©Operative Dentistry, 2006, **31-3**, 377-383

Microleakage in Conventional and Bonded Amalgam Restorations: Influence of Cavity Volume

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Clinical Relevance

The volume of cavity preparations showed no influence on amalgam restoration microleakage. In most situations, bonded amalgam performed similarly to conventional amalgam restorations. It was also found that microleakage was higher in margins located in cementum-dentin.

SUMMARY

This study verified the relationship between the volume and microleakage of conventional and bonded amalgam restorations. Also, the microleakage influence of intermediate materials, substrates and the direction of sectioning was investigated. Fifty-six bovine incisors were selected. Standard Class V cavities were prepared in buccal and lingual surfaces. For each tooth, two cavity sizes were prepared, corresponding to two cavity volumes: one larger (A) and the other smaller (B). The cervical wall was located in cementum/dentin and the incisal wall in enamel. The teeth were distributed in four groups (n=28) according to the intermediate material employed (glass-ionomer cement, resin cement, adhesive system and copal varnish–control). The materials were applied following manufacturers' directions. After restoration, the teeth were submitted to thermal cycling. They were then immersed in a dye solution and sectioned in two directions inciso-cervical (IC) and mesio-distal (MD) sections to evaluate the microleakage. Data were subjected to non-parametric statistical analysis (Wilcoxon's paired test and Kruskal-Wallis test). No significant difference was found between the two cavity sizes. Leakage in enamel was statistically lower than in the cementum/dentin interface ($p<0.05$). In some situations, glass-ionomer or resin cement lined amalgam restorations presented less dye leakage than copal varnish lined restorations ($p<0.05$). No significant difference was observed in microleakage between IC or MD

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DOI: 10.2341/05-49

sectioning. Within the limitations of this study, it was concluded that cavity size and direction of section were not significant factors for microleakage, while substrate and intermediate materials had a significant effect on the sealing ability in amalgam restorations.

INTRODUCTION

Despite the decrease in placement of amalgam restorations attributed to poor esthetic characteristics and potential mercury contamination, this material still provides the best cost-effectiveness as a direct posterior restorative material, mainly when used in public health (Corbin & Kohn, 1994). Even the alleged side effects related to the presence of mercury have been questioned based on the lack of scientific evidence (Dodes, 2001).

Amalgam restorations have been used for more than a century. Although the quality of the amalgam alloy has increased during this period, marginal sealing remains a challenge for the clinician. Factors such as thermal conductibility (Rossomando & Wendt, 1995), thermal expansion coefficient and lack of adhesion (Mahler & Bryant, 1996) facilitate initial microleakage soon after placement of amalgam restorations. Sealing improves with aging due to the corrosion process releasing oxides that will be deposited into the amalgam/tooth interface (Ben-Amar, Cardash & Judes, 1995). Bonded amalgam, using different adhesive agents, has been proposed to increase initial sealing (el Badrawy, 1999; Marchiori & others, 1998; Pimenta & others, 1998; Summitt & others, 2001; Cenci & others, 2004) and enhance the fracture resistance of restored teeth (el Bradawy, 1999).

However, the application of adhesive materials under amalgam restorations for sealing improvement could be influenced by cavity size. In a meta-analytic review regarding bonding studies, Leloup and others (2001) verified that bond strength is inversely proportional to the bonding area. In small areas, tension development in the dentin/material interface is more homogeneous, and there is minor influence of polymerization shrinkage and thermal changes. Also, in a smaller cross-sectional area, if natural defects or stress-concentrating voids are uniformly but relatively sparsely distributed in dentin, these samples may then have more uniform stress distribution and thus produce higher tensile strengths (Sano & others, 1994).

Similarly, the size of the cavity preparation could have an influence on the bonded amalgam restoration performance. Cavity size influenced the longevity of amalgam restorations (Mjör & Toffenetti, 1992), and large amalgam restorations produced more deterioration than small-sized cavities (Wilson, Wastell & Norman, 1996). Improved resistance to fracture was only observed in those teeth presenting small cavity preparations (Lindemuth, Hagge & Broome, 2000).

Thermal cycling has influenced the degree of leakage in restorative materials with thermal conductibility higher than that of the dental structure (Rossomando & Wendt, 1995; Sommer & others, 2003). Amalgam exhibits thermal conductibility 20 times higher than tooth structure and composites. In addition, microleakage may be dependent on the size of the restoration, that is, the thermal conductance in relation to the total volume of the material (Rossomando & Wendt, 1995).

Additionally, the way (direction) that specimens are cut may influence leakage measurements (Raskin & others, 2001). Dye penetration tends to be higher in the proximal regions than in the center of the restorations (Mixson & others, 1991).

The null hypotheses to be tested are that different cavity preparation sizes (volumes), the directions of specimen sectioning, the intermediate material and the substrates used produce the same sealing ability for amalgam restorations. Thus, the purpose of this study was to verify the influence of restoration volume on the microleakage of bonded and conventional Class V amalgam restorations with margins located in enamel and cementum/dentin while also identifying the sealing performance of different intermediate materials, therefore, evaluating the dye penetration in two directions.

METHODS AND MATERIALS

Fifty-six bovine incisors were selected. Soon after extraction, the teeth were scraped to remove debris and pulp tissue. They were then frozen and stored in saline solution until use in the experiment (Derhami, Coli & Brannstrom, 1995). The teeth were observed under magnification to select specimens that were free of cracks. One experienced operator performed all of the cavity preparations and restorative procedures.

Two box-shaped Class V preparations of different volumes were performed in each tooth on both the buccal and lingual surfaces. Each group had the same number of cavity sizes allocated in each face. Standardization was obtained with a specially developed appliance based on a table of coordinates. The incisal margin was located in enamel and the cervical margin in cementum/dentin. Carbide burs (# 330) were used in a high-speed handpiece under air-water cooling and were replaced after five preparations to ensure cutting ability. The two cavity preparation sizes were: (Lc) larger cavity: 1.7(± 0.2) x 2.0(± 0.1) x 4.0(± 0.1) mm and (Sc) small cavity: 1.7(± 0.2) x 2.0(± 0.1) x 2.0(± 0.1) mm, corresponding to the depth, inciso cervical and mesio distal distances, respectively. The aim of these preparations was to set two cavity volumes:

Table 1: *Materials Used in This Study*

Material	Manufacturer	Batch #
Copalex	Inodon Produtos Odontológicos, Porto Alegre, RS, Brazil	0002
RelyX Luting Cement	3M ESPE, St Paul, MN, USA	0BR
Single Bond	3M ESPE, St Paul, MN, USA	OEJ
RelyX ARC	3M ESPE, St Paul, MN, USA	BFBF
Alloybond	Southern Dental Industries, Baywater, Victoria, Australia	992682
GS-80	Southern Dental Industries, Baywater, Victoria, Australia	000433301

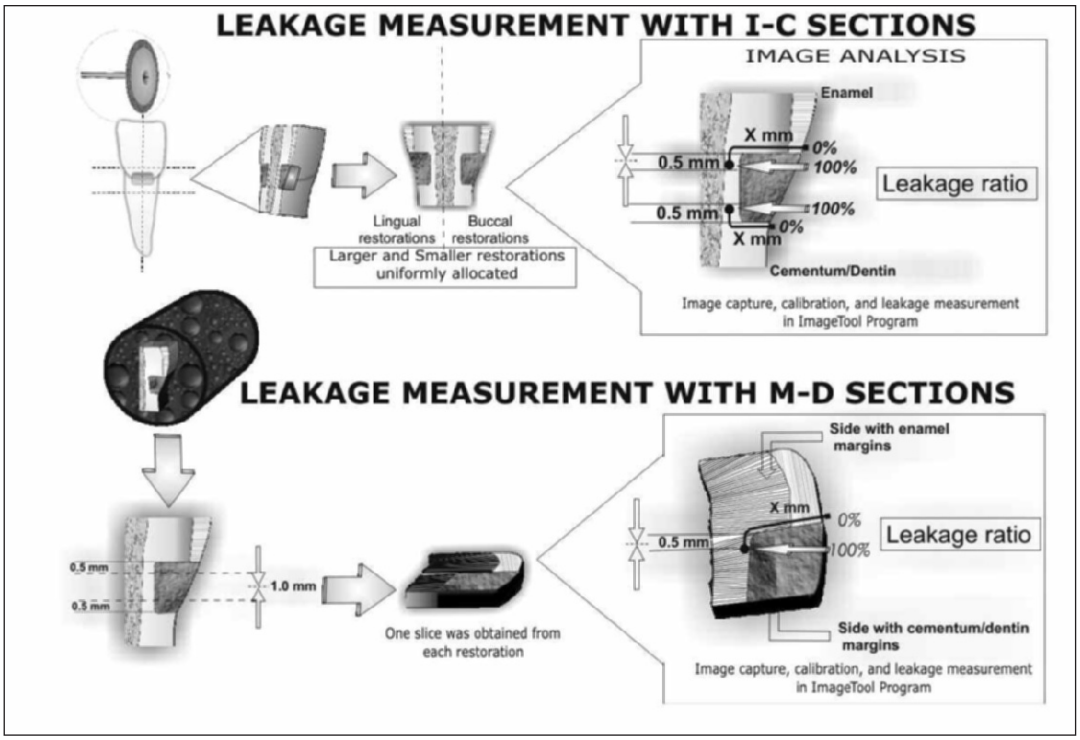

Figure 1: *Leakage measurement method used.*

V(Lc) approximately 13.6 mm^3 and V(Sc) approximately 6.8 mm^3, so that V(Lc) was twice that of V(Sc).

The teeth were randomly divided in four groups with 14 specimens in each group (n=28 cavities). The two cavity size preparations were equally distributed in each group among the buccal and lingual surfaces. Before the restorative procedures, the cavo-superficial angle was defined using a hand instrument; prophylaxis with pumice was performed and the cavities were washed and dried.

The materials used (Table 1) were applied according to the manufacturer's indications. The four groups were restored as follows:

Group Cv: copal varnish–Control (Copalex; Inodon Produtos Odontológicos, Porto Alegre, RS, Brazil). Two coats of varnish were applied. A gentle air stream was used after each application. After the second coat, a 60-second delay was observed before the application of amalgam.

Group Gic: resin-modified glass ionomer (RelyX Luting Cement; 3M ESPE, St Paul, MN, USA). After the powder and liquid were mixed, a thin coat of the material was applied in the cavity preparation with a brush.

Group Rc: dentin-bonding agent (Single Bond, 3M ESPE) + resin cement (RelyX ARC, 3M ESPE). The entire cavity was conditioned with 37% phosphoric acid for 15 seconds. After washing, the cavity was dried with a gentle air stream, keeping the dentin moist. Two coats of Single Bond were applied and each application was photo-cured for 10 seconds. Resin cement was mixed and a thin layer was applied using a brush.

Group As: adhesive system for amalgam (Alloybond, Southern Dental Industries, Baywater, Victoria, Australia). Cavity preparation was etched with 37% phosphoric acid for 20 seconds. After etching, the preparation was washed and lightly dried, keeping the dentin moist. Alloybond primer was applied, gently dried and photo cured for 10 seconds. Base and catalyst pastes were mixed and placed on the cavity walls.

Amalgam was inserted into the cavity before the adhesive materials set. Admixed capsuled alloy (GS-80; Southern Dental Industries) was prepared in an amalgamator (Ultramat 2, Southern Dental Industries) that was set at 4600 rpm for 8 seconds. Amalgam was hand condensed in two increments using Ward and Hollenback instruments, and a 3S Hollenback carver was used for any carving. The specimens were stored in saline solution for one week at 37°C. After storage, the restorations were polished using rubber cups and polishing pastes.

Table 2: *Median of Microleakage Score Measured in Incisal-cervical (I-C) Sections According to Materials, Cavity Sizes and Margin Locations*

	Restorations Sectioned Incisive-cervical (I-C)			
	Large Restorations		Small Restorations	
Material	Enamel	Cementum/Dentin	Enamel	Cementum/Dentin
GCV (copal varnish)	[B]0.48 a b	[A]0.73 a b	[B]0.24 b	[A]0.60 b
GGIC (RelyX luting)	[B]0.00 b c	[A]0.53 b	[B]0.23 b	[A]0.63 b
GRC (RelyX ARC)	[B]0.00 c	[A]0.66 a b	[B]0.00 b	[A]0.70 a b
GAS (Alloy Bond)	[B]0.88 a	[A]1.00 a	[A]1.00 a	[A]1.00 a

Different superscript capital letters on the horizontal for the same restoration size represent differences statistically significant between enamel and cementum/dentin (Wilcoxon paired test, p<0.05). Different minuscule letters on vertical show differences between groups according to Kruskal-Wallis multiple comparison non-parametric test (p<0.05).

Table 3: *Median of Microleakage Score Measured in Mesio-distally (M-D) Sections According to Materials, Cavity Sizes and Marginal Locations*

	Restorations Sectioned Mesio-distally (M-D)			
	Large Restorations		Small Restorations	
Material	Enamel	Cementum/Dentin	Enamel	Cementum/Dentin
GCV (copal varnish)	[A]1.00 a b	[A]1.00 a	[A]0.89 a b	[A]0.82 a
GGIC (RelyX luting)	[A]0.86 b c	[A]1.00 a	[A]0.44 b c	[A]0.76 a
GRC (RelyX ARC)	[B]0.34 c	[A]0.72 a	[B]0.38 c	[A]0.64 a
GAS (Alloy Bond)	[A]1.00 a	[A]1.00 a	[A]1.00 a	[A]1.00 a

Different superscript capital letters on the horizontal for the same restoration size represent differences statistically significant between enamel and cementum/dentin (Wilcoxon paired test, p<0.05). Different minuscule letters on vertical show differences between groups according to Kruskal-Wallis multiple comparison non-parametric test (p<0.05).

The specimens were submitted to thermal cycling for 500 cycles between 5°C and 55°C with 60 seconds of dwell time. The root apex of each tooth was sealed with resin composite. The entire surface was then painted with two coats of nail varnish, except for the restorations and the 1.0 mm surrounding them. The specimens were immersed in buffered 0.5% methylene blue dye solution for 4 hours, washed in tap water for 8 hours and scaled to remove the nail varnish.

For dye leakage measurements, the specimens were cut in two directions using a diamond saw: 1) the specimens were cut longitudinally in a bucco-lingual direction (incisal-cervical sections, I-C sections); 2) after leakage readings of I-C sections, each tooth was cut in a transversal direction (mesio-distal, M-D sections), resulting in one slice for proximo-proximal leakage evaluation (Figure 1).

Dye penetration was assessed under magnification (20x) in a stereomicroscopy (Metrimpex Hungary, PZO-Labinex) with a digital capture image device. The images were stored as TIFF files on a computer hard drive. Leakage measurement analysis was performed on a Gateway 2000 computer using the free UTHSCSA ImageTool program (developed at the University of Texas Health Science Center at San Antonio, Texas, USA and made available on the Internet by an anonymous FTP from ftp://maxrad6.uthscsa.edu). The leakage number was taken from the following ratio:

$$\text{Leakage Number} = \frac{\text{Distance evidenced for dye}}{\text{Overall distance determined for margin } (=100\%)}$$

The leakage distance from the margins to the determined limit was recorded in mm, and the leakage number was a result of the proportion of dye leakage. After leakage measurement in inciso-cervical sections, the specimens were embedded in transparent polystyrene resin for transversal sections (mesio-distal cuts). Blocks were positioned in a precision cutting machine 1000 Isomet (Buehler Ltd, Lake Bluff, IL, USA). A 1-mm thick slice was obtained and leakage was measured from both sides (enamel margins and cementum margins) (Figure 1). The leakage number for the M-D sections was recorded according to the previous formula.

The experimental data were subjected to statistical analysis using non-parametric tests (Wilcoxon's paired test and Kruskal-Wallis). All statistical testing was performed at significance level $p<0.05$.

RESULTS

In Table 2, data from dye leakage in the I-C sections are presented. At the enamel margins, the restorations lined with resin cement (RC) on both sizes fully prevented dye leakage, exhibiting statistically less leakage than Group CV (control) in larger cavities and AS

($p<0.05$). At the cementum/dentin margins, Group GIC showed statistically less leakage than AS ($p<0.05$) in large restorations. The dye penetration in cementum was significantly higher ($p<0.05$) than enamel in small cavities, where leakage in both substrates was similar except for the AS group.

Leakage data regarding the M-D sections are presented in Table 3. Different groups exhibited similar performances in enamel and cementum/dentin margins, except for group RC, which showed less leakage in enamel for both cavity sizes ($p<0.05$). Also, the RC group demonstrated less leakage in enamel than Groups CV and AS ($p<0.05$).

The Wilcoxon's test was used to compare the leakage patterns between different restorations sizes and sectioning directions. No statistically significant difference was found between the smaller and larger cavities. Also, despite the fact that the M-D sections usually exhibit higher leakage scores, there was no significant difference between the sectioning directions.

A weak positive correlation was found between the leakage level of the I-C and M-D sections through Pearson's correlation. The correlation was stronger ($p<0.05$) in small restorations (r=0.579) than in large restorations (r=0.437) (Figure 2).

DISCUSSION

Microleakage is still a concern in restorative dentistry, as it has been related to pulp alterations, sensitivity and secondary caries, which are the most common causes of restoration failure (Manhart & others, 2004). Currently, no outstanding method is available to determine microleakage (Alani & Toh, 1997). Despite the limitations, dye leakage methodology remains a popular tool to investigate the sealing ability of restorative materials, due to its low cost and the technique being very simple (Raskin & others, 2001). Furthermore, measurements of marginal-sealing effectiveness and bond-strength testing (the two most commonly employed methodologies to determine bonding capacity in the laboratory) are valuable for predicting clinical performance (Van Meerbeek & others, 2003).

Using bovine teeth, it was possible to select specimens with similar age, increasing sample size and enhancing reliability of the results. Bovine teeth are an acceptable alternative to human teeth, with the exception of deep bovine dentin (Mota & others, 2003). To avoid such interference, the cavity floor was located in superficial dentin.

The hypotheses tested in this study were partially rejected, since the substrate and intermediate material influenced leakage patterns in some situations. However, there was no significant difference between larger and smaller cavities, and there was no significant difference in both sectioning directions (I-C or M-D sections).

Despite the thermal conductance of amalgam, resulting in possible higher volumetric alterations, the two cavity preparation sizes exhibited similar performances. Lindemuth and others (2000) observed a correlation between the size of the amalgam restorations and the resistance to fracture of the restored teeth. Nevertheless, the higher resistance to fracture in teeth with smaller cavities could be explained with minor removal of sound dental tissue in teeth with conservative cavities. There is a clear relationship between increasing cavity preparation size and decreasing fracture resistance (Mondelli & others, 1980). The similar performance between the two restoration volumes could be attributed to the time necessary for changes in temperature between the surface of the amalgam restoration and the amalgam near the cavity floor. If a longer dwell time was set for the two temperatures, perhaps the restorations would suffer greater alterations due to the change in temperature of the total restoration mass, which could result in the presence of larger interfaces in those cavities with larger volumes. However, in the clinical situation, thermal changes in the mouth are short events and, even the one-minute employed in this study seems excessive (Sommer & others, 2003).

Many studies have demonstrated an inverse correlation between the bond strength of composites and the cross-sectional area of adhesion (Sano & others, 1994; Van Meerbeek & others, 2003). The findings of this study have not confirmed this inverse correlation for bonded

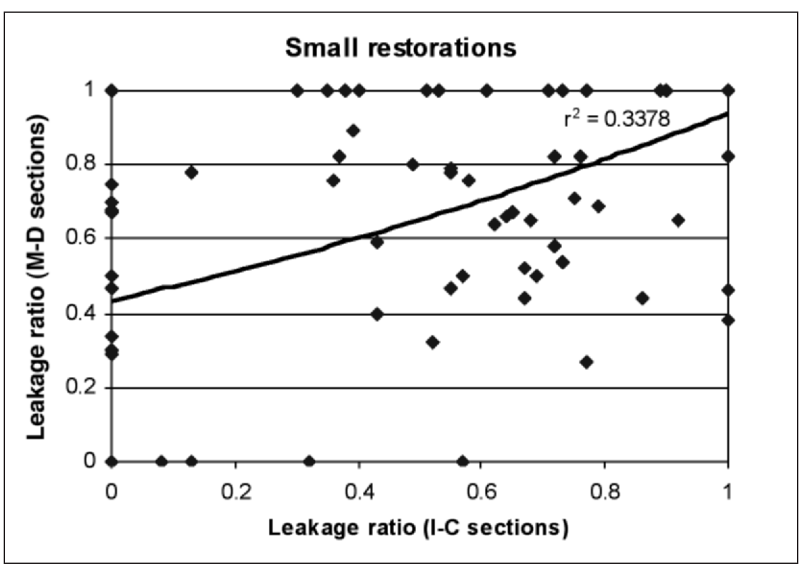

Figure 2: *A weak correlation between leakage in I-C and M-D sections is showed for small restorations.*

amalgam restorations. The reason for this could be that, in the bonded amalgam technique, the layer of intermediate adhesive material is too thin and is incorporated into the amalgam mass, resulting in lower polymerization shrinkage and, as a consequence, less stress development. Thus, the stress developed in larger cavities could be similar to that of smaller cavities because of the thin adhesive layer resulting in similar behaviors.

Dye leakage was higher in the cementum/dentin margins, which is in agreement with previous reports (Marchiori & others, 1998; Meiers & Turner, 1998; Cenci & others, 2004). This difference is related to the difference in mineral composition between the two substrates. While enamel is a highly mineralized tissue, dentin is less mineralized, thus, presenting more organic compounds. Also, dentin is a moist tissue, making bonding with adhesive more unstable (Van Meerbeek & others, 2003). In addition, cementum/dentin is more porous, enhancing the permeability to dye penetration in relation to enamel.

No material completely prevented microleakage along the interface. Alloybond lined restorations disclosed the highest degree of dye leakage in nearly all situations. The bond strength of adhesive materials depends on the composition, monomer conversion rate and cross-linking (Van Meerbeek & others, 2003). The adhesion between the amalgam and bonding substrate competes with the stress of polymerization (Carvalho & others, 1996), which can cause marginal sealing failure. The poor performance of Alloybond is possibly related to its composition. This system is specially designed for amalgam restorations, presenting in its formulation dimetracrylates. According to the manufacturer, the composition will produce a double linking after polymerization, resulting in a stronger resinous matrix with improved chemical adhesion. However, such reactions may cause higher polymerization stress, thus increasing microleakage. Micromechanical interlocking between the amalgam and intermediate material is considered to be responsible for adhesion in bonded amalgam restorations (Grobler & others, 2000). An improved performance in bonded amalgam restorations has been reported with the presence of a more viscous intermediate material (Meiers & Turner, 1998; Grobler & others, 2000; Cenci & others, 2004). Alloybond provides less viscous mixture and also produces higher leakage than thicker intermediate materials in enamel (RelyX ARC) and cementum/dentin (RelyX Luting Cement). In viscous materials, the mechanical interlocking could be more effective than less viscous materials, resulting in higher bond strengths and improved sealing.

Resin-modified glass ionomer exhibited the lowest leakage in cementum/dentin margins, similar to findings previously reported (Marchiori & others, 1998; de Morais, Rodrigues Jr & Pimenta, 1999; Cenci & others, 2004). The better performance could be attributed to the high dimensional stability of the material (Culbertson, 2001), lower thermal conductibility and chemical adhesion to dentin (Cenci & others, 2004). Although resin-modified glass ionomer exhibits good performance in cementum/dentin, the material has showed a lower resistance to dissolution caused by acids from the oral environment when compared to composites (Culbertson, 2001). Nevertheless, the release of fluoride to dental structure would increase the mineral content (Osinaga & others, 2003), turning the surface more resistant to acids produced by bacteria, thus, aiding in the prevention of secondary caries.

In this study, bonded amalgam restorations, in most situations, failed to produce improved resistance to dye leakage when compared to conventional amalgam restorations. Clinical evaluation studies (Davis & Overton, 2000; Summitt & others, 2001) observed similar behavior between bonded and unbonded amalgam restorations. Since bonded amalgam restorations are more expensive and more time-consuming, other advantages besides marginal sealing should be demonstrated for their application in clinical practice.

Previous studies have reported an influence in the direction of cutting the specimens in obtaining leakage results (Mixson & others, 1991; Raskin & others, 2001). Nevertheless, the findings of this study did not demonstrate that the sectioning direction would influence microleakage. Usually, higher leakage scores were observed in M-D sections but without statistical significance when compared to I-C sections.

CONCLUSIONS

Within the limitations of this study, it could be concluded that:

1. Cavity size (volume) did not influence microleakage in conventional and bonded restorations.
2. Less leakage was observed in enamel than in cementum/dentin margins.
3. In most conditions, bonded amalgam restorations performed similarly to conventional amalgam restorations.
4. The direction of sectioning did not significantly influence the leakage observed.

Acknowledgements

The authors thank Professors Antonio Luiz Pizarro Schurter and Leonardo Rochefort Vianna (CEFET/RS) for their development of the appliance used for cavity standardization.

(Received 7 April 2005)

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