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Influence of Curing Methods and Matrix Type on the Marginal Seal of Class II Resin-based Composite Restorations *In Vitro*

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Clinical Relevance

Selection of photo-curing protocol (high intensity vs soft-start) and matrix type (transparent vs metal) did not influence the margin quality and marginal seal of Class II resin-based composite restorations.

SUMMARY

This study determined the influence of light curing protocols and matrix type on the margin quality and marginal seal of Class II resin-based composite restorations.

In extracted human molars, box-shaped MOD cavities with 1 mm wide interproximal bevels were prepared with cervical margins located at least 1 mm coronal to the cemento-enamel junction. The prepared teeth were mounted in a jig featuring artificial training teeth that served as adjacent teeth. A contoured sectional metal matrix band was placed in one interproximal area, and a section of a contoured transparent matrix band was placed in the opposite interproximal area. Both were kept in position using wooden wedges. After etching (35% H_3PO_4 gel) and the application of a three-step etch & rinse dentin adhesive (Optibond FL, Kerr), a thin layer of flowable resin-based composite (Revolution, Kerr) was applied to the interproximal margins. The cavities were restored by placing one horizontal and two oblique increments of a fine hybrid resin-based composite (Herculite XRV, Kerr). The curing protocols included one standard halogen protocol (Elipar Trilight, 3M ESPE, 40 seconds @ 800 mW/cm²), 3 halogen soft-start protocols (Step: Elipar HiLight, 3M ESPE; 10 seconds @ 150 mW/cm², 30 seconds @ 850 mW/cm²; Ramp: Elipar TriLight, 3M ESPE, 5 seconds @ 100 mW/cm², exponential increase for 10 seconds, 25 seconds @ 800 mW/cm²; Pulse delay: VIP Light, BISCO, cervical increment: 10 seconds @ 500 mW/cm², occlusal increments: 3 seconds @ 200 mW/cm², final irradiation after a 5 minute interval: 30 seconds @ mW/cm²) and 2 plasma arc high intensity protocols (PAC: Lightning Cure, ADT, 10 seconds @ 1400 mW/cm²; APO: Apollo 95E, DMDS, 2 x 3 seconds @ 1570 mW/cm²). The restored teeth were stored in 0.9% saline at 37°C for 4 weeks and submitted to thermal cycling [TC] with 2500 cycles between 5°C and 55°C after 2 weeks. The

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DOI: 10.2341/04-194

margin quality before and after TC was analyzed in SEM using the replica technique, and the marginal seal was determined using the dye penetration test (50% $AgNO_3$, 2 hours) at the end of the study.

The matrix type did not significantly influence the quality and seal of the respective margins. For the complete restoration margin, one of the high intensity protocols (APO) produced a higher percentage of "continuous margin" compared to pulse delay irradiation after TC and lower percentages of "marginal opening" compared to halogen standard irradiation before and after TC. Halogen step irradiation produced a superior marginal seal compared to pulse delay curing at the occlusal margins; equivalent results were observed for all curing modes at the cervical margins. Neither a general advantage of soft-start irradiation nor a general disadvantage of high intensity curing was confirmed.

INTRODUCTION

For many years, resin-based composites have been the first material of choice for the restoration of anterior cavities. The same is true for preventive resin restorations and for the restoration of small primary caries lesions in posterior teeth. Here, the opportunity to bond to enamel and dentin using the adhesive technique eliminates the need to sacrifice additional sound hard tissue during the preparation of retentive cavities. However, restoration of large primary defects or replacement of defective posterior restorations using direct resin-based composites is far more demanding. First, the functional load is much higher in posterior teeth compared to anterior teeth. Second, mid-size to large posterior cavities feature higher volumes than anterior cavities. Therefore, the side effects of polymerization contraction of resin-based composites are much more critical. Finally, accessibility for manipulation of the materials and moisture control during operative procedures is worse in the posterior region and poses additional clinical problems.

Polymerization shrinkage of resin-based composites may create tensile stress within the tooth and restoration and may result in debonding at the interface or crack formation close to cavity margins or even on the buccal or lingual surfaces of cusps. Several concepts have been suggested to address this problem. Incremental techniques reduce the volume of material cured in the cavity at a given time and therefore may reduce the amount of stress created. The volumetric defect of previous increments is supposedly supplemented by consecutive increments, thus reducing the effects of shrinkage on the margin quality of restorations.

Traditionally, it has been assumed that the shrinkage of photo-activated materials is directed towards the light source. Consequently, a three-sited light-curing technique was recommended. This technique comprises irradiation of the cervical increment from a cervical direction by the use of light-reflecting wedges and the irradiation of a buccal and a lingual increment through the lateral cavity walls from the respective site (Lutz, Krejci & Oldenburg, 1986a; Lutz & others, 1986b; Krejci, Sparr & Lutz, 1987). The composite is then expected to shrink towards the margin rather than away from it, thus avoiding the formation of margin gaps. Although apparently verified by a scrape test (Lutz & others, 1986b), the effectiveness of composite cure via light-reflecting wedges was called into question by photometric measurements (Lösche, 1999) and by the high solubility of composites observed after wedge-mediated irradiation (Ciamponi, Del Portillo Lujan & Ferreira Santos, 1994). In addition, photo-activated resin-based composites were demonstrated to shrink away from free surfaces and toward bonded surfaces rather than toward the light source (Versluis, Tantbirojn & Douglas, 1998; Suh & Wang, 2001). The favorable effect of the three-sited light-curing technique on margin quality was more consistently explained by lower irradiance administered by curing via reflecting wedges and through lateral cavity walls (Lösche, 1999).

Although the amount of shrinkage of a given material cannot be reduced without compromising completeness of polymerization (Rueggeberg & Tamareselvy, 1995), the side effects on margin quality may be alleviated by modifying curing kinetics. During the initial stages of polymerization reaction, contraction may be compensated for by flow within the material (Davidson & de Gee, 1984), and only after development of a certain modulus of elasticity, contraction strain will produce contraction stress. By conducting or at least starting polymerization at low levels of irradiance, more time should be available for flow to compensate for contraction strain, and the final stress level might be reduced. A favorable effect of these soft-start protocols on margin fidelity has been reported in the literature (Uno & Asmussen, 1991; Unterbrink & Muessner, 1995; Feilzer & others, 1995; Mehl, Hickel & Kunzelmann, 1997). However, all data have been collected by studying Class V restorations. As the impact of curing contraction on margin quality of restorations depends on their ratio of free vs bonded surfaces, the so-called "configuration factor" (Feilzer, de Gee & Davidson, 1987), Class I and Class V fillings may be regarded as the most critical situation for this type of research. In Class II fillings, each consecutive increment features a more favorable ratio of bonded vs free surfaces, and thus facilitates the compensation of contraction strain by flow from free surfaces. On the other hand, the larger volume of Class II cavities may increase the impact of polymerization shrinkage. Moreover, curing units based on short-arc lamps have been marketed featuring a very high irradiance designed to reduce the time required for photo-activating resin-based composites, therefore, saving clinicians' time. This technique is likely to result in a very fast polymerization reaction and was anticipated to produce high contraction stress levels and poor restoration margins.

Another matter of interest concerning direct Class II resin-based composite restorations is the creation of tight, anatomically correct interproximal contacts. Transparent matrix strips, as are routinely used in the anterior region, will not impair photo-activation of the resin-based composite. On the other hand, transparent matrix strips may hamper the creation of tight contacts, as they are thicker than metal matrix bands. The latter, however, may interfere with photo-activation.

This study compares the influence of different irradiation protocols and matrix type on the marginal seal and margin fidelity of Class II resin-based composite restorations. The hypotheses were: 1) Soft-start irradiation improves, whereas, high intensity irradiation compromises marginal seal and margin quality; 2) The transparent matrix allows for better margin quality and marginal seal than metal matrix.

METHODS AND MATERIALS

Extracted human third molars free of caries and other defects were cleaned and embedded in acrylic resin, leaving the crown and 2 mm of the root exposed. Box-shaped MOD cavities (occlusal depth/width: 3 x 2.5 mm, interproximal depth/width: 4 x 4 mm; Figure 1) were prepared with the cervical margins located at least 1 mm coronal to the cemento-enamel junction. At the interproximal margins, a bevel 1 mm wide was prepared using reciprocating files (Bevelshape B40C, Intensiv, CH-6916 Grancia, Switzerland). The prepared teeth were mounted in a jig, providing artificial training teeth on either side of the prepared cavity, to simulate a clinical interproximal relation. The whole setup allowed for individual adjustment of both the vertical position of the test specimens in the jig and the horizontal position of the adjacent teeth in relation to the test specimens.

A contoured sectional metal matrix band (Sectional Matrix Retainer System, 3M ESPE, Seefeld, Germany, currently distributed as Composi-Tight System, Garrison Dental Solutions, Spring Lake, MI, USA) was placed in one of the interproximal areas and kept in position using a wedge of appropriate size (Sycamore Interdental Wedges, Hawe-Neos Dental, Bioggio, Switzerland). A corresponding section was cut from a contoured transparent matrix (Hawe Molarbands Transparent, Hawe-Neos Dental) and placed in the other interproximal area. Both matrices were adapted to the buccal and lingual flat surfaces using specially designed clamps (Sectional Matrix Retainer System). Enamel and dentin were etched using 35% H_3PO_4-gel (Ultra-Etch, Ultradent, South Jordan, UT, USA) for 60 and 15 seconds, respectively. The cavities were carefully rinsed, and excess water was removed using suction, leaving the dentin moist. A three-step dentin bonding agent (DBA) (Optibond FL, Lot 904727 [Prime]/Lot 903803 [Adhesive], Kerr, Orange, CA, USA) was applied according to manufacturer's instructions and light-cured as required by the different irradiation protocols specified below.

A small amount of flowable resin-based composite (RBC) (Revolution, shade A2, Lot 9-1181, Kerr) was applied to the interproximal cavity margins using the steel syringe tips provided by the manufacturer. The tip of a dental explorer was moved along the crevice between the beveled margins and the matrices in order to remove voids eventually entrapped in the flowable composite, which subsequently was light-cured according to each respective protocol. The cavities were restored using a fine hybrid RBC (Herculite XRV, shade A2 Dentine, Lot #902091, Kerr), placing a horizontal cervical increment and two oblique occlusal increments as displayed in Figure 1.

Light irradiation was performed according to following protocols:

1) Halogen standard irradiation (Std) (= control group): Light curing unit: Elipar TriLight (3M ESPE); DBA: setting std, 20 seconds (constant irradiance, 800 mW/cm^2); RBC: setting std, 40 seconds.

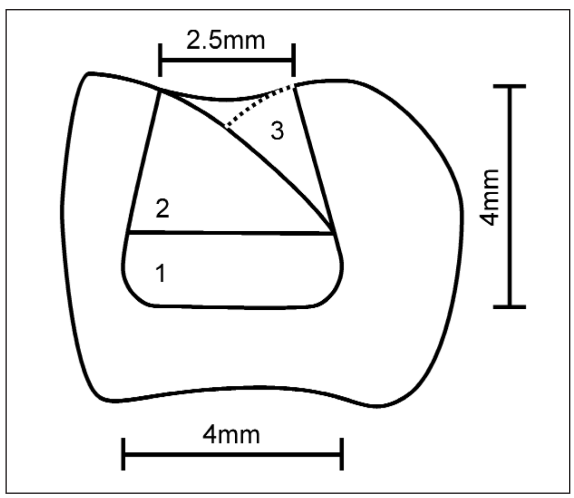

Figure 1. *Cavity dimensions and shape of the increments: the horizontal increment (1) was placed only in interproximal boxes, and the oblique increments (2, 3) were placed both in interproximal boxes and the occlusal cavity. The dotted line specifies the shape of the third increment in the occlusal cavity.*

2) Halogen step irradiation (Step): Light curing unit: Elipar HiLight (3M ESPE); DBA: setting Standard, 20 seconds (constant irradiance, 850-mW/cm²); RBC: setting 2-Step, 40 seconds (10 seconds @ 150 mW/cm², 30 seconds @ 850 mW/cm²).

3) Halogen ramp irradiation (Ramp): Light curing unit: Elipar TriLight (3M ESPE); DBA: setting std, 20 seconds (constant irradiance, 800 mW/cm²); RBC: setting exp, 40 seconds (5 seconds @ 100 mW/cm², gradual increase between 100 and 800 mW/cm² within 10 seconds, 25 seconds @ 800 mW/cm²).

4) Halogen pulse delay curing (Pulse): Light curing unit: VIP Light (BISCO, Schaumburg, IL, USA); DBA: 20 seconds (constant irradiance, 500 mW/cm²); flowable RBC: 40 seconds @ 500 mW/cm²; cervical increment: 10 seconds @ 500 mW/cm²; occlusal increments: 3 seconds @ 200 mW/cm²; after 5 minutes: final irradiation, 30 seconds @ 500 mW/cm² (10 seconds from occlusal, buccal and lingual direction, respectively).

5) ADT plasma arc irradiation (PAC): Light curing unit: Lightning Cure (American Dental Technologies, Corpus Christi, TX, USA); DBA and RBC: 10 seconds @ 1400 mW/cm² (with tip shield in place, creating a distance of 7 mm between the curing tip and the irradiated object).

6) Apollo plasma arc irradiation (APO): Light curing unit: Apollo 95E (DMDS, F-11560 Fleury d'Aude, France); DBA and RBC: setting 3s, 2 irradiations (3 seconds @ 1570 mW/cm² per irradiation).

All irradiation was performed twice, with the curing tips centered over the mesial and distal halves of the restoration, respectively. Apart from the exception specified above (pulse delay curing), all irradiation performed from the occlusal direction. Irradiance of the curing lights was determined and monitored throughout the study using a handheld radiometer (Curing Radiometer, Demetron, Danbury, CT, USA). A neutral density filter (#66.0220 ND 0.3, Rolyn Optics Co, Covina, CA, USA) was used to reduce irradiance of the plasma arc lights to a level that could be handled by the radiometer. All restorations were placed by one operator following appropriate pre-study training. Restorative procedures were standardized as much as possible in a clinically related study. Despite standardization of the cavity dimensions, the variations typically found in extracted teeth did not allow the authors to standardize the exact volume of each increment.

The specimens were stored in deionized water at 37°C for 30 days. A thermal cycling (TC) of 2500 cycles between 5°C and 55°C with a dwell time of 30 seconds at either temperature was carried out after day 15.

Prior to and after water storage and TC, margin quality was assessed in SEM (DSM 940, Zeiss, Oberkochen, Germany) using the replica technique (Roulet & others, 1989). The evaluation criteria were "continuous margin" (continuous transition between restorative material and dental hard tissues with location of the interface discernible only due to different surface textures or minor irregularities), "marginal opening" (distinct separation between restorative material and dental hard tissues), "overfilled margin," "underfilled margin," "enamel margin fracture" and "restoration margin fracture." Areas that could not be assessed due to limitations of the replica technique were excluded from evaluation. The length of the margin showing each of the different criteria was expressed as the percentage of the total length. Initially, the margin quality was analyzed separately for each of the following six segments: cervical margin with either metal or transparent matrix, axial margin with either metal or transparent matrix or occlusal margin at the working or non-working side. In addition, the results of the combined cervical, axial and occlusal margins and for the complete restoration margin were calculated.

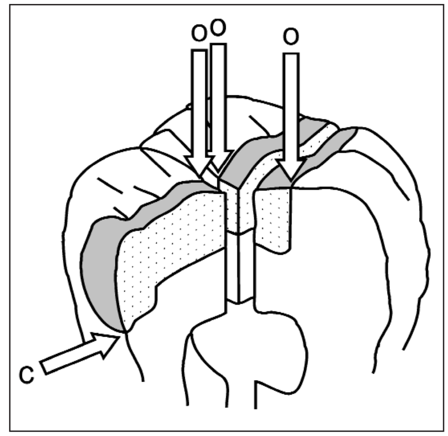

Figure 2. *Schematic drawing of a specimen sectioned in the bucco-lingual and mesio-distal direction for evaluation of dye penetration depth at the occlusal (o) and cervical margins (c).*

The specimens were coated using nail varnish, leaving the area 1 mm adjacent to the restoration and the restoration itself, exposed. After immersion in 50% $AgNO_3$ solution for two hours, the specimens were cleaned using tap water and stored in developing solution for six hours using transparent vials placed on a slide sorter to provide simultaneous illumination. The specimens were sectioned in a mesio-distal and bucco-lingual direction (Figure 2) using a water-cooled diamond saw (Woco 50 med, Conrad, Clausthal-Zellerfeld, Germany). The depth of dye penetration was measured on each of the eight cross-sections using a traveling light microscope (Tessovar, Zeiss), and the maximum penetration value was recorded for the occlusal penetration depth at the working or the non-working side and for cervical penetration depth at the metal or transparent matrix side, respectively. Subsequently, the maximum values at the occlusal and cervical margin were calculated.

For each curing mode, 10 specimens were prepared. The differences between the various segments of the complete restoration margin and the results before vs after thermal cycling were analyzed separately for each curing mode using multiple Wilcoxon tests with Bonferroni-Holm adjustment at a $p<0.05$ level of significance. The differences among treatment groups for each margin segment separately and for the complete margin were tested using non-parametric ANOVA (Kruskal-Wallis test) with Nemenyi's post-hoc test at the same level of statistical significance as stated above.

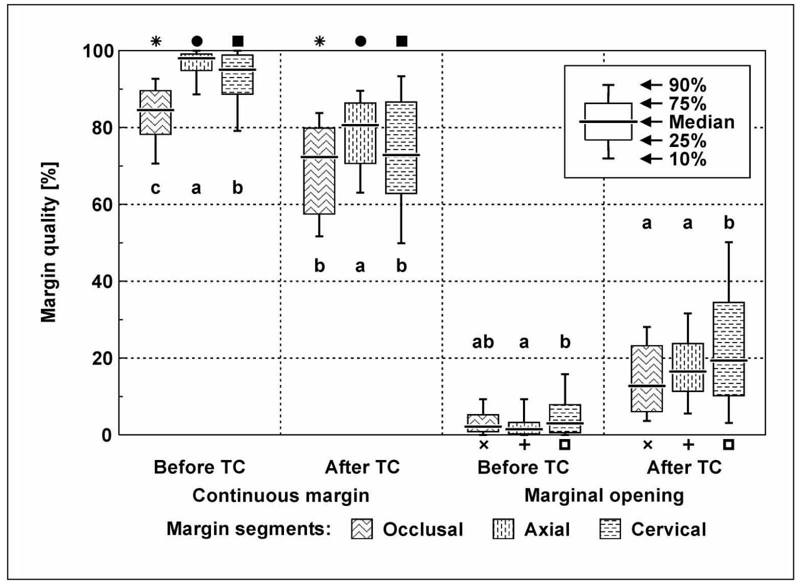

Figure 3. *Margin quality at the different margin segments for all curing modes combined. (Box plots: horizontal line: median; boxes: interquartile range; whiskers: 10-90 percentile). Identical letters specify segments not significantly different (multiple Wilcoxon tests with Bonferroni-Holm adjustment:* p*>0.05). Identical symbols indicate significant differences before vs after thermal cycling (TC) (Wilcoxon:* p*<0.05).*

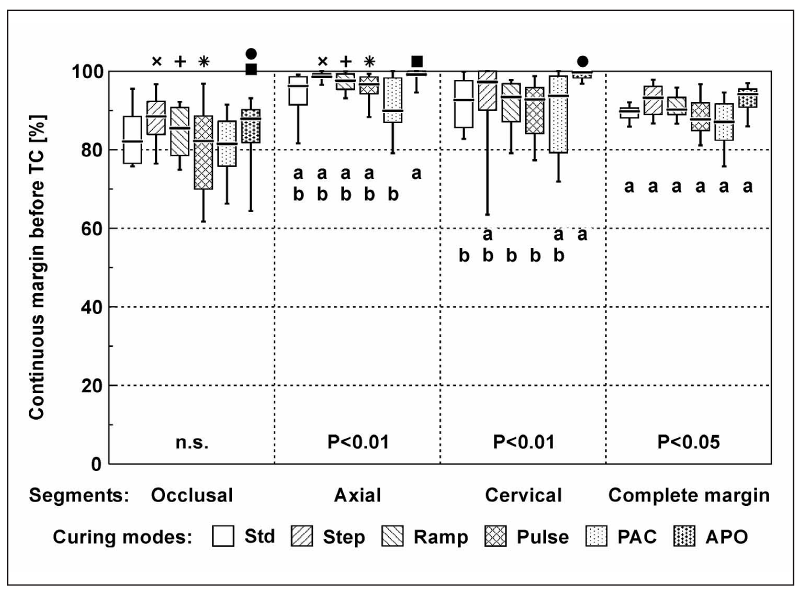

Figure 4. *Continuous margin before thermal cycling (TC). Box plots as in Figure 3. Probability values: results of the non-parametric ANOVA (Kruskal-Wallis test). Identical letters specify groups not significantly different (Nemenyi post-hoc test:* p*>0.05). Identical symbols indicate significant differences between the respective margin segments (Wilcoxon:* p*<0.05).*

RESULTS

With regard to margin quality and marginal seal, there were no significant differences observed ($p>0.05$; data not presented separately) between matrix types (metal vs transparent) at the cervical and axial segments or between the working vs non-working side of the occlusal margin. Consequently, all cervical, axial and occlusal margin segments were combined for further analyses, respectively. The margin qualities "continuous margin" and "marginal opening" accounted for 94.0%/91.7%, respectively, (before/after TC) of the total margin length. Therefore, the results of the remaining criteria will not be reported below.

Figure 3 shows the quality at the different margin segments before and after TC for all curing modes combined. Before TC, the highest percentage of "continuous margin" was observed at the axial segments (median: 98.0%), followed by the cervical and occlusal segments (95.1%/84.5%). All differences were statistically significant ($p<0.05$). After TC, for all segments, lower percentages of "continuous margin" were observed ($p<0.05$), with axial segments featuring a better quality (80.7%) than occlusal and cervical segments (72.3%/72.8%). Before TC, the median values for "marginal opening" were low, ranging between 1.5% and 3.0% (axial/cervical margin; $p<0.05$), with occlusal margins falling in-between (2.2%; ns). After TC, all segments featured significantly higher percentages of "marginal opening" ($p<0.05$). Here, the quality of the cervical margins was inferior (19.3%) to the axial and occlusal margins (16.5%/12.7%; $p<0.05$).

Figure 4 presents the percentages of "continuous margin" before TC. Following step, ramp, pulse and APO irradiation, axial margins featured higher percentages of "continuous margin" than occlusal margins ($p<0.05$). The same was true for cervical margins after APO curing. Significant differences among the curing modes were observed for axial and cervical segments ($p<0.01$) and the complete margin ($p<0.05$). Axially, APO irradiation performed better than PAC curing; APO was superior to standard (std), ramp and pulse irradiation. In the case of the complete margin, the post-hoc test failed to specify the groups responsible for the overall significant difference.

After TC, lower percentages of "continuous margin" were observed for all combinations of the margin segment and curing mode (Figure 5; $p<0.05$; the results for the comparison before vs after TC are not specified in Figures 4 and 5). With APO and pulse curing, axial margins were superior to occlusal margins. The same is true for cervical margins following APO irradiation. Significant differences among curing modes were observed for axial segments ($p<0.001$) and the complete margin ($p<0.05$). Axially, APO irradiation produced more "continuous margin" than std, pulse or PAC irradiation. Regarding the complete margin, APO performed better than pulse curing.

Figure 6 displays the percentages of "marginal opening" before TC. For the complete margin and for the axial and cervical segments, APO cured restorations featured less "marginal opening" compared to std irradiated fillings ($p<0.05$). Moreover, APO irradiation produced less "marginal opening" compared to PAC curing at cervical and ramp curing at the axial margins. No significant differences among curing modes were observed at the occlusal segment. After TC, higher percentages of "marginal opening" were observed for all combinations of margin segment and curing mode (Figure 7; $p<0.05$; the results for the comparison before vs after TC are not specified in Figures 6 and 7). For the axial segment and the complete margin, an equivalent distribution of significant differences was observed as before TC. Occlusally, however, step curing produced less "marginal opening" than pulse curing ($p<0.05$); in contrast, no significant differences among curing protocols were found for the cervical segments. Only before TC were significant differences among margin segments observed. Following pulse irradiation, occlusal margins featured more "marginal opening" than axial margins ($p<0.05$). With all other curing modes, differences among the margin segments failed to reach the level of statistical significance.

Dye penetration results are displayed in Figure 8. At occlusal margins, penetration depth was higher following pulse irradiation compared to step curing ($p<0.05$). At the cervical margins, differences among curing protocols were not statistically significant. Except for pulse irradiation, dye penetration depth was higher at cervical margins than at occlusal margins. This difference is significant in the case of step and ramp irradiation.

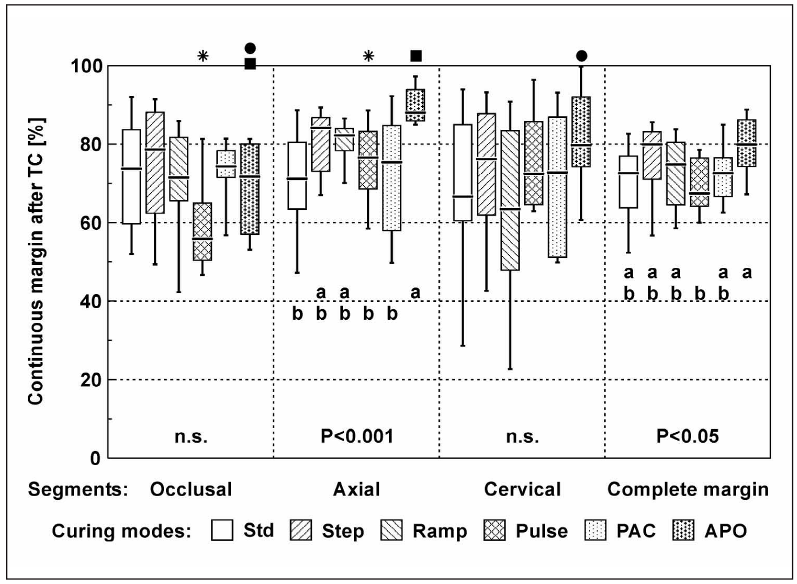

Figure 5. *Continuous margin after thermal cycling (TC). Box plots, probability values, letters and symbols as in Figure 4.*

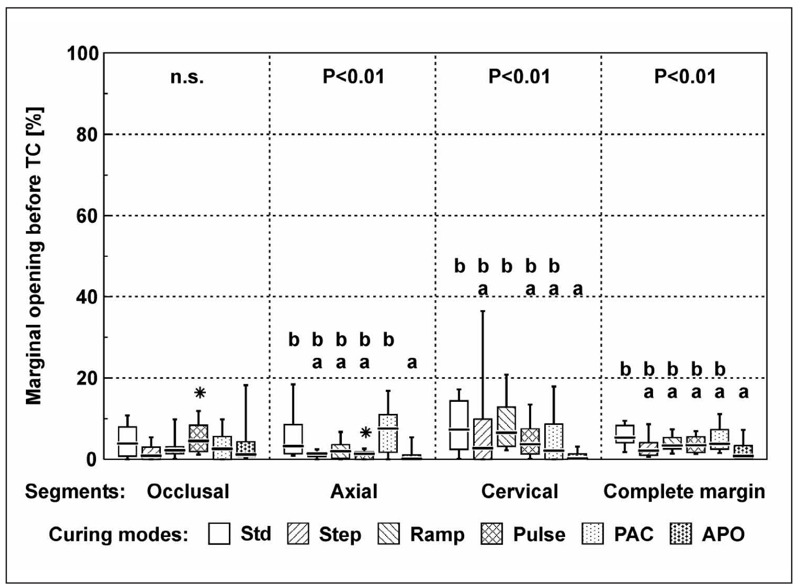

Figure 6. *Marginal opening before thermal cycling (TC). Box plots, probability values, letters and symbols as in Figure 4.*

DISCUSSION

The data presented above failed to confirm the hypothesis that soft-start irradiation improves and high intensity curing compromises the margin quality and marginal seal of Class II resin-based composite restorations. These results are in conflict with reports by Deliperi, Bardwell and Papathanasiou (2003), who observed less microleakage after soft-start irradiation and confirmed reports by Stoll and others (2000), who did not find adverse effects of high intensity curing on margin quality and marginal seal.

The concept of compensation of shrinkage strain and, thus, the reduction of contraction stress has been inferred from observations made on geometrically defined specimens in a universal testing machine (Davidson & de Gee, 1984) rather than in a clinically related experimental setup. Soft-start irradiation pro-

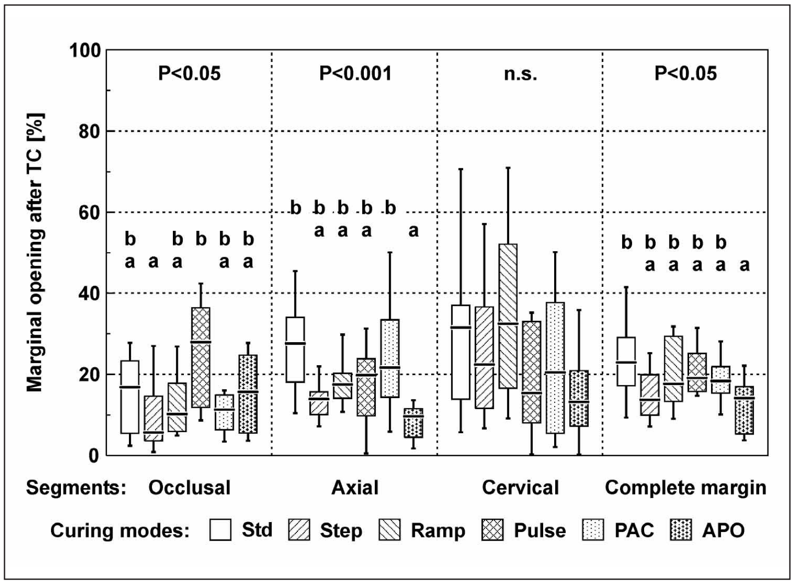

Figure 7. *Marginal opening after thermal cycling (TC). Box plots, probability values, letters and symbols as in Figure 4.*

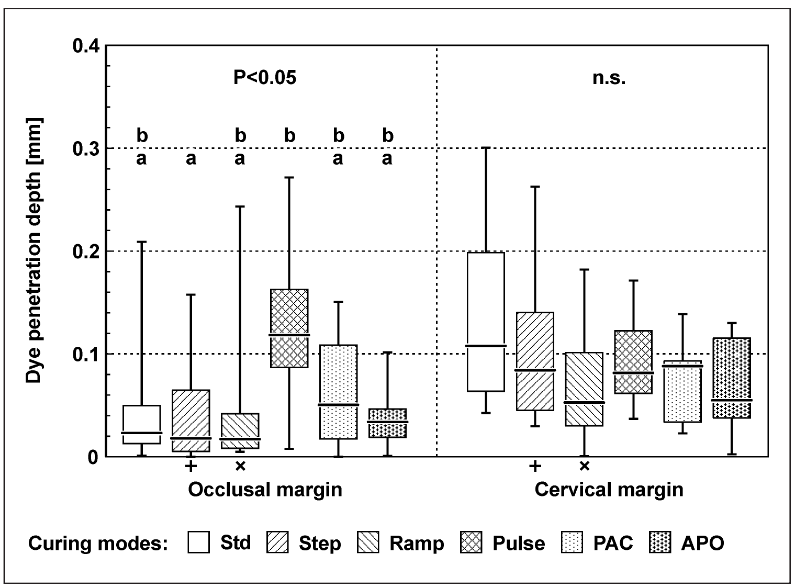

Figure 8. *Dye penetration depth. Box plots, probability values, letters and symbols as in Figure 4.*

tocols have been shown to slow down the development of shrinkage strain as observed in the deflecting disk experimental setup (Hofmann & others, 2003a,b) and reduce post-gel shrinkage as recorded using strain gauges (Sakaguchi & Berge, 1998). Similarly, reduction of contraction stress was verified in photo-elastic studies (Ernst, Kürschner & Willershausen, 1997; Ernst & others, 2000, 2003) and in tests using proprietary setups including load cells and feedback loop devices compensating for compliance of the setup (Lim & others, 2002).

The evaluation of soft-start protocols using cavity tests, however, has produced controversial results. Several studies clearly support soft-start irradiation (Feilzer & others, 1995; Mehl & others, 1997; Yoshikawa, Burrow & Tagami, 2001; Yoshikawa & others, 2003). In one study, the only protocol that produced considerably better margins resulted in clearly underirradiated specimens (Uno & Asmussen, 1991). In two other studies, only one in four combinations of two dentin adhesives and two resin-based composites (Unterbrink & Muessner, 1995) or only one in four combinations of dentin adhesive and resin-based composites by the same manufacturer (Ernst & others, 2003) resulted in statistically significant differences between standard and soft-start curing.

Moreover, the majority of cavity studies have been performed using Class V cavities, with the cervical margin located in dentin, or cylindrical cavities, which were completely surrounded by dentin (Yoshikawa & others, 2001, 2003). As bond strength to dentin is lower and less dependable than bond strength to enamel, it may be hypothesized that the advantages of soft-start irradiation, though existing, failed to show in a study such as this one, where the margins, completely located in enamel, can withstand contraction forces. On the other hand, a number of Class V studies with dentin margins failed to show a superiority of soft-start curing as well (Friedl & others, 2000; Hasegawa & others, 2001; Ernst & others, 2003; Hofmann & others, 2003c).

The higher percentage of "marginal opening" at the cervical margins can be explained by the lower thickness and inferior quality of cervical enamel, which is less able to withstand polymerization contraction forces. The lower percentage of "continuous margin" at the occlusal compared to the axial segments is not reflected in a higher percentage of "marginal opening" but rather in a higher percentage of excess formation, which has not been specified separately above. The excess formation on occlusal surfaces is mainly observed at fissures, and the restorative material extending to these fissures should not be regarded as a short-coming of the restoration, but rather as a preventive resin restoration. The deterioration of margin quality during water storage and thermal cycling is commonly attributed to the different coefficients of thermal expansion of dental hard tissues on the one hand and resin-based composites on the other, which produce stress at the respective interfaces.

The favorable results of APO irradiation observed at some margin segments is possibly explained by the lower radiant exposure featured by this protocol, which may have produced less well cured restorations, while simultaneously producing less shrinkage. Yet, this explanation remains speculative, as the degree of conversion was not determined in this study. The inferior results of the halogen pulse delay protocol are in conflict with first reports in the literature (Kanca & Suh, 1999). However, recent observations indicate that pulse delay protocols may produce more linear polymer networks and lower cross link densities than standard protocols (Asmussen & Peutzfeldt, 2001; Soh & Yap, 2004); the clinical implications of these observations, however, have yet to be determined. The results of the dye penetration analysis more or less reflect those of the SEM analysis.

The current data also failed to confirm the second hypothesis of the study, namely, that transparent matrix bands allow for a better margin quality and marginal seal than metal matrices. This confirms observations by Szep and others (2001) and is in conflict with reports by Scherer and others (1989) and Cvitko, Denehy and Boyer (1992). The influence of matrix type on margin quality may be of a complex nature anyway. First, it is not clear whether transparent matrix bands allow for a better curing of composites compared to metal bands. Metal matrix bands only allow light irradiation from the occlusal direction, and they block light from flat surfaces and light-reflecting wedges; therefore, they may impair polymerization at gingival margins. However, one study observed higher hardness values at the gingival margin using a metal matrix band compared to a transparent band (Kays, Sneed & Nuckles, 1991). In this study, the curing light was directed from an angle towards the matrix band, thus allowing for a reflection of the curing light; and the best results were observed using a front surface mirror as a matrix. Moreover, even despite the use of transparent bands and wedge-mediated irradiation, the respectively cured composite showed a high solubility (Ciamponi & others, 1994).

If the restorative material close to the restoration margins is severely under-irradiated, then the mechanical properties may be low enough to fail to withstand stress during thermal or functional loading, and margin deterioration may occur. Traditionally, this might be expected after the use of metal matrix bands. On the other hand, if transparent matrices allow for better light irradiation, this might result in a higher degree of cure, more shrinkage (Rueggeberg & Tamareselvy, 1995; Silikas, Eliades & Watts, 2000) and an inferior margin quality. In fact, the superior margin quality obtained by the three-sited light-curing technique has been explained by the lower irradiance administered via light-reflecting wedges and by curing through lateral cavity walls (Lösche, 1999). For now, matrix systems may be selected according to clinical considerations, for example, suitability for the creation of tight interproximal contacts (Peumans & others, 2001) and personal preference of the practitioner.

Future studies should verify the results of this study in the case of cavities extending below the cemento-enamel junction.

CONCLUSIONS

High intensity curing did not compromise and soft-start irradiation did not improve the margin quality and marginal seal of Class II resin-based composite restorations. Metal and transparent matrices produced equivalent results.

(Received 16 November 2004)

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