-μ aluminum oxide powder with regard to effectiveness in preparing an amalgam surface for bonding.

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