Clin Oral Invest (2008) 12:53–59
DOI 10.1007/s00784-007-0145-9

ORIGINAL ARTICLE

# The influence of the cavity preparation design on marginal accuracy of laboratory-processed resin composite restorations

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Received: 29 January 2007 / Accepted: 19 July 2007 / Published online: 10 August 2007


**Abstract** The aim of this study was to evaluate the influence of different cavity preparation designs on marginal accuracy of laboratory-processed resin composite restored teeth. Eighty mandibular human third molars were selected. There were two experimental factors, occlusal isthmus width (narrow vs wide) and cuspal coverage (inlay, one-cusp onlay, two-cusp onlay, and all-cusp onlay), resulting on eight groups ($N$=10). Indirect composite restorations (SR Adoro, Ivoclar-Vivadent) were manufactured and positioned over each respective preparation. Marginal accuracy evaluation was accomplished using a stereomicroscope at three points on buccal, lingual, mesial, and distal regions with 40× magnification. The results showed significant differences ($P$=0.00) with wide inlay showing the best overall marginal accuracy and narrow inlay the worst one. Two-way analysis of variance (ANOVA) showed significant differences when considering the factor occlusal isthmus width ($P$=0.00). In general, preparations with wide occlusal isthmus presented better results than narrow ones, except for wide all-cusp onlays; however, the test failed to show differences when considering the cuspal coverage ($P$=0.42) or the interaction between both factors ($P$=0.30). The effect of occlusal width extension on marginal accuracy of indirect composite resin restorations is significant, with lower values of gaps width in wide preparations, but since in a clinical situation this would mean greater removal of sound tooth structure, less-aggressive preparations combined with other restorative procedures seem to be more feasible.

**Keywords** Marginal accuracy · Cavity preparation design · Indirect composite resin · Inlay · Onlay

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## Introduction

The second generation of laboratory-processed resin composites (LPRC) has been available since the early 1990s [17] for a wide range of prosthodontics' applications, combining the use of heat, pressure, vacuum, and high light intensity polymerization. These materials are believed to present superior mechanical properties compared to direct composite materials due to post-polymerization methods and individual matrix polymer components [23]. In spite of that, some researches have not confirmed this statement [34] suggesting that their composition is quite similar to composites of direct usage.

Among the several aspects of any restorative system that require investigation [3], marginal accuracy seems to be of great importance due to its influence on the clinical longevity of restorations [1, 6, 10, 13, 21, 32]. Poorly adapted restorations, showing marginal misfit, facilitates plaque accumulation, gingival sucular fluid flow and bone loss, microleakage, recurrent caries, periodontal disease [6, 21, 32, 42], pulpal irritation and consequent sensivity [15], marginal fracture, and disintegration of the luting cement [6, 18, 31, 39]. Thus, Leinfelder et al. [21] suggested, as a general rule, that the interfacial gap should not exceed 100 µm, although McLean and von Fraunhofer [24] had suggested a gap limit of 120 µm. According to Holmes et al. [13], there are many different locations between a tooth and a restoration where the measurements can be made, but marginal discrepancy (or accuracy), which would always be the largest measurement of error at the margin, is measured as the distance of the restoration to tooth structure right at the margins.

The marginal accuracy of restorations is influenced by cavity shape and size, type and location of finishing line, restorative procedure, material placement and finishing techniques, material type, and the use of liners/bases [5, 38, 39] Irrespective of the most successful gap dimension, the search for best adaptation tends to lie on the restorative material type to be used. The marginal fit of indirect composite restorations have been studied in several researches [5, 6, 15, 19, 22, 32, 39], and the comparison between ceramic vs composite inlays has been discussed controversially in the literature [32, 39], in vitro and in vivo. LPRC materials have exhibited better marginal accuracy than ceramics [32], and this occurrence is attributed to the necessity of duplication of refractory dies, the use of die spacers, the destruction of the refractory die in the removal of the ceramic restoration, and finally to the contraction of the ceramic material. This fact becomes increasingly important when the behavior of the material is influenced by its volume [38]. However, Taylor and Lynch [38] stated that the effect of the cavity shape and size on marginal accuracy has not been extensively studied, and Sjogren [31] questions the influence of the overall preparation design on the fit of indirect restorations. Cho et al. [6] proved that as the occlusal convergence angles increases (6, 10, and 15 degrees), the marginal accuracy of LPRC crowns is negatively influenced. However, Burke et al. [4] related that preparations with a reduced cavity wall taper require more internal adjustment, and this fact could prejudice marginal accuracy. In another study, Cho et al. [5] showed that different finishing lines influenced the marginal accuracy of LPRC full crown restorations.

Few data are available on the marginal accuracy LPRC inlay or onlay restorations for posterior teeth with varying the cavity preparation designs. Therefore, the aim of this study was to determine the influence of the cavity preparation design on marginal accuracy of LPRC restorations. The null hypothesis to be tested was that different cavity preparation designs have no influence on marginal accuracy of LPRC restorations.

## Materials and methods

Eighty freshly extracted human third molars of similar size were selected for this study. The teeth were collected after patients had signed an informed consent, in accordance with the ethics committee of Federal University of Uberlândia, Brazil (protocol #029/2003). Calculus deposits and soft tissue were removed with a hand scaler, and the teeth were stored in 0.2% thymol solution.

Teeth were divided into eight groups ($N$=10, Fig. 1, Table 1), according to cavity preparation design. The preparations were fabricated according to two factors in

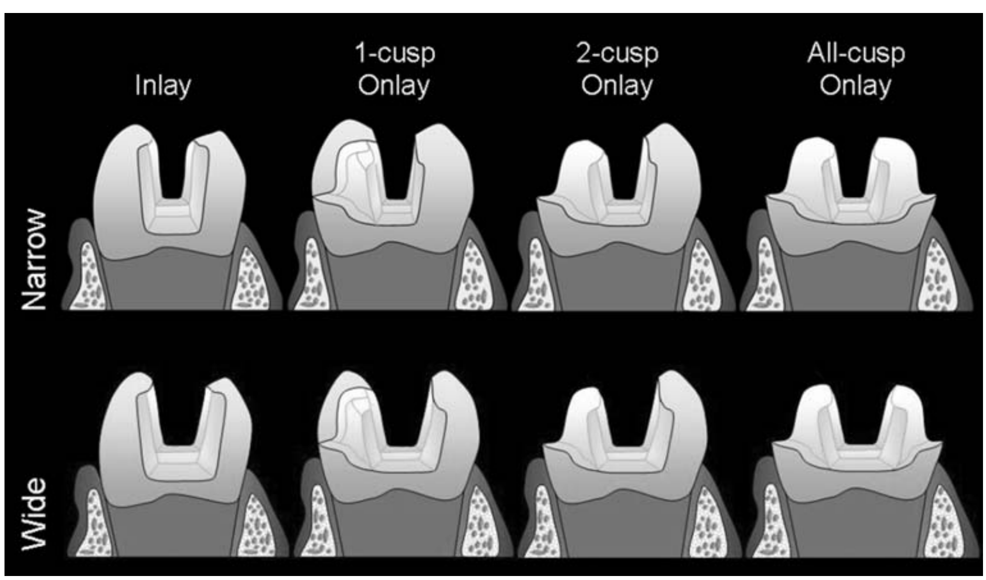


**Fig. 1** Cavity preparation characteristics of experimental groups

**Table 1** Mean, standard deviations of the marginal accuracy values (μm) and statistical categories defined by Fisher LSD test and *T* test ($p<0.05$) for the combination of experimental factors

| Groups according to factors in study | | Marginal accuracy (μm) | | |
|---|---|---|---|---|
| Occlusal Isthmus Width | Cuspal Coverage | Group mean±SD | Mesial+distal (proximal mean±SD) | Buccal+lingual (occlusal mean±SD) |
| Narrow | – | $128.8\pm97.34^{A}$ | $149.37\pm117.45^{a}$ | $108.13\pm68.98^{a}$ |
| Narrow | 2-cusp | $122.0\pm88.2^{AB}$ | $186.59\pm66.0^{a}$ | $57.42\pm32.1^{b}$ |
| Narrow | All-cusp | $116.5\pm61.12^{ABC}$ | $128.61\pm98.5^{a}$ | $104.38\pm48.3^{a}$ |
| Wide | All-cusp | $110.6\pm91.6^{ABC}$ | $117.63\pm77.5^{a}$ | $103.53\pm34.0^{a}$ |
| Narrow | 1-cusp | $102.6\pm81.0^{ABC}$ | $128.72\pm69.9^{a}$ | $76.53\pm49.9^{b}$ |
| Wide | 1-cusp | $80.6\pm62.84^{BC}$ | $101.8\pm64.6^{a}$ | $59.33\pm52.3^{b}$ |
| Wide | 2-cusp | $77.8\pm60.21^{C}$ | $93.74\pm59.5^{a}$ | $61.94\pm61.8^{a}$ |
| Wide | – | $73.3\pm54.73^{C}$ | $96.35\pm77.0^{a}$ | $58.27\pm57.5^{b}$ |

Different superscripted letters mean statistical significant differences among the groups (vertical comparison only). Different superscripted lower case letters mean statistical significant differences between teeth regions (horizontal comparison only).

study: occlusal isthmus width, with two levels, narrow and wide, with narrow operationalized at 2.5 mm and wide operationalized at 5 mm; and cuspal coverage, with four levels, inlay, one-cusp onlay, two-cusp onlay, and all-cusp onlay. The groups were (Fig. 1, Table 1) narrow inlay, wide inlay, narrow one-cusp onlay (coverage of mesio-buccal cusp), wide one-cusp onlay (coverage of mesio-buccal cusp), narrow two-cusp onlay (coverage of buccal cusps), wide two-cusp onlay (coverage of buccal cusps), narrow all-cusp onlay, and wide all-cusp onlay. The teeth roots were embedded in polystyrene resin and their crowns received standardized preparations with #3131 diamond rotary cutting instruments (KG Sorensen, São Paulo, Brazil) on a cavity preparation machine [33] (Federal University of Uberlândia, Minas Gerais, Brazil) so that all the cavities of a given group would have uniform dimensions. One expert operator was responsible for making all the preparations.

The teeth were prepared with the following standardized preparation criteria: a 6° axial wall taper, a 2.5-mm deep occlusal isthmus, and a 1.5-mm wide chamfer placed 1.5-mm cervical to the prepared occlusal pulpal wall, at proximal boxes. A 2.5-mm occlusal reduction was defined from the top of each cusp, and on these groups, a 1.5-mm wide chamfer was placed 1.5-mm cervical to occlusal reduction. The proximal boxes were 1.5-mm deep and their buccal-lingual interfacial distance (occlusal isthmus width) was prepared according to the experimental group: wide (5.0 mm) or narrow (2.5 mm). Cavo-surface angles were approximately 90°, and the internal angles were all rounded.

To reduce all the possible sources of error in the fabrication process, only one expert technician made all the restorations. A one-stage impression was taken of each prepared tooth in a condensation silicon (Silon 2APS, Dentsply, Mildford, DE, USA) by the use of a stock plastic tray (Tigre, São Paulo, Brazil) and poured with type IV stone (Durone IV, Dentsply, Mildford, DE, USA). Stone dies were isolated with SR Adoro Model Separator (Ivoclar-Vivadent, Schaan, Liechtenstein, Germany) before laboratory resin insertion. The preparation roughness and changes in geometry were necessary to clarify the influence of the cavity preparation design; thus, a die spacer was not used because it was suspected that it could mask the results [16]. SR Adoro Liner 200 (Ivoclar-Vivadent, Schaan, Liechtenstein, Germany) was applied in a 0.1-mm-thick layer and light polymerized with an halogen light source (Targis Quick, Ivoclar, 180 $mW/cm^2$ at 10-mm distance) for 10 s. After that, SR Adoro A3 was added in increments with no more than 2.0 mm in thickness. Each layer were first pre-polymerized with Targis Quick (180 $mW/cm^2$ at 10-mm distance) for 10 s, and then, the definitive restoration was post-polymerized in an oven (Lumamat 100; Ivoclar Vivadent) with program 1 at 95°C and high light intensity for 25 min. According to manufacturer instructions, as this polymerization process comprises two steps, the first one can have a lower light output intensity, which will be compensated by the next step.

Because of the fact that a die spacer was avoided, it was common for the stone die to fracture when restorations were removed. After removing the restorations from stone dies, it was necessary to perform internal adjustment for accurate seating due to the great number of angles and changes in geometry [10]. A careful internal adjustment was accomplished by one operator with a low-speed hand piece (Kavo, Joinville, Santa Catarina, Brazil) and #2131 diamond burs (KG Soresen, Barueri, Brazil). To simulate the clinical situation immediately before cementation, the internal surface of the restorations was 50 μm aluminum oxide sandblasted for 5 s at a pressure of four bars and 2 cm of source-to-sample distance (Microjato Plus, Bio-Art, São Paulo, Brazil), as sandblasting and application of a silane coupling agent is the best surface treatment to LPRC restorations [35]. After sandblasting, a linear measurement was taken between the restoration margin, and the tooth structure at the cavo-surface-angle (error at the margin) [13], after the restoration, was set in place and stabilized with hueless glue (Tenaz, São Paulo, Brazil) at two points on occlusal margins [32]. The marginal fit, observed in linear measurement, was recorded at selected points with values expressed in microns (μm). The marginal accuracy was assessed with a digital stereomicroscope (Model STN, Olympus, Tokyo, Japan) at three points on buccal, lingual, mesial, and distal regions (Fig. 2) with 40× magnification and 0.0005 mm accuracy. The mesio-distal (proximal) and buccal-lingual (occlusal), marginal accuracy values were pooled together to enable a comparison between proximal and occlusal marginal fit. Furthermore, a grand mean for all narrow and wide groups was obtained for comparison between themselves.

Statistical analysis was performed with analysis of variance (ANOVA) following Fischer least significant difference (LSD) test ($P<0.05$) in Minitab 14 statistical software (Minitab, State College, PA, USA) to compare the groups. A two-sample $T$ test ($P<0.05$) was used to compare proximal vs occlusal marginal fit in each group and also to compare the grand mean from narrow and wide groups. Two-way ANOVA ($4\times2$; $P<0.05$) was used with a general linear model procedure to analyze the interaction between the factors: cuspal coverage and occlusal isthmus width.

## Results

Table 1 shows the mean marginal accuracy and standard deviations of the groups and tooth regions. The recorded data were checked for test distribution with the Anderson–Darling test ($P<0.05$), which revealed normal test distribution for all groups. ANOVA following Fisher LSD test ($P<0.05$) showed significant differences among all groups (Table 1), meaning that cavity preparation design has an influence on marginal accuracy of indirect composite restorations; then, the null hypothesis had to be rejected. The best marginal accuracy was presented by wide inlay (73.3 μm) and the worst one by narrow inlay (128.8 μm), and with the exception of wide all-cusp onlay, all other wide groups had lower values for gap width than the remaining groups (Table 1). A tendency for higher values for gap width in narrow preparations rather than in wide ones could be noted. When analyzing occlusal vs proximal regions, two-sample $T$ test ($P<0.05$) showed that at least for the groups wide inlay, narrow one-cusp onlay, wide one-cusp onlay, and narrow two-cusp onlay, the marginal accuracy is significantly better at the occlusal regions than at proximal ones. The remaining groups did not present statistical different values between these regions ($P>0.05$).

Two-way ANOVA showed a particular difference when considering the occlusal isthmus width alone ($P=0.001$), but the cuspal coverage ($P=0.425$) or even the interaction between these factors ($P=0.301$) did not show any significance. The difference in occlusal isthmus width was analyzed through a two-sample $T$ test ($P<0.05$), as there were two types of occlusal isthmus width (narrow and wide), showing that wide occlusal isthmus width preparations had a significantly better fit than narrow ones for inlays and two-cusp onlays (Figs. 3 and 4). When a grand mean for all narrow groups was obtained and compared to the grand mean for wide ones, the latter showed significantly better fit than the former (Fig. 3).

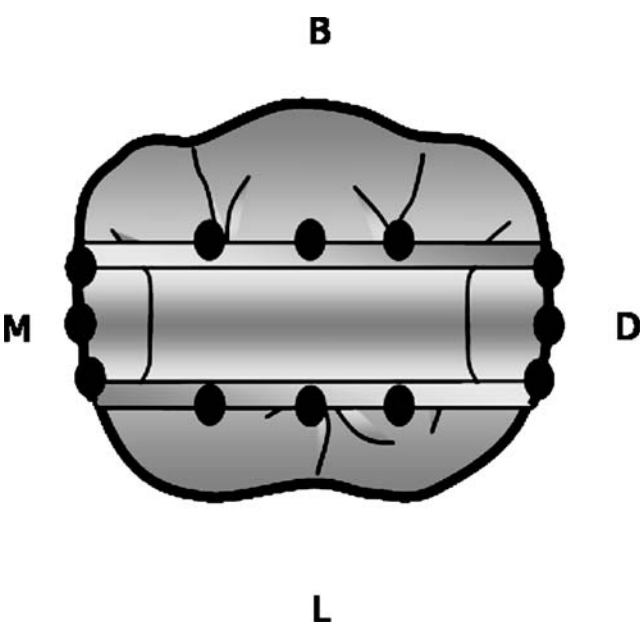

Fig. 2 Location of the measurements. *M* Mesial; *B* buccal; *L* lingual; *D* distal

## Discussion

Several studies have assessed the marginal accuracy of different LPRC materials and restoration geometries [5, 6,

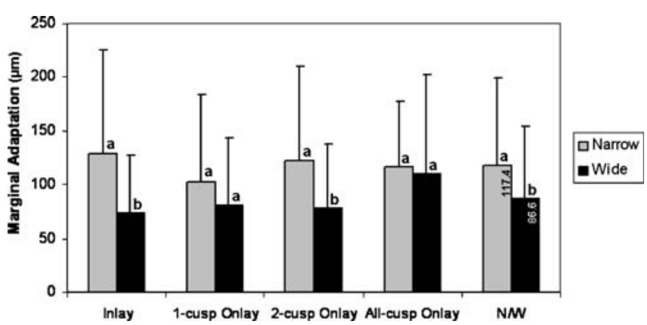

Fig. 3 Means (μm) of marginal gaps of narrow vs wide occlusal isthmus width preparations. *N/W* Grand mean for narrow and wide occlusal isthmus groups. *Different letters above bars* mean statistical significant differences ($P<0.05$) within the same cuspal coverage type of preparation, by $T$ test

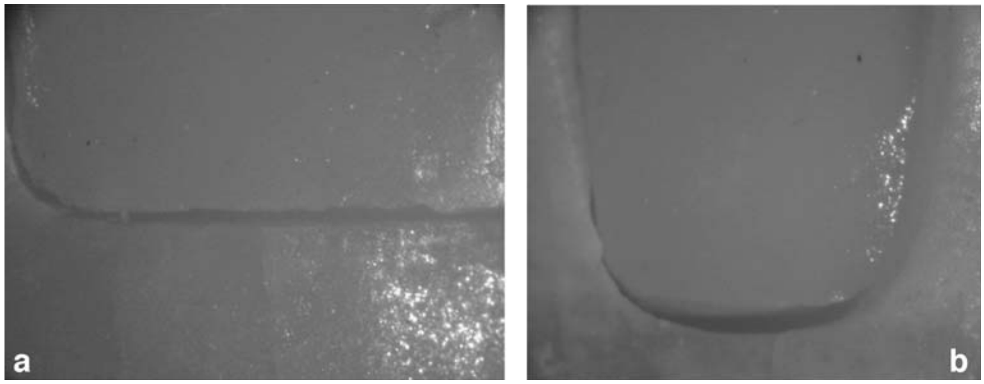


**Fig. 4** View of the proximal region. Example of reasonable marginal fit of extensive groups (**a**) and poor marginal fit of conservative groups (**b**)

18–20, 22, 26, 32, 39, 40], always finding different results. Soares et al. [32] found gaps varying between 20.83 to 43.08 μm on extensive Targis inlays, while Loose et al. [22] related gaps ranging from 15 to 150 μm and Cho et al. [6] from 0 to 149 μm. According to Taylor and Lynch [38], the principal reason for this to happen is the greatest methodology variation, but different results can also be related to the variations in type of tooth preparation [6, 14, 31], the location and number of measurement points [11, 31, 32], the material characteristics [6, 32], the finishing technique [38], and whether the fit was determined before or after luting the restoration [10, 31].

The present investigation employed a quantitative assessment of primary marginal fit of indirect composite restorations by means of stereomicroscopy with 40× magnification, using 12 measurement points per sample and determining the fit just before cementation and after laboratory adjustments. It was not the aim of this study to measure the gaps after luting the restorations, but previous studies have shown that the luting space is wider after cementation [10, 31]. Groten et al. [11] have suggested the use of at least 50 measurement points to obtain clinical relevant information about gap size around the restoration, but their study was performed on full crown restorations and not on partial ones. According to the same authors [11], this reasoning should be subjected to crowns only because different preparation forms and geometries may affect observations on inlay castings or other restoration forms in a different way.

Leinfelder et al. [21] have suggested that the interfacial gap should not exceed 100 μm. Wider gaps seem to increase wear of the luting cement [27], but Kawai et al. [18] related that cement vertical wear loss occurs even in 50-μm gaps. On this study, five groups exceeded 100 μm. It is most probable that this occurrence is related to two factors: the internal restoration surface sandblasting and the necessity of internal adjustment for accurate seating. Aluminum oxide sandblasting and application of a silane-coupling agent is the best surface treatment for LPRC restorations [35], but it is probable that it can affect the marginal integrity of restorations, depending on the ability of the technician. However, to simulate the situation immediately before cementation, this procedure was accomplished before marginal fit evaluation. Supposing this was the reason for wide gaps, it no longer means that it is necessary to drop the sandblasting procedure, but it is mandatory to perform it with greater care and preferentially by an expert technician. More studies are necessary to elucidate this issue.

Inlay restorations are more irregular, with a great number of angles, which generally makes necessary internal adjustment for accurate seating [10]. In addition, changes of the form of indirect composite resin inlays during construction cannot be compensated for by the properties of specially designed cast materials [20]. This study showed wide occlusal isthmus width preparations having better fit than narrow ones, being that three out of four groups of wide preparations did not exceed 100 μm. Furthermore, when the total mean gap of all narrow groups was compared to the one of wide groups, a significant difference was observed (Fig. 3). One of the reasons for this observation may be the expansion of stone casts. Stone casts are known to expand during the setting reaction [7]. As narrow preparations resulted on stone casts that required greater volume of stone, in comparison to wide preparation groups, it is expected that they may suffer greater expansion; greater stone cast expansion could result in inaccurate seating of the restoration, which would further require more internal adjustment. Working with refractory die materials, Hayashi et al. [12] showed that expansion of the dies resulted on insufficient space to insert the inlays into the original cavities, and the cavity shape affected the expansion of the die and adaptation of restorations. Type IV stones generally expand in rates of around 0.07% [7], and similarly to refractory materials, this expansion can affect adaptation of restorations. The type IV stone used on this study has a maximum expansion of 0.12% (manufacturer information). During construction of the restoration, the narrow groups required more internal adjustment than wide ones, principally at internal angles and gingival wall of proximal boxes, and this seem to have resulted on poor marginal fit. However, care was taken not to damage the external surface of restoration to avoid the production of marginal discrepancies. It is suspected that the use of a die spacer would eliminate this problem, but further studies are necessary.

Composite volumetric shrinkage, typically in the order of 1.5–5% [9], can be affected by the shape of the cavity [9, 41], and it is directed to the center of the resin mass in a non-bonding situation (e.g., indirect restoration being constructed on a stone cast) [41]. As the polymer acquires rigidity in a very short period of time during light-curing (gel point), modified light-curing protocols, as lower initial irradiance (used in this study), have been suggested to extend the period of composite viscous-flow and then reduce contraction stresses and gap formation [9, 30]. Although Stansbury et al. [36] states that the gel point is conversion dependant, occurring at 5% conversion, and it is not expected to be dramatically altered by slowing down the polymerization process, Peutzfeldt and Asmussen [30] showed a positive correlation of composite shrinkage and gap formation only after the first 10 s of polymerization. When constructing the restorations, this study employed a low irradiance pre-polymerization for 10 s, which is expected to have the positive effect of delaying the shrinkage to the post-polymerization process. Post-polymerization was accomplished at high temperature to allow network formation in a more expanded state [36], probably reducing the effects of composite shrinkage on gap formation.

The narrow inlays, which required the most conservative restoration, presented the worst marginal accuracy (128.8 μm; Table 1). In comparison, the wide two-cusp onlays, which required a more extensive restoration, presented good adaptation (77.8 μm). It is known that for restorations that merely fill the preparation without adhesion, cuspal coverage is necessary to reduce potential risks of fracture, when the occlusal isthmus measures one half the intercuspal distance or wider [25]. As an alternative to such an external tooth splinting, studies have investigated the suitability of using adhesive techniques to provide internal tooth splinting between the tooth and the restoration for the stabilization of weakened teeth [8, 28]. On this study, the effect of cuspal coverage on marginal accuracy was not significant. From this point of view, this fact suggests that the removal of sound tooth structure for cuspal coverage is unreasonable.

Some factors as errors due to impressions, stone models and composite shrinkage can surely have an influence on gap formation, but it seems that preparation design guided these influences on this study. Reducing, as much as possible, the gap dimension is always advisable, both on occlusal surfaces, where wear is most probable to take place, and on proximal surfaces. Mesial and distal boxes are generally left close to the periodontium, and if the restoration has poor marginal fit, it is possible to cause plaque accumulation, caries, and periodontal disease. In agreement with Soares et al. [32], Gemalmaz et al. [10], and Thordrup et al. [39], this study showed occlusal margins having better fit than proximal ones. The proximal region has a complex geometry, with different angles and a higher material volume, and generally requires adjustment before cementation, resulting on poor marginal accuracy. It is advisable that preparations on these regions should keep a minimum distance from periodontal tissue, as greater as possible.

The results of this study address important and reasonable clinical guidelines to indirect composite resin restorations because different cavity preparations altered the marginal accuracy of SR Adoro restorations, but it is still uncertain if this is true for other composite resin materials. The effect of occlusal width extension on marginal accuracy of indirect composite resin restorations is significant, but it is not recommended for the clinician to extend preparations from narrow to wider occlusal isthmus because this would cause the unnecessary removal of sound tooth structure. Irrespective of the cavity preparation design, preparations weaken teeth [2, 28], and greater preparations will rise the chances of reducing tooth strength [37], which is not desirable. It seems more feasible to alter the treatment plan and use other restorative procedures for less-aggressive preparations. As observed by Pallesen and Qvist [29], there is not a significant difference between fillings and inlays with respect to failure rates, which enables different treatment options for these preparations. However, if an indirect procedure is chosen, it should be remembered that a careful attention must be paid after luting these restorations because studies have shown that marginal gaps are always greater after luting [10, 31]. Further investigations are therefore required to identify the effect of different restorative materials and techniques.

**Acknowledgements** Authors are grateful to Dentsply and KG Sorensen for full donation of the materials used in this study, and to Ivoclar-Vivadent for partial donation.

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