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Shear Bond Strength of the Amalgam-Resin Composite Interface

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Clinical Relevance

On the basis of the results of this *in vitro* study, resin composite may be an effective way to repair or mask the appearance of amalgams placed in visible areas of the mouth.

SUMMARY

Objective: This study compared the initial and one year shear bond strengths (SBS) of resin composite bonded to amalgam using Amalgambond-Plus. Methods: Resin composite cylinders (Point 4, Kerr Corporation) were bonded to either etched-enamel (A), 50% etched enamel-50% polished amalgam (B), airborne-particle abraded amalgam (C), carbide bur prepared amalgam (D) and airborne-particle abraded 50% amalgam-50% etched-enamel (E). Shear bond strengths were determined using a standardized testing device (Ultradent Products) in a universal testing machine (Instron model 4204). The failed interfaces were evaluated with SEM to obtain visual evidence of the failure mode. Results: ANOVA indicated significant differences among the groups (p<0.0001). SBS in MPa (Mean/SD) were for A at year 0: (24.63/4.19), A at year 1: (16.84/7.25), B at year 0: (9.13/2.18), B at year 1: (15.54/6.41), C at year 0: (16.82/3.60), C at year 1: (15.26/3.90), D at year 0: (9.27/4.03), D at year 1: (7.97/7.17), E at year 0: (16.67/4.87) and E at year 1: (8.63/3.64). Conclusion: *In vitro* testing demonstrated that resin composite masking has the strongest, most durable SBS on airborne-particle abraded amalgam and airborne-particle abraded enamel-amalgam surfaces and could be used as a method to improve the esthetics of amalgam restorations.

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INTRODUCTION

Each year, millions of amalgams are placed in visible areas of the mouth. Amalgam restorations have been known for their durability and reliability for more than 100 years; however, the dark color of these restorations presents an esthetic quandary and has been a chief complaint of many patients. Dentistry's first attempts to mask amalgam restorations were done with silicate cements,[1] then later with resin composites.[2-7]

Another concern in dentistry has been how to best repair amalgam restorations.[8-12] Fruits and others[8] studied the interfacial bond strengths between fresh amalgam and old and fresh amalgam with abraded and unabraded surfaces, showing that there were no significant differences in bond strength between abraded and unabraded surfaces, and the mean bond strength was greater in groups of specimens that did not use a bonding agent. Other studies have suggested that adhesive systems could improve bonding between old and new amalgam through mechanical interlocking between the adhesive system and freshly condensed amalgam.[9-10] Also, resin composites have been used to repair amalgam restorations; Özcan and others[13] evaluated the effect of different surface conditioning methods on the shear bond strength of resin composite to fresh amalgam, concluding that bond strengths of resin to amalgam substrates varied according to surface conditioning techniques. Abu-Hanna and Mjör[14] reported an alternative technique using resin composite and amalgam to restore teeth that normally would require indirect restorations as a low-cost alternative, with successful clinical results over a short-term.

Amalgam bonding systems (ABS) have been created to improve bonding between amalgam and dentin, diminishing initial microleakage at the amalgam preparation interface. These systems have the capacity to wet the hydrophobic amalgam and hydrophilic enamel surfaces; they usually contain 4-methyloxy ethyl trimellitic anhydride (4-META).[15] The original Amalgambond Adhesive System (Parkell Inc, Farmingdale, NY, USA) consisted of dentin and enamel activators (citric acid and ferric chloride solution), adhesive agent (HEMA: hydroxyethyl methacrylate solution), base (4-META/MMA: 4-methacryloxyethyl trimellitate anhydride/methyl methacrylate) and catalyst (TBB: tri-n-butyl borane). In addition, the Amalgambond Plus Adhesive System has an additive (PMMA: Poly-methyl methacrylate powder) that is said to improve retention.[12]

The durability of the bond strength of resin composite to amalgam is still controversial; therefore, this project examined and compared the shear bond strength (SBS) of the interface between amalgam prepared in various ways and resin composite.

METHODS AND MATERIALS

This study was conducted in two stages. Stage 1 accessed the initial SBS of resin composite to various surfaces, and stage 2 accessed the SBS of resin composite to the same surfaces after one-year storage in water at 37°C. A total of 50 resin composite cylinders were randomly selected and bonded to one of the five surfaces. The five groups were (Figure 1): Group A (control): etched-enamel, Group B: 50% etched enamel-50% polished amalgam, Group C: airborne-particle abraded amalgam, Group D: carbide bur prepared amalgam and Group E: 50% airborne-particle abraded amalgam-50% etched enamel.

Polymethylmethacrylate (Duralay, Reliance Dental, Worth, IL, USA) bases were fabricated with a recess of 10x5x3 mm in the center. The recess was used to embed the enamel samples and/or condense amalgam according to each study group. A high copper amalgam with high silver content and spherical particle formula (Tytin, Kerr Corporation, Orange, CA, USA) was condensed following the manufacturer's directions. All surfaces were ground flat with 400 grit SiC sandpaper discs using copious amounts of water and stored in tap water at 37°C for 24 hours. Fifty micrometer aluminum oxide (Al_2O_3) airborne-particle abrading was performed (Microetcher, Danville, CA, USA) on Groups C and E, followed by ultrasonic cleaning (Teledyne, Hanau, Buffalo, NY, USA). Group D surfaces were prepared with a straight, crosscut fissure carbide bur #557 (SS White Burs Inc, Lakewood, NJ, USA) to create roughness. The shear bond specimens were prepared using a standardized testing device (Ultradent Products, South Jordan, UT, USA). Prior to resin composite application, all the sample surfaces were etched with 35% phos-

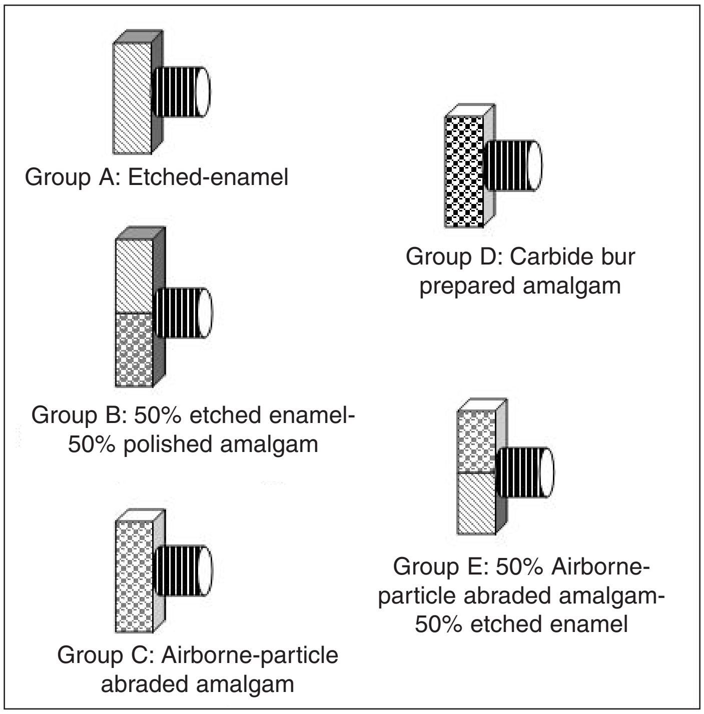

Figure 1*: Schematic representation of study groups.*

phoric acid (Ultra-Etch, Ultradent) for one minute, rinsed with an air-water syringe for 30 seconds, then air dried. The 4-META based adhesive (Amalgambond Plus-system Parkell, Edgewood, NY, USA) was applied to the sample surfaces following the manufacturer's directions. The specimens were then placed in a jig, the mold was lowered onto the surface and lightly tightened to hold the specimens in place. The adhesive was light cured through the mold for 20 seconds with a 500 mW/cm^2 output hand-held curing light (Belle Glass, HP Teklite, Belle de St Claire, Orange, CA, USA). Resin composite (Point 4, Kerr Corporation, Orange CA, USA) was condensed into the cylindrical mold and light cured for 40 seconds.

Table 1: *Mean shear bond strength, standard deviation, and REGWQ grouping of the interface between different amalgam surface treatments and composite resin at year 0 and year 1.*

Group (Year)	Mean SBS (MPa)	SD	N	REGWQ Grouping	Failure Mode
A(0)	24.63	4.17	10	W	Co
A(1)	16.84	7.25	9	X	Co
B(0)	9.13	2.18	10	ZY	Mx
B(1)	15.54	6.41	10	XY	Mx
C(0)	16.82	3.60	10	X	Co
C(1)	15.26	3.90	10	XY	Co
D(0)	9.27	4.04	10	ZY	Ad
D(1)	7.97	7.17	10	Z	Ad
E(0)	16.67	4.87	10	X	Co
E(1)	8.63	3.64	10	Z	Mx

Co: Cohesive Failure. Ad: Adhesive Failure. Mx: Mixed Failure

The SBS test was performed using the standardized testing device in a universal testing machine (Instron model 4204, Canton, MA, USA) at a crosshead speed of 1 mm/minute. The specimens were loaded to failure and the peak load was recorded in pounds. The SB strength was calculated and reported in MPa. After initial testing, the specimen surfaces were re-prepared in the same manner as described previously. Resin composite cylinders were again bonded to the various surfaces and stored in distilled water at 37°C for one year. After one year of storage, the SBS was determined for these specimens. The SBS data were analyzed for significant differences by use of one-way analysis of variance followed by the Ryan Einot Gabriel Welsch multiple range test (REGW-Q) using a 0.05 confidence level.

The failed surfaces of three randomly selected specimens from each group were examined under scanning electron microscopy (SEM)–(JEOL, model JSM-820, USA Inc, Peabody, MA, USA) at 30x and 250x magnification. Failures were classified as adhesive, cohesive or mixed. Adhesive failure was defined as a complete debonding of the bonding agent (adhesive) from the treated surface (adherent). Cohesive failure was defined as a fracture that occurred in the resin composite and showed remnants of bonding agent or resin composite on both sides. Mixed failure was defined as a fracture that showed evidence of adhesive and cohesive failures. Logistic regression was used to determine whether the average adhesive strength found for the group was a significant (α=0.05) factor in the occurrence of a cohesive failure.

RESULTS

The mean/(SD) shear bond strength values, standard deviation and REGWQ grouping for each group are summarized in Table 1. The results indicate that the SBS of etched-enamel (A) was significantly higher (p<0.05) than the other study groups at year 0. Group A at year 0 and year 1, and Groups C and E at year 0 were significantly different (p<0.05) from Groups E and D at year 1. Group B (50% etched-enamel–50% polished amalgam) at year 0 was not significantly different from the same group at year 1. Group C at year 0 and year 1, and Group E at year 0 were not significantly different (p<0.05) from Group A and Group B at year 1. Group D at year 0 and year 1 was not significantly different (p<0.05) from Group E at year 1 and Group B at year 0.

Based on a logistic regression, the authors of this study found that the average shear bond strength was a significant (p<0.001) factor in the occurrences of a cohesive failure.

Based on SEM observations, a regression analysis was performed in order to report failure mode frequencies. Cohesive failure (Co) was defined as a fracture that occurred in the resin composite and showed remnants of bonding agent or resin composite on both sides; adhesive failure (Ad) was defined as a complete debonding of the bonding agent from the treated surface, and mixed failure (Mx) was defined as a fracture that showed evidence of adhesive and cohesive failures.

The SEM showed adhesive failure in Group D (Figure 2), cohesive failure in Groups A, C (Figure 3) and E and mixed failure in Group B (Figure 4). Groups with cohesive failure (control, airborne-particle abraded amalgam and 50% enamel-50% airborne-particle abraded amalgam) had the highest bond strengths, and the group with adhesive failure had the lowest bond strengths. In general, when mixed and adhesive failures were observed more frequently, the mean of shear bond strength was decreased. Likewise, when the frequency of cohesive failure increased, the mean of shear bond strength also increased.

DISCUSSION

Dental amalgam has been used successfully for more than a century as a restorative material. The popularity of this material is a result of its several distinct advantages, such as its relatively low cost, multiple uses, proven longevity, good wear resistance, low technique sensitivity and ability to self-seal.[16] Contemporary resin composites provide an esthetic alternative to amalgam restorations. This study evaluated the shear bond strength of the amalgam-resin composite interface, applying one commonly used adhesive system with different types of amalgam surfaces. Although *in vitro* tests may not reflect intraoral conditions, findings under controlled conditions are helpful and can be applicable to predicting clinical performance.

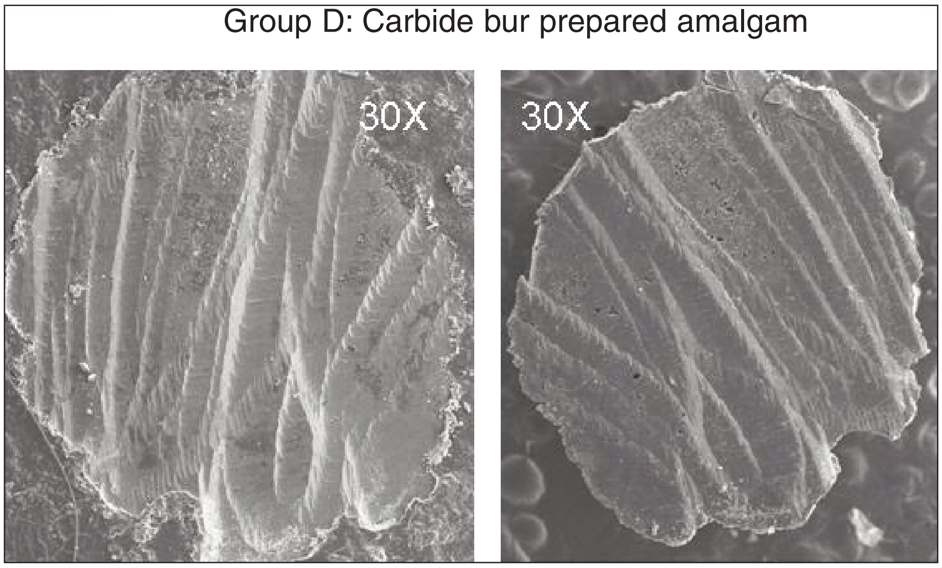

Figure 2*: SEM image of carbide bur prepared amalgam (left) showing adhesive failure after SBS test. Notice a complete debonding of the resin composite cylinder (right), taking the entire adhesive from the amalgam surface and replicating the grooves of the prepared amalgam.*

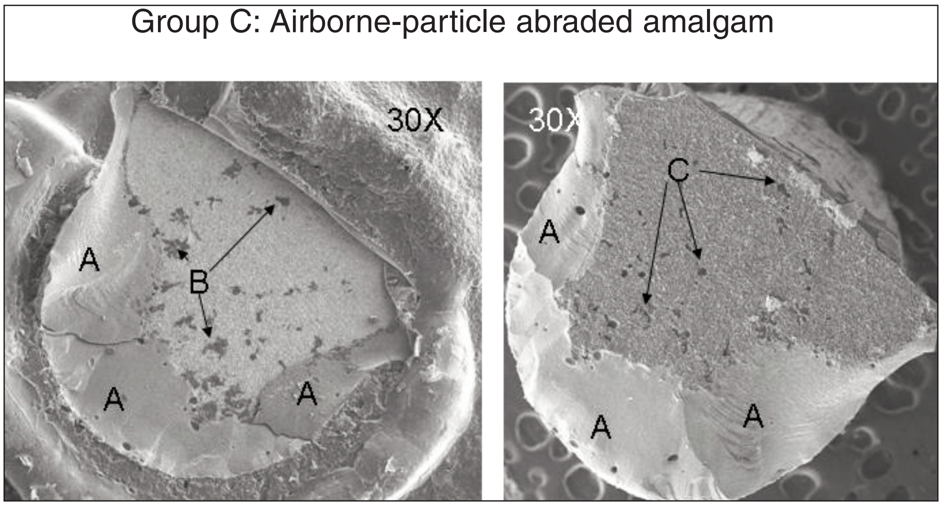

Figure 3*: SEM image of airborne-particle abraded amalgam surface specimen after SBS test displaying remnants from the resin composite cylinder (A), amalgam surface with adhesive residues (B), and resin composite with partial adhesive coverage (C) demonstrating cohesive failure.*

The amalgam surfaces used in this study were developed in different ways: airborne-particle abraded and polished carbide bur prepared. Airborne-particle abrading of dental alloys with alumina particles is commonly used to clean alloy surfaces, increase micro-retention and surface area and improve bonding.[17-20]

The initial SBS of airborne-particle abraded amalgam in this study was significantly higher than carbide prepared amalgam; this is probably due to changes in the surface property of the amalgam increasing the energy interaction (lowering contact angle) with the adhesive agent. Airborne-particle abrading also produced porosities, increasing the surface area of the amalgam, therefore generating interlocking with the bonding agent. These results are in agreement with other investigators, such as Özcan and others, Al-Jazairy, Sperber and others, Zachrisson and others, Ruse and others, Lacy and others and Lubow.[13,18,21-25] Nevertheless, Fruits and others[8] found that there was not a significant difference between abraded and non-abraded amalgam surfaces and suggested that the use of a bonding agent had a significant effect on the bond strength of resin composite to amalgam. The carbide-bur prepared surface, after one year in this study, presented the lowest SBS, proving to be significantly different from the Airborne-particle abraded amalgam group at year 0 and the control group, which could suggest that the surface created by a carbide bur does not generate the necessary roughness to produce sufficient interlocking of the bonding agent. Although data collected in studies on amalgam repair has contradictory results, some agree[12] and others disagree[25] that roughening with a fissure bur gives improved strength.

The selection of bonding agent for this study was based on evidence reported by many authors of amalgam repair studies, stating that adhesives with 4-META and PMMA powder produced significantly higher SBS,[13,24,26-29] although the manufacturer does not recommend use of the high performance additive for direct resin composite placement. The macro shear bond strength, reported by Roberson and others[15] for etched-

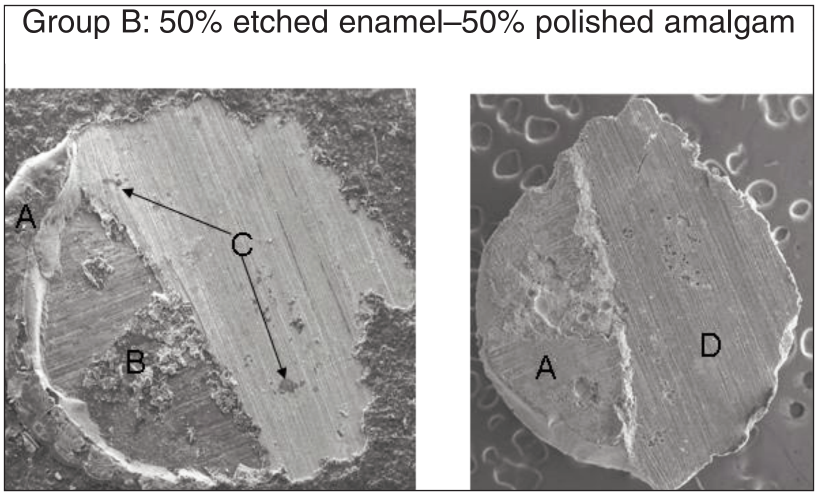

Figure 4*: SEM image of a 50% etched enamel—50% polished amalgam specimen after SBS test. The enamel surface shows areas of retained resin composite cylinder (A), and areas of a mixture of adhesive and resin composite (B). The polished amalgam surface shows small remnants of adhesive (C) demonstrating that most of the adhesive was retained with the resin composite (D), demonstrating mixed failure.*

enamel/ABS/resin composite, was 10-12 MPa; in this study, the mean value for the control group was 24 MPa initially and 16 MPa one year later. For etched-enamel/ABS/amalgam, Roberson and others[15] reported values between 2-22 MPa and Bichacho and others[30] found that Amalgambond has stronger bonding to fresh amalgam than to enamel. Ruzickova and others[31] obtained resin bond strength values between 8.4-8.7. MPa for a different bonding system whose composition is also 4-META/MMA-TBB. In this study, the mean values of Group C were 16.81 MPa initially and 15.26 MPa one year later. The initial SBS of Group E could be comparable to the airborne-particle abraded amalgam group; however, Group E showed a significant decrease with aging after one year. These results may suggest that, to have the same amalgam surface condition underneath the bonding agent, will affect the SBS with aging. More *in vitro* tests and clinical studies need to be conducted to corroborate this theory.

The SEM examination of fractured specimens confirmed the SBS results. Groups with airborne-particle abraded amalgam presented cohesive failure within the resin composite, showing remnants of bonding agent on the amalgam surface. A similar type of failure in the control group suggested that adhesion of the bonding agent to the amalgam surface was a mechanical adhesion due to the roughness created by airborne-particle abrading the surface. This is in agreement with the findings of Abdel-Aziz and Alhadainy,[32] who stated that bond failure occurred between amalgam and the luting agent. The carbide bur prepared amalgam presented an adhesive failure; the bonding agent was completely debonded from the amalgam surface. The SBS found in Group B increased from year 0 to year 1, but this difference was not significantly different. SEM analysis showed a mixed failure. This failure may be explained by the fact that the specimen was 50% etched enamel and 50% polished amalgam where the cohesive failure was found on the enamel side and adhesive failure on the polished amalgam. In general, these findings are probably due to the variability inherent in the use of enamel obtained from extracted teeth; however, the fact that 4-META-based adhesive has been shown to have good SBS to enamel and dentin needs to be considered.[33] More studies need to be conducted to establish the influence of aging on SBS of the amalgam-enamel interface.

CONCLUSIONS

Within the limitations of this *in vitro* study, the following were found:

1. The strongest SBS between composite and amalgam was achieved when the amalgam surface was airborne-particle abraded.
2. Preparing the amalgam surface with a carbide bur did not create enough micromechanical retention to promote interlocking between the amalgam surface and the bonding agent.

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References

1. Liatukas EL (1970) Amalgam restorations with silicate cement facings for anterior teeth *Journal of Prosthetic Dentistry* **23(5)** 560-561.
2. Durnan JR (1971) Esthetic dental amalgam-composite resin restorations for posterior teeth *Journal of Prosthetic Dentistry* **25(3)** 175-176.
3. Barkmeier WW & Cooley RL (1979) Amalgam restoration with a composite resin window *Quintessence International Dental Digest* **10(4)** 31-34.
4. Gourley JM & Ambrose ER (1982) Veneering amalgam restorations *Journal of the Canadian Dental Association* **48(1)** 49-50.
5. Anglis LF & Fine L (1982) The amalgam-composite resin restoration *Journal of Prosthetic Dentistry* **47(6)** 685.
6. Gordon M, Laufer BZ & Metzger Z (1985) Composite-veneered amalgam restorations *Journal of Prosthetic Dentistry* **54(6)** 759-762.
7. Plasmans PJ & Reukers EA (1993) Esthetic veneering of amalgam restorations with composite resin-combining the best of both worlds? *Operative Dentistry* **18(2)** 66-71.

8. Fruits TJ, Duncanson MG Jr & Coury TL (1998) Interfacial bond strengths of amalgam bonded to amalgam and resin composite bonded to amalgam *Quintessence International* **29(5)** 327-334.
9. Zardiackas LD & Stoner GE (1983) Tensile and shear adhesion of amalgam to tooth structure using selective interfacial amalgamation *Biomaterials* **4(1)** 9-13.
10. Roeder LB, DeSchepper EJ & Powers JM (1991) *In vitro* bond strength of repaired amalgam with adhesive bonding systems *Journal of Esthetic Dentistry* **3(4)** 126-132.
11. Diefenderfer KE, Reinhardt JW & Brown SB (1997) Surface treatment effects on amalgam repair strength *American Journal of Dentistry* **10(1)** 9-14.
12. Hasegawa T & Retief DH (1996) Shear bond strengths of two commercially available dentine-amalgam bonding systems *Journal of Dentistry* **24(6)** 449-452.
13. Özcan M, Vallittu PK, Huysmans MC, Kalk W & Vahlberg T (2006) Bond strength of resin composite to differently conditioned amalgam *Journal of Materials Science: Material in Medicine* **17(1)** 7-13.
14. Abu-Hanna AA & Mjör IA (2004) Combined amalgam and composite restorations *Operative Dentistry* **29(3)** 342-344.
15. Roberson TM, Heymann H & Swift EJ Jr (2002) *Sturdevant's Art & Science of Operative Dentistry* Mosby St Louis.
16. Anderson MH & McCoy RB (1993) Dental amalgam. The state of the art and science *Dental Clinics of North America* **37(3)** 419-431.
17. Lim BS, Heo SM, Lee YK & Kim CW (2002) Shear bond strength between titanium alloys and composite resin: Sandblasting versus fluoride-gel treatment *Journal of Biomedical Materials Research Part B, Applied Biomaterials* **64B(1)** 38-43.
18. Lubow RM & Cooley RL (1986) Effect of air-power abrasive instrument on restorative materials *Journal of Prosthetic Dentistry* **55(4)** 462-465.
19. Goldstein RE & Parkins FM (1994) Air-abrasive technology: Its new role in restorative dentistry *Journal of the American Dental Association* **125(5)** 551-557.
20. Berry EA III, Eakle WS & Summit JB (1999) Air abrasion: An old technology reborn *Compendium of Continuing Education in Dentistry* **20(8)** 751-759.
21. Al-Jazairy YH (2001) Shear peel bond strength of compomers veneered to amalgam *Journal of Prosthetic Dentistry* **85(4)** 396-400.
22. Sperber RL, Watson PA, Rossouw PE & Sectakof PA (1999) Adhesion of bonded orthodontic attachments to dental amalgam: *In vitro* study *American Journal of Orthodontics and Dentofacial Orthopedics* **116(5)** 506-513.
23. Zachrisson BU, Büyükyilmaz T & Zachrisson YO (1995) Improving orthodontic bonding to silver amalgam *The Angle Orthodontist* **65(1)** 35-42.
24. Ruse ND, Sekimoto RT & Feduik D (1995) The effect of amalgam surface preparation on the shear bond strength between composite and amalgam *Operative Dentistry* **20(5)** 180-185.
25. Lacy AM, Rupprecht R & Watanabe L (1992) Use of self-curing composite resins to facilitate amalgam repair *Quintessence International* **23(1)** 53-59.
26. Özer F, Ünlü N, Öztürk B & Sengun A (2002) Amalgam repair: Evaluation of bond strength and microleakage *Operative Dentistry* **27(2)** 199-203.
27. Walker AC Jr & Reese SB (1983) Bond strength of amalgam to amalgam in a high-copper amalgam *Operative Dentistry* **8(3)** 99-102.
28. Jessup JP, Vandewalle KS, Hermesch CB & Buikema DJ (1998) Effects of surface treatments on amalgam repair *Operative Dentistry* **23(1)** 15-20.
29. Giannini M, Paulillo LAMS & Ambrosano GM (2002) Effect of surface roughness on amalgam repair using adhesive systems *Brazilian Dental Journal* **13(3)** 179-183.
30. Bichacho N, Pilo R, Brosh T, Berkovich M & Helft M (1995) Shear bond strength of composite resin to fresh amalgam *Operative Dentistry* **20(2)** 68-73.
31. Ruzickova T, Staninec M, Marshall GW & Hutton JE (1997) Bond strengths of the adhesive resin-amalgam interface *American Journal of Dentistry* **10(4)** 192-194.
32. Abdel-Aziz AH & Alhadainy HA (1998) Evaluation of interfacial bond strengths between amalgam and composite inlay *American Journal of Dentistry* **11(3)** 131-133.
33. Hasegawa T, Retief DH, Russell CM & Denys FR (1992) A laboratory study of the Amalgam Bond Adhesive System *American Journal of Dentistry* **5(4)** 181-186.