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Amalgam Repair: Quantitative Evaluation of Amalgam-resin and Resin-tooth Interfaces with Different Surface Treatments

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Clinical Relevance

Repairing defective amalgam restorations with resin composite offers a minimally invasive solution compared to replacement; etch&rinse adhesive systems are suggested to reduce microleakage.

SUMMARY

Aim: The successful addition of new restorative materials to an existing restoration may be the most conservative course of treatment. Repairing amalgam restorations with resin materials remains a viable clinical alternative to amalgam replacement. This *in vitro* study evaluated the effect of different adhesive systems and surface treatments on the integrity of amalgam-resin and resin-tooth interface after partial removal of pre-existing amalgam.

Materials and Methods: Fifty defect-free human molars were restored with amalgam occlusally. The teeth were thermocycled (1,000x) between 5°C and 55°C, with a dwell time of 30 seconds. The mesial and distal parts of the amalgam fillings were removed, leaving only the middle part of amalgam. One side of the cavity was finished with a coarse diamond bur, while the other part of the amalgam was finished with a fine diamond bur. The samples were then randomly divided into five groups (n=10/group) and received the following adhesive systems: Group 1: All Bond 3 (BISCO, Inc); Group 2: Clearfil SE Bond+Alloy Primer (Kuraray); Group 3: Kuraray DC Bond (Kuraray); Group 4: Xeno V (Dentsply); Group 5: XP Bond (Dentsply). All the cavities were restored with resin composite (TPH Spectrum,

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Dentsply). All the materials were used according to the manufacturer's directions. The specimens were re-thermocycled (1,000x), sealed with nail varnish, stained with 0.5% basic fuchsin for 24 hours, sectioned mesiodistally and photographed digitally. The extent of dye penetration on the tooth-sealant interface was measured by image analysis software (ImageJ, Scion Image, Frederick, Maryland, USA) for both coarse-finished and fine-finished surfaces at the resin-tooth and resin-amalgam interface. The data were analyzed statistically with one-way ANOVA and post hoc Tukey tests (α=0.05).

Results: All Bond 3 and XP bond (etch&rinse) produced the best results at each section. All the materials exhibited more microleakage at the amalgam interface than the tooth interface. Surface finishing with different burs did not statistically affect microleakage.

Conclusion: In terms of microleakage reduction, etch&rinse adhesives may be preferred over self-etch adhesives for amalgam repair.

INTRODUCTION

The replacement of defective restorations represents the major part of restorative dentistry in today's general practice.[1] The main reasons for replacement include secondary caries and marginal defects.[2] Other reasons for replacement involve amalgam or cuspal fracture, inadequate marginal integrity or inadequate interproximal contact.[2-3]

Occasionally, the criteria for replacing a restoration are subjective, where small deviations from ideal concepts determine the replacement, especially in cases where the restorations are clinically acceptable with localized defects.[4] Thus, dentists are frequently faced with a clinical decision to replace or repair an amalgam restoration. When a restoration is replaced, there is a loss of healthy dental tissue, including tissue away from the localized defects, thus increasing the preparation and restoration size.[5] The cost of replacing an existing restoration is at least the same as the original restoration and is probably more costly if indirect restorations are deemed necessary. The complete replacement of these large restorations is time-consuming, technically difficult and may be potentially damaging to the pulp.[3]

The successful addition of new restorative materials to an existing restoration may be the most conservative course of treatment in certain situations. By removing part of the restoration to the full depth at the site of the defect, the clinician can make a firm diagnosis regarding its extent, as the defects often are well delineated. Provided that the main part of the restoration is satisfactory, the "exploratory" cavity preparation can then be filled with an appropriate material.[6] Similarly, the presence of a narrow or stained non-carious marginal defect has been shown to be an insufficient reason for replacing amalgam restorations.[7] The repair of an amalgam restoration can be a less invasive procedure than its complete removal and replacement.[8] Repairing margin defects may increase the longevity of the restoration,[9] eliminating areas that are difficult for the patient to properly cleanse, while conserving the remaining tooth structure.[10]

Continuous developments in adhesive resin technology also improve the sealing quality of amalgam repairs, beginning with the introduction of the 4-META bonding agent (Amalgambond, Parkell, Farmingdale, NY, USA) in 1990. Studies related to the repair of amalgam and resin-based composite restorations have been published during recent decades.[11-13] Many researchers have studied the repair strength of amalgam, with conflicting results ranging between 11%[14] and 97%[15] of the intact samples, with most studies approximating 50%.[16] The conflicting nature of these conclusions cause suspicion about the clinical acceptance of amalgam repairs.[13]

The wide range of results found in the literature can be attributed to various factors, such as time of repair, use of a mercury-rich interface between the repair surfaces, the effects of roughening the fractured segment, the type of alloy used and the use of adhesive resins. Each factor has been evaluated by researchers, with little agreement among studies.[17]

This *in vitro* study assessed the repair quality of amalgam restorations at amalgam-resin and resin-tooth interfaces after partial removal of pre-existing amalgam using different 1) surface finishing methods and 2) adhesive systems, using quantitative microleakage assessment and SEM methods.

METHODS AND MATERIALS

Fifty caries-free, readily available intact human molars were collected and stored in distilled water. The teeth were cleaned and polished with pumice and rubber cups for 10 seconds. Occlusal cavities were prepared on each tooth using a high-speed handpiece with air/water spray. A new bur was used for every five teeth. The average facio-lingual width of the cavities was approximately one-third of the intercuspal width, and the depth was 3 millimeters. The cavities were restored with high copper, microfine lathe-cut amalgam (Cavex Avalloy, Haarlem, Holland). The alloys were triturated according to the manufacturer's instructions using an amalgamator (SDI Ultramat 2, Victoria, Australia). A standard amalgam carrier and technique were used to transfer increments to the cavity preparation. After condensation, the amalgam was carved into the margins following the contours of the tooth but was not finished and polished. The restorations were stored in distilled water for 24 hours, after which thermal cycling in deionized water was performed at 5 ± 2°C to 55 ± 2°C for 1,000 cycles, with a dwell time of 30 seconds and a transfer time of 10 seconds.

Mesial and distal parts of the amalgam fillings were removed, leaving only the middle-third of the amalgam. One side of the cavity was finished with a coarse diamond bur (1.6 mm flat-ended cylinder, Ref: 835-012-4ML, Diatech, Alstatten, Switzerland), while the other part was finished with a fine diamond bur (Diatech). The samples were then randomly divided into five groups (n=10/group) to receive the following adhesive systems according to the manufacturer's directions (Table 1):

Group 1: All Bond 3 (BISCO, Inc, Schaumburg, IL, USA) (dual cure, etch&rinse adhesive system)

Group 2: Clearfil SE Bond+Alloy Primer (Kuraray, Okayama, Japan) (self-etch adhesive system with alloy primer)

Group 3: Kuraray DC Bond (Kuraray) (dual-cure, self-etch adhesive system)

Group 4: Xeno V (Dentsply DeTrey, Konstanz, Germany) (one-step, self-etch adhesive system)

Group 5: XP Bond (Dentsply DeTrey) (etch&rinse, self-priming adhesive system)

All of the cavities were restored with resin composite (TPH Spectrum, Dentsply DeTrey) and light polymerized with a halogen light of 500 mW/cm² intensity (Hi-

Table 1: *Material Descriptions and Manufacturers of the Materials Used in This Study*

Material Description	Material	Chemical Composition	Manufacturer	Procedures
Dual-cure etch&rinse adhesive system	All Bond 3	Ethanol (Part A) NTG-GMA Salt (Part A) Bis-GMA (Part B) HEMA (Part B) BPDM (Part B) Bis-GMA Resin: Urethane Dimethacrylate Triethyleneglycol Dimethacrylate Glass Filler	BISCO, Inc, Schaumburg, IL, USA	• 15 seconds etch and rinse thoroughly, leave visibly moist • Mix equal Part A + Part B well for 5 seconds • Apply 1-2 coats • Air dry • Light cure for 10 seconds • Apply All Bond 3 resin • Light cure for 10 seconds
Self-etch adhesive system	Clearfil SE + Alloy Primer	Primer: MDP, HEMA, dimethacrylate monomer, water, catalyst Bond: MDP, HEMA, dimethacrylate monomer, microfiller, catalyst	Kuraray, Okayama, Japan	• Apply primer to tooth structures, leave 20 seconds • Apply alloy primer to amalgam surfaces • Apply bond and light cure for 10 seconds
Dual cure self-etch adhesive system	DC Bond	Liquid A: HEMA, Bis-GMA, dibenzoyl peroxide, 10-Methacryloyloxydecyl dihydrogen phosphate, Colloidal silica dl-Camphorquinone Initiators Others Liquid B: ethanol, water, accelerators	Kuraray, Okayama, Japan	• Mix an equal amount of parts A&B • Apply bond (20 seconds) and dry • Light cure for 10 seconds
One-step self-etch adhesive system	Xeno V	Bifunctional acrylic amides, acrylamido alkylsulfonic acid, inverse functionalized phosphoric acid ester, acrylic acid, Camphorquinone, butylated benzenediol, water, tert-butanol	Dentsply DeTrey, Konstanz, Germany	• Apply and agitate for 20 seconds • Air flow for 5 seconds • Light cure for 20 seconds
Etch&Rinse (self-priming) adhesive system	XP Bond	PENTA, TCB resin, UDMA, TEGDMA, HEMA, nanofiller, Camphorquinone, butylated benzenediol, tert-butanol	Dentsply DeTrey, Konstanz, Germany	• Acid-etch 15 seconds for enamel and 15 seconds for dentin • Rinse thoroughly for 15 seconds and dry • Apply bond and leave for 20 seconds undisturbed • Light cure for 10 seconds

HEMA: 2-hydroxyethyl methacrylate; BHT: Butylated hydroxy toluene; TEGDMA: Triethylenglycoldimethacryate; BisGMA: bisphenol-A-diglycidylether dimethacrylate; UDMA: Urethane dimethacrylate, PENTA: Dipentaerytrhritol pentacrylate-phosphoric acid; TCB: Butan-1,2,3,4-tetracarboxylic acid, di-2-hydroxyethylmethacrylate ester.

Lux Ultra, Benlioglu, Ankara, Turkey). The specimens were again thermocycled as previously mentioned (1,000x) and immersed in 0.5 basic fuchsin solution (Wako Pure Chemical Industries, Osaka, Japan) for 24 hours. After a thorough rinsing with distilled water, the samples were air dried and embedded in epoxy resin (Struers, Copenhagen, Denmark). The specimens were sectioned mesiodistally with a slow speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA) and digitally photographed. The extent of dye penetration on the tooth-sealant interface was measured in length by image analysis software (ImageJ, Scion Image) for both the course-finished and fine-finished surfaces at both the resin-tooth and resin-amalgam interfaces. The data were statistically analyzed with one-way ANOVA and post hoc Tukey tests (α=0.05).

RESULTS

A total of 90 sections were examined for the quantitative evaluation of dye penetration. All the groups exhibited microleakage between the amalgam-resin interface and the tooth-resin interface. Statistical analysis of the dye penetration of both groups, with respect to different regions of the cavities, is presented in Table 2.

One-way ANOVA revealed that the difference between the experimental regions (resin-tooth or resin-amalgam), with respect to adhesive systems, was statistically significant (p<0.05). The post hoc Tukey multiple comparison tests revealed the following results:

The amalgam-resin interface finished with coarse-bur: All Bond 3 and XP Bond (etch&rinse adhesive systems) exhibited statistically significant results compared with the other adhesive systems (p<0.05). There was no statistically significant difference between the DC Bond, Xeno V and SE Bond + Alloy Primer adhesive systems (p>0.05) (Table 2).

Tooth-resin interface finished with coarse bur: The Xeno V adhesive system presented the worst microleakage, with statistically different results (p<0.05) from the other materials; however, there were no statistically significant differences between All Bond 3, SE Bond + alloy primer, DC Bond and XP Bond (p>0.05) (Table 2).

Amalgam-resin interface finished with fine-bur: This region showed similar results compared with groups finished with a coarse bur. All Bond 3 and XP Bond exhibited better microleakage values when compared with the other adhesive systems (p<0.05) (Table 2).

Tooth-resin interface finished with fine bur: All Bond 3 and XP Bond showed statistically significant results from Xeno V (p<0.05) but similar results with SE + alloy primer and DC Bond (Table 2).

Differences between the regions in each material were analyzed by one-way ANOVA. The results

Table 2: *The Statistical Analysis of the Experimental Groups with Respect to the Regions of the Cavity*

Region	Materials	N	Mean ± SE	Minimum (mm)	Maximum
Amalgam-resin interface finished with course-bur	Allbond 3[a]	18	.094 ± .0019	.00	.20
	Clearfil SE Bond[b]	18	2.211 ± .335	.10	4.60
	DC Bond[b]	18	1.988 ± .317	.05	4.00
	Xeno V[b]	18	2.094 ± .305	.10	4.20
	XP Bond[a]	18	.194 ± .025	.10	.50
Tooth-resin interface finished with course-bur	Allbond 3[a]	18	.072 ± .014	.00	.20
	Clearfil SE Bond[a]	18	.169 ± .046	.05	.90
	DC Bond[a]	18	.189 ± .025	.10	.40
	Xeno V[b]	18	.400 ± .099	.10	1.50
	XP Bond[a]	18	.050 ± .012	.00	.10
Amalgam-resin interface finished with fine-bur	Allbond 3[a]	18	.111 ± .021	.00	.30
	Clearfil SE Bond[b]	18	2.259 ± .343	.10	4.20
	DC Bond[b]	18	2.433 ± .230	.30	4.10
	Xeno V[b]	18	2.039 ± .330	.10	3.70
	XP Bond[a]	18	.183 ± .023	.10	.40
Tooth-resin interface finished with fine-bur	Alllbond 3[a]	18	.083 ± .014	.00	.20
	Clearfil SE Bond[a]	18	.172 ± .035	.03	.70
	DC Bond[a]	18	.250 ± .053	.10	.80
	Xeno V[b]	18	.339 ± .108	.10	2.00
	XP Bond[a]	18	.050 ± .012	.00	.10

SE: standard error
mm: milimeters
[a,b]:Groups identified with the same letter in each region are not statistically significant.

revealed that there were no statistically significant differences between each region of the restoration for only All Bond 3 ($p>0.05$), meaning that there was no difference among each region when using All Bond 3, while this material also presented the least microleakage. Post hoc Tukey tests were performed for multiple comparisons (Table 3).

The results revealed that there was no statistical difference between the microleakage values of surfaces with either coarse or fine finish ($p>0.05$). However, amalgam-resin surfaces exhibited statistically more microleakage than tooth-resin surfaces for the other adhesive systems ($p<0.05$) (DC Bond, XP Bond, Xeno V and Clearfil SE + Alloy primer).

DISCUSSION

Amalgam comprises about 40% of the restorations being replaced, with a median age of 12 to 15 years for the replaced restorations.[18] A successful technique for the repair of existing amalgam restorations would certainly be advantageous for the clinician interested in conservative dental treatment. These types of repairs and esthetic procedures may be selected in cases when it is desirable to reduce further trauma to the tooth or avoid additional stress on the patient.[8]

Recently, three treatment options versus total replacement were described.[6] These options may increase the longevity of the defective restoration and preserve tooth structure. The alternative options for treating defective amalgam restorations include repairing, sealing and refurbishing. 1) Repairing consists of removal of part of the restoration and any defective tissue adjacent to the defective area and restoration of the removed site. 2) Sealing includes application of a resin-based sealant in a small, defective site or deficient margin (up to .2 mm). 3) Refurbishing involves removal of surface defects or excess from amalgam restorations using finishing burs.

Sardenberg and others reported that replacing ditched amalgam restorations with other similar restorations resulted in significant dental structure loss, while maintaining or replacing them by resin restoration did not result in significant loss.[19] The microleakage of amalgam restoration repaired with amalgam was beyond the scope of this study. Although amalgam-to-amalgam repair is a widely utilized technique, previous studies report that only 40%-70%[20-22] bond strength is achieved with this technique. The intro and these are both correct. The ratio ranges from 11%-97% with a median of 50%. With the improvement of composite materials, "minimally invasive dentistry" has achieved more attention. In the current study, the repaired cavities were minimally invasive, though designed for composite repair. It was the intention of the authors of the current study to evaluate the "minimally invasive repair" of amalgam restorations.

In vivo studies related to the repair of amalgam indicate a significant impact on the improvement of clinical performance of amalgam restorations with minimal intervention.[3-4,23]

An important factor in the quality of amalgam repair is the interfacial bond between the joined surfaces. The interfacial bond has been studied in terms of microleakage and bond strength. Variables that were investigated include a clean, uncontaminated substrate; roughening the amalgam surface; providing additional undercuts and using repair material that is different from the substrate; and the use of adhesive systems designed for metallic surfaces. Most studies on the quality of repaired amalgam evaluate the flexural or bond strength and microleakage of the repaired amalgam.[13]

Microleakage tests are useful methods for evaluating the sealing performance of adhesive systems. Among the different methods employed, dye penetration measurement on sections of restored teeth is the most commonly used technique. In the current study, image analysis was performed to obtain quantitative results, instead of a conventional subjective scoring. The relative merit of this objective approach, when compared with a subjective scoring system, was to discard the need for scoring by separate evaluators and for consensus scoring in borderline cases, as well as to reduce the need for statistical procedures with regards to interexaminer reliability.[24]

As a part of this research, both halves of the specimens were measured for dye penetration with 50 specimens and 90 sections. This would have tended to nearly double the number of mutually exclusive specimens in the sample and exaggerate the statistical power to detect differences. However, the quantitative Image J analysis showed that the two sections of the same tooth demonstrated different microleakage values. The first intention was to investigate only one section, but after realizing that the two sections show different extents of dye penetration, it was decided to include both sections. This difference might be attributed to the thickness of the low-speed blade.

Research relating to the use of adhesive resins to facilitate amalgam repair has consistently found either no improvement in repair strength[21] or a decrease in repair strength.[26] Leelawat and others were the only investigators to find a significant increase in strength when utilizing resin adhesives.[14]

The effect of roughening the surface of existing amalgams is another factor that has been studied. Jessup and Vandewalle reported improved bond strengths after roughening the surface of samples with a carbide bur prior to repair.[17] Hadavi and others reported simi-

Table 3: *Statistical Analysis of the Experimental Groups with Respect to the Materials*

MATERIALS	REGION	N	Mean ± SE (mm)	Minimum	Maximum
AllBond 3	Amalgam-resin interface finished with coarse-bur	18	.094 ± .0019	.00	.20
	Tooth-resin interface finished with coarse-bur	18	.072 ± .014	.00	.20
	Amalgam-resin interface finished with fine-bur	18	.111 ± .021	.00	.30
	Tooth-resin interface finished with fine-bur	18	.083 ± .014	.00	.20
Clearfil SE Bond	Amalgam-resin interface finished with coarse-bur[a]	18	2.211 ± .335	.10	4.60
	Tooth-resin interface finished with coarse-bur[b,c]	18	.169 ± .046	.05	.90
	Amalgam-resin interface finished with fine-bur[a]	18	2.259 ± .343	.10	4.20
	Tooth-resin interface finished with fine-bur[a,c]	18	.172 ± .035	.03	.70
DC bond	Amalgam-resin interface finished with coarse-bur[a]	18	1.988 ± .317	.05	4.00
	Tooth-resin interface finished with coarse-bur[b,c]	18	.189 ± .025	.10	.40
	Amalgam-resin interface finished with fine-bur[a]	18	2.433 ± .230	.30	4.10
	Tooth-resin interface finished with fine-bur[a,c]	18	.250 ± .053	.10	.80
Xeno V	Amalgam-resin interface finished with coarse-bur[a]	18	2.094 ± .305	.10	4.20
	Tooth-resin interface finished with coarse-bur[b,c]	18	.400 ± .099	.10	1.50
	Amalgam-resin interface finished with fine-bur[a]	18	2.039 ± .331	.10	3.70
	Tooth-resin interface finished with fine-bur[a,c]	18	.339 ± .108	.10	2.00
XP Bond	Amalgam-resin interface finished with coarse-bur[a]	18	.194 ± .025	.10	.50
	Tooth-resin interface finished with coarse-bur[b,c]	18	.050 ± .012	.00	.10
	Amalgam-resin interface finished with fine-bur[a]	18	.183 ± .023	.10	.40
	Tooth-resin interface finished with fine-bur[a,c]	18	.050 ± .012	.00	.10

SE: standard error
mm: milimeter
[a,b,c]:Groups identified with the same letter in each region are not statistically significant.

lar results after sample preparation with diamond and carbide burs.[25] However, the results of the current *in vitro* study could not correlate microleakage and surface roughness of the joined surfaces.

Roberts and others found that the use of a bonding agent did not measurably improve the degree of protection against microleakage provided by the resin composite.[27] Unlike the current findings, Ozer and others found a significant improvement in microleakage, especially at the amalgam-resin interface, when using adhesive systems.[13] It is interesting to note that the results of the current study highlighted the amalgam-resin interface as the weakest part of the repaired restorative complex.

As a large number of improved resin brands are being released on the market, it is important for dentists to be aware of the probable longevity and likely modes of failure when repairing existing amalgam restorations. It seems reasonable to suggest an efficient adhesive system and a surface treatment to optimize the repair procedure.

Numerous bonding systems are available that fall under two main categories: etch&rinse and self-etch adhesives. Etch&rinse adhesive systems use phosphoric acid-etching of enamel and dentin before bonding, which is thought to be beneficial, as it is considered that the demineralized and uninfiltrated dentin zone becomes the weak point of the bond, owing to the hydrolytic degradation of collagen over time.[28-29] Although the reduction or absence of demineralized dentin for the simplified "self-etching" systems was believed to primarily prevent hydrolytic degradation of bonded structures, it recently has been shown that hydrolysis of collagen may well take place in the long-term.[30] This is clinically significant, since the degradation between resin-dentin bonds may enable access for microleakage.

Self-etch adhesive systems have become increasingly popular in the last decade. The combination of etchant and primer into one system is advantageous in that it reduces the application time and technique-related sensitivity.[31] On the other hand, there is an ongoing debate on the efficacy of bonding to enamel with self-etch adhesives.[32] Some authors support the manufacturer's recommendations that the adjunctive use of phosphoric acid etching is necessary when bonding to uncut enamel,[32] while others argue that the bond strengths of self-etch adhesives are equal to that of total-etch adhesives on unground enamel.[33] To date, no correlation has been established between microleakage scores and the bond strengths of dental adhesive systems.[34]

In fact, all of the specimens in the current study exhibited some microleakage, both at the amalgam-resin interface and the resin-tooth interface. However, etch&rinse systems performed significantly better than other two-step or one-step self-etch adhesive systems. The results also demonstrate that the accompanying alloy primers did not significantly improve sealing in the restorative complex.

All-bond 3 is a hydrophobic, radiopaque-filled bonding resin that is also HEMA-free. The absence of HEMA in the resin layer is a desirable feature that makes the bonding layer less prone to water sorption. Water sorption can be a critical cause in degradation of the bond, while also promoting further decay of the tooth structure. Hydrophobic adhesives are expected to be more durable than current formulas that are on the market.

The better performance of etch&rinse systems may also be related to micromechanical interlocking of the resin system to acid-etched surfaces. However, it should be noted that additional roughening with coarse burs did not facilitate bonding, both in amalgam and tooth surfaces.

CONCLUSIONS

In terms of preventing microleakage, etch&rinse adhesives may be preferred for amalgam repair. The use of coarse versus fine diamonds for preparation did not impact microleakage.

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References

1. Mjör IA, Moorhead JE & Dahl JE (2000) Reasons for replacement of restorations in permanent teeth in general dental practice *International Dental Journal* **50(6)** 361-366.

2. Hickel R & Manhart J (2001) Longevity of restorations in posterior teeth and reasons for failure *The Journal of Adhesive Dentistry* **3(1)** 45-64.

3. Moncada G, Fernandez E, Martin J, Arancibia C, Mjör I & Gordan VV (2008) Increasing the longevity of restorations by minimal intervention: A two-year clinical trial *Operative Dentistry* **33(3)** 258-264.

4. Gordan VV, Riley JL 3rd, Blaser PK & Mjör IA (2006) 2-year clinical evaluation of alternative treatments to replacement of defective amalgam restorations *Operative Dentistry* **31(4)** 418-425.

5. Gordan VV, Shen C & Mjör IA (2004) Marginal gap repair with flowable resin based composites *General Dentistry* **52(5)** 390-394.

6. Mjör IA & Gordan VV (2002) Failure, repair, refurbishing and longevity of restorations *Operative Dentistry* **27(5)** 528-534.

7. Kidd EA, Joyston-Bechal S & Beighton D (1995) Marginal ditching and staining as a predictor of secondary caries around amalgam restorations: a clinical and microbiological study *Journal of Dental Research* **74(5)** 1206-1211.

8. Fruits TJ, Duncanson MG & Coury TL (1998) Interfacial bond strength of amalgam bonded to amalgam and resin composite bonded to amalgam *Quintessence International* **29(5)** 327-334.

9. Mjör IA (2000) Excellence in diagnosing failures: A challenge for the 21st century *Operative Dentistry* **25(1)** 62.

10. Anusavice KJ (1995) Treatment regimens in preventive and restorative dentistry *Journal of the American Dental Association* **126(6)** 727-743.

11. Puckett AD, Holder R & O'Hara JW (1991) Strength of posterior composite repairs using different composite/bonding agent combinations *Operative Dentistry* **16(4)** 136-140.

12. Mjör IA (1993) Repair versus replacement of failed restorations *International Dental Journal* **43(5)** 466-472.

13. Ozer F, Unlu N, Ozturk B & Sengun A (2002) Amalgam repair: Evaluation of bond strength and microleakage *Operative Dentistry* **27(2)** 199-203.

14. Leelawat C, Scherer W, Chang J, Vijayaraghavan T & LeGeros J (1992) Bonding fresh amalgam to existing amalgam: A shear and flexural strength study *Journal of Esthetic Dentistry* **4(2)** 46-49.

15. Jorgensen KD (1968) Bond strength of repaired amalgam *Acta Odontologica Scandinavia* **26(6)** 605-615.

16. Berge M (1982) Flexural strength of joined and intact amalgam *Acta Odontologica Scandinavia* **40(5)** 313-317.

17. Jessup JP, Vandewalle KS, Hermesch CB & Buikema DJ (1998) Effects of surface treatments on amalgam repair *Operative Dentistry* **23(1)** 15-20.

18. Forss H & Wildstrom E (2004) Reasons for restorative therapy and longevity of restorations in adults *Acta Odontologica Scandinavia* **62(2)** 82-86.

19. Sardenberg F, Bonifácio CC, Braga MM, Imparato JC & Mendes FM (2008) Evaluation of the dental structure loss produced during maintenance and replacement of occlusal amalgam restorations *Brazilian Oral Research* **22(3)** 242-246.

20. Hadavi F, Hey JH, Czech D & Ambrose ER (1992) Tensile bond strength of repaired amalgam *Journal of Prosthetic Dentistry* **67(3)** 313-317.

21. Shen C, Speigel J & Mjör IA (2006) Repair strength of dental amalgams *Operative Dentistry* **31(1)** 122-126.

22. Roberson MT, Heyman HO & Swift EJ Jr (eds) *Sturdevant's Art and Science of Operative Dentistry*, Mosby, USA

23. Moncada GC, Martin J, Fernandez E, Vildosola PG, Caamano C, Caro MJ & Mjör I (2006) Alternative treatments for resin-based composite and amalgam restorations with marginal defects: A clinical trial *General Dentistry* **54(5)** 314-318.

24. Korasli D, Ziraman F, Ozyurt P & Cehreli SB (2007) Microleakage of self-etch primer/adhesives in endodontically treated teeth *Journal of the American Dental Association* **138(5)** 634-640.

25. Hadavi F, Hey JH, Ambrose ER & El-Badray HE (1991) The influence of an adhesive system on shear bond strength of repaired high-copper amalgams *Journal of Prosthetic Dentistry* **16(5)** 175-180.

26. Carr-Hosie MA, Miranda FJ, Collard EW & Duncanson MG Jr (1992) The effect of Amalgambond on the flexural strength of dental amalgam *Ohio Dental Association Journal* **82(3)** 20-24.

27. Roberts HW, Charlton DG & Murchison DF (2001) Repair of non-carious amalgam margin defects *Operative Dentistry* **26(3)** 273-276.

28. Hashimoto M, Ohno H, Kaga M, Endo K, Sano H & Oguchi H (2000) *In vivo* degradation of resin-dentin bonds in humans over 1 to 3 years *Journal of Dental Research* **79(6)** 1385-1391.

29. Hashimoto M, Ohno H, Sano H, Tay FR, Kaga M, Kudou Y, Oguchi H, Araki Y & Kubota M (2002) Micromorphological changes in resin-dentin bonds after 1 year of water storage *Journal of Biomedical Materials Research* **63(3)** 306-311.

30. Hashimoto M, Ohno H, Sano H, Kaga M & Oguchi H (2003) Degradation patterns of different adhesives and bonding procedures *Journal of Biomedical Materials Research. Part B Applied Biomaterials* **66(1)** 324-330.

31. Tay FR & Pashley DH (2001) Aggressiveness of contemporary self-etching systems I. Depth of penetration beyond smear layers *Dental Materials* **17(4)** 296-308.

32. Perdigão J & Geraldeli S (2003) Bonding characteristics of self-etching adhesives to intact versus prepared enamel *Journal of Esthetic and Restorative Dentistry* **15(1)** 32-41.

33. Tay FR, Pashley DH, King NM, Carvalho RM, Tsai J, Lai SC & Marquezini L Jr (2004) Aggressiveness of self-etch adhesives on ground enamel *Operative Dentistry* **29(3)** 309-316.

34. Fortin D, Swift EJ Jr, Denehy GE & Reinhardt JW (1994) Bond strength and microleakage of current dentin adhesives *Dental Materials* **10(4)** 253-258.