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Marginal and internal adaptation of class II restorations after immediate or delayed composite placement

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Abstract

Direct class II composite restorations still represent a challenge, particularly when proximal limits extend below the CEJ. The aim of this in vitro study was to evaluate the influence of the type of adhesive and the delay between adhesive placement and composite insertion on restoration adaptation. Direct class II MOD box-shaped composite restorations ($n = 8$ per group) were placed on intact human third molars, with proximal margins 1 mm above or under CEJ. All cavities were filled with a horizontal layering technique, immediately after adhesive placement (IP) or after a 24 h delay (DP). A filled three-component adhesive (OptiBond FL: OB) and a single-bottle, unfilled one (Prime & Bond 2.1: PB) were tested. Marginal adaptation was assessed before and after each phase of mechanical loading (250,000 cycles at 50 N, 250,000 cycles at 75 N and 500,000 cycles at 100 N); internal adaptation was evaluated after test completion. Gold-plated resin replicas were observed in the SEM and restoration quality evaluated in percentages of continuity (C) at the margins and within the internal interface, after sample section. Adaptation to beveled enamel proved satisfactory in all groups. After loading, adaptation to gingival dentin degraded more in PB-IP ($C = 55.1\%$) than PB-DP ($C = 86.9\%$) or OB-DP ($C = 89\%$). More internal defects were observed in PB samples (IP: $C = 79.2\%$ and DP: $C = 86.3\%$) compared to OB samples (IP: $C = 97.4\%$ and DP: $C = 98.3\%$). The filled adhesive (OB) produced a better adaptation than the 'one-bottle' brand (PB), hypothetically by forming a stress-absorbing layer, limiting the development of adhesive failures. Postponing occlusal loading (such as the indirect approach) improved also restoration adaptation.

Keywords: Composite; Class II restorations; Marginal adaptation; Internal adaptation

1. Introduction

Although composite polymerization shrinkage has been reduced in modern composite formulations [1–4], it still precludes the direct techniques to be simply applied in large class II restorations. Therefore, compensatory restorative methods have to be considered, such as incremental techniques [5–8,11] or the insertion of ceramic inserts into proximal cavities [9]. An alternative or supplementary solution is to get polymerization stresses partially absorbed by a lining or base made of a more 'elastic' material, such as a thick bonding resin layer [10], flowable composite, glass ionomer or compomer [6,12,13,59]. The expected benefit of these different approaches is to reduce the stresses developed within the tooth-restoration system, responsible for adhesive or cohesive failures.

Base and liners actually act as stress absorbers or stress breakers during the insertion and polymerization of subsequent composite layers or during functional loading. A group of products was recently introduced, which makes use of a thick filled adhesive, applied separately from the primer, according to this 'stress absorption' principle, while the very popular 'one-bottle' adhesives rely on the formation of a very thin adhesive layer. Although both types of adhesive systems provide bond strength values of similar range [14–17], it remained to be determined if they provide the same quality of restoration adaptation.

Apart from the influence of restorative materials and techniques, different parameters have to be considered to estimate the damaging potential of polymerization stresses [57]. Amongst the most important, are the configuration factor [19,20], the material properties [21], the cavity size, the presence or absence of enamel around cavity margins and the dentin quality, morphology and location [23,61]. These parameters will determine how well adhesion to cavity walls, polymerization stresses and compensatory phenomena, such as flow and elastic deformations, balance

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each other. In clinical conditions, a satisfactory marginal and optimal internal adaptation might be difficult to achieve for large and deep restorations, due to an unfavourable combination of aforementioned elements.

The semi-direct and indirect techniques [24] are aimed to solve this problem by confining composite polymerization shrinkage to the thin cementing gap, thus reducing the magnitude of stresses [25,26]. Another advantage of this approach, although generally ignored, is the preservation of the adhesive interface during the intermediary or temporary phase and as well, an improved bond strength, all resulting from the delay preceding the cementation phase [27–29]. This is likely to have a very positive influence on the restoration marginal and internal adaptation.

Therefore, the aim of the present study was to confirm the hypothesis that the delay between the adhesive application and composite built-up could have a significant impact on restoration adaptation. The hypothesis was tested for two different adhesive systems.

2. Materials and methods

2.1. Specimen preparation

Freshly extracted human third molars were used for this study. The inclusion criteria were that the teeth were free of decay and presented a complete apexification. The teeth were kept in an isotonic sodium azide solution (0.2%) at 4 °C until the experiment started, to prevent bacteria or fungus growth in the storage medium.

For each specimen, the root length was adjusted to fit in the test chamber of the mechanical loading device (Department of Cariology, Endodontics and Pedodontics, Laboratory of Electronics of the Faculty of Medicine, University of Geneva). After the specimen was properly positioned, it was fixed with light-curing composite on a metallic holder (Baltec; Balzer, Liechtenstein) and the root base was embedded with self-curing acrylic resin to complete the tooth stabilization. Box-shaped class II cavities (MOD) with parallel walls and bevelled enamel margins were prepared, with proximal margins located 1.0 mm below (mesially) and above (distally) the cementum–enamel junction (Fig. 1). The dimensions of the preparation were 4.0 mm in width and 2 mm in depth, at the bottom of the proximal box, and $2 \times 4\ mm^2$ (depth × width) in the occlusal area. The cavities were prepared using coarse diamond burs under profuse water spray (Geneva Prep Set; Intensiv; Viganello, Switzerland) and finished with fine grained burs of the same shape (Geneva Prep Set).

The 40 prepared teeth were randomly assigned to one of the four experimental groups, corresponding to the two adhesive systems and the delay in composite placement.

2.2. Restorative procedures

The same restorative material (TPH Spectrum, DeTrey-Dentsply; Konstanz, Germany) but two different adhesive systems were evaluated (Optibond FL, Kerr; Orange, CA, USA; Prime & Bond 2.1, DeTrey-Dentsply).

After completion of the preparation, enamel was selectively etched for 30 s prior to a 15 s full cavity etching. The cavity was thoroughly rinsed for 30 s and gently air dried (3 s air spray with low pressure) so that conditioned dentin was kept slightly moist. Then, adhesives were placed according to manufacturer's instructions and light-cured for 40 s.

The restorative material was either placed immediately following light-curing of the adhesive (immediate placement: IP) or after 24 h (delayed placement: DP). The samples, of which filling was postponed, were stored in a

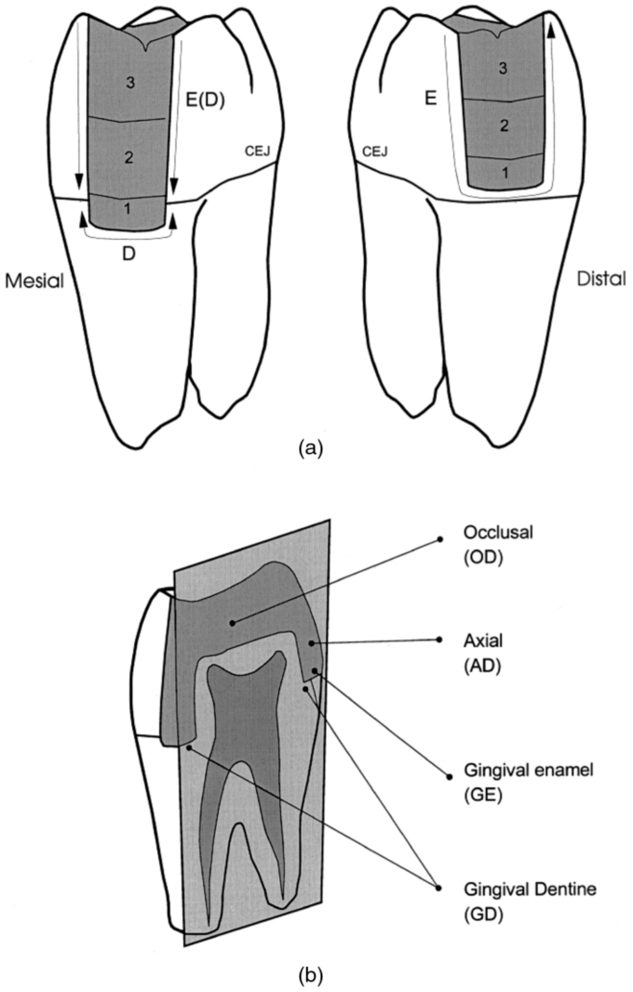

Fig. 1. Representation of the cavity design and sections under evaluation. (a) 1–3 represent the three subsequent increments of the horizontal layering method; (b) representation of the different areas under evaluation for the internal adaptation of class II restorations.

Table 1
Composition of products under investigation (manufacturer's data)

Products	Product name (manufacturer)	Composition	Batch numbers
Conditioner	Ultraetch (Ultradent; Salt-lake City, USA)	H_3PO_4 37% gel	–
Adhesive I	Optibond FL (Kerr, Romulus, CA, USA)	Primer: 2 (hydroxyethyl) methacrylate (HEMA), Glycerol phosphate dimethacrylate (GPDM), Mono (2-methacryloxy ethyl) phtalate, Ethyl alcohol, Water	712501
		Bonding resin: Bis-Phenol-A-bis-(2-hydroxy-3-methacryloxypropyl)ether (BisGMA), 2-Hydroxyethylmethacrylate (HEMA), Barium Aluminoborosilicate, Disodium hexafluorosilicate, Fumed Silica, Glycerol Demethacrylate	711352
Adhesive II	Prime & Bond 2.1 (Dentsply De Trey; Kontsanz, Germany)	Dymethacrylate resins, PENTA (dipentaerythritol penta acrylate monophosphate), photoinitiators, stabilizers cetylamine hydrofluoride, acetone	960820
Restorative material	TPH spectrum (Dentsply De Trey; Kontsanz, Germany	mod. BisGMA, BisEMA, TEGDMA, barium alumino boro silicate glass, colloidal silica, Initiators, stabilizers	961016

damp container (sample in a water saturated atmosphere) to prevent sample dehydration.

A horizontal layering method [5] (Fig. 1a), was applied for the filling of proximal boxes (three layers, the first one having a 1 mm thickness) followed by the remaining occlusal volume. Each increment was separately cured for 40 s with a halogen light-curing unit (Visilux XL 3000, 3M, St Paul, MN, USA), the power density of which is about 525 mW/cm^2. The material characteristics and references are given in Table 1.

Flame and pear-shape fine diamonds burs (Intensiv No 4205L; 4255; 5205L and 5255) and polishing discs (Pop On XT, 3M; St Paul, MN, USA) were used for restoration finishing and polishing.

2.3. Mechanical loading

The stress test was carried out after a 24 h delay. The pulpal chamber was penetrated buccally or palatinally with a tube (sealed with DBA), which was connected to a simulated pulpal circuit of saline water, under a pressure of 14 cm H_20 [30,31]. All specimens were successively submitted to 250,000 cycles with 50 N loading force, 250,000 with 75 N and 500,000 cycles with 100 N, representing a total of 1,000,000 loading cycles. The axial force was exerted at a 1.5 Hz frequency, following a one-half sine wave curve. These conditions are believed to simulate about 4 yr. of clinical service [32,33]. Restored teeth were contacted by antagonist artificial cusps, made of stainless steel, the hardness of which is similar to natural enamel (Vickers hardnesses: enamel = 320–325; steel = 315). The diameter of the cusps was 4 mm and they were placed 1 mm above the restoration occlusal surface, about 1.5 mm out of the central fossa. The specimen being mounted on a rubber disc, a sliding movement of the restored tooth was made possible between the first contact on the inclined plane and the central fossa. The functions of this experimental device are similar to the machine

Table 2
Results of the marginal adaptation evaluation at the different proximal locations, according to the number of mechanical loading cycles (percentages of continuity ± SD)

Nb of cycles	Location	PB-IP	PB-DP	OB-IP	OB-DP
0	Enamel (distal)	98.9 (3.2)	100 (–)	99.5 (1.4)	98.7 (2.5)
250,000		98.9 (3.2)	99.4 (1.8)	99.5 (1.4)	98 (2.8)
500,000		96.6 (5.7)	98.6 (2.9)	98.5 (2.3)	95.7 (5.4)
1,000,000		94.5 (7.1)	87.2 (31.3)	94.9 (5.5)	93.0 (7.4)
0	Enamel (mesial)	100 (–)	100 (–)	98.8 (3.5)	99.6 (0.7)
250,000		100 (–)	99.4 (1.2)	100 (–)	99.2 (0.7)
500,000		100 (–)	99.0 (1.8)	99.1 (1.6)	98.8 (1.7)
1,000,000		95.2 (13.4)	97.6 (4)	93.6 (13.8)	95.0 (10.3)
0	Dentin	100 (–) A	96.5 (8.4)	88.8 (31.8)	99.8 (0.7) A
250,000		78.1 (10) A,B	95.5 (10.4)	91.4 (16.7)	97.0 (5.8) B,A
500,000		69.5 (14.4) B,a	91 b (11.6)	85.1 (16.5) a,b	95.4 (5.3) B,A,b
1,000,000		55.1 (22.6) B,a	86.9 b (10.1)	78. 0 (19.1) a,b	89.0 (9.1) B,b

For comparison between groups (rows), means with same lower case letter are not statistically different at $p = 0.05$ using the Scheffé F-test. For comparison between the number of cycles (columns), means with same capital letter are not statistically different at $p = 0.05$ using the Scheffé F-test. No significant difference was found for rows and columns without letter.

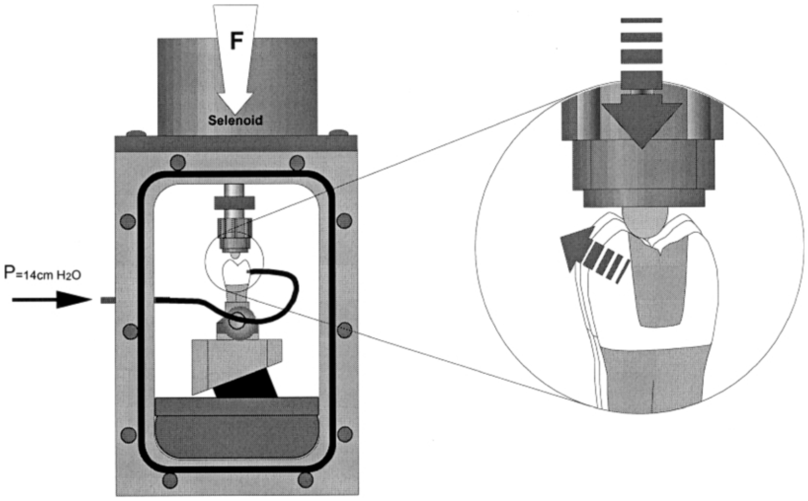

Fig. 2. Representation of the fatigue device simulating masticatory forces. The movement of the artificial cusp and samples is illustrated by arrows.

developed by Krejci et al. [32]. The experimental set-up is illustrated in Fig. 2.

2.4. Specimen evaluation

Before the fatigue test, as well as after completion of each loading phase, the restorations margins were cleaned with a brush and fine pumice and acid-etched with 37% H_3PO_4 gel (30 s on enamel and 10 s on dentin). Then, gold-sputtered epoxy resin replicas (Epofix, Struers; Copenhagen, Denmark) were made from polyvinylsiloxane impressions (President light and heavy body, Coltène AG). The proximal tooth-restoration interface was analyzed quantitatively with the scanning electron microscopy (SEM) (Digital SEM XL20, Philips, Eindhoven, Netherlands) by employing a recognized evaluation method [34,35]. The following evaluation criteria were applied: continuity, overfilling, underfilling, marginal opening, marginal restoration or tooth fracture. The restoration margins were observed at a standard 150 × magnification. When necessary for the assessment accuracy, higher magnifications were used. Results for the restoration marginal adaptation, before and following the different loading phases, are expressed as percentages of margins in 'continuity' for the three segments under evaluation—enamel margins on the distal tooth side (E), and enamel (ED) and dentin (D) margins on the mesial tooth side (Fig 1(a)). The restoration occlusal adaptation was not assessed.

At completion of the mechanical loading, the teeth were embedded in a slow self-curing epoxy resin (Epofix) and sectioned mesio-distally into three parts, with a central slice of 1 mm, using a slow rotating saw (Isomet 11-1180; Buehlers, Evanston IL, USA). The sections were successively polished with 200, 400 and 600 grit SiC paper and etched for 1 min with a 37% H_3PO_4 gel. Impressions were then taken from the four available surfaces for fabricating gold-sputtered resin replicas. In order to avoid observation artefacts, special care was taken not to dehydrate the samples prior taking the impression with a 'moisture tolerant' material [63].

The restoration internal adaptation was assessed quantitatively on the gold-sputtered replicas under the SEM, at a 150 × magnification, and was judged according to two criteria: continuity and interfacial opening. Results are expressed as the percentage of interface in continuity, relative to the whole dentin interface (total), and in addition, to the following dentin segments: gingival enamel (GE), gingival dentin (GD), axial dentin (AD) and occlusal dentin (OD) (Fig. 1(b)). For each sample, results are expressed as a mean value, resulting from the evaluation of the four sections. The localization of bonding failures within the adhesive interface was tentatively identified, using higher magnifications (up to 1000 ×). A single trained evaluator performed all SEM observations.

All results were submitted to a parametric statistical analysis. The differences between the groups, before and after each fatigue phase, the evolution of the dentin marginal adaptation during mechanical loading and the differences between the groups and locations for the internal adaptation were explored by an ANOVA and Sheffe *F*-test (as a multiple comparison test) [36]. All tests were carried out at a 95% level of significance.

3. Results

The results of the marginal adaptation are presented in Figs. 3–5 and in Table 2, together with statistical analysis. The results of the internal adaptation evaluation are presented in Fig. 6 and Table 3; together with the statistical analysis.

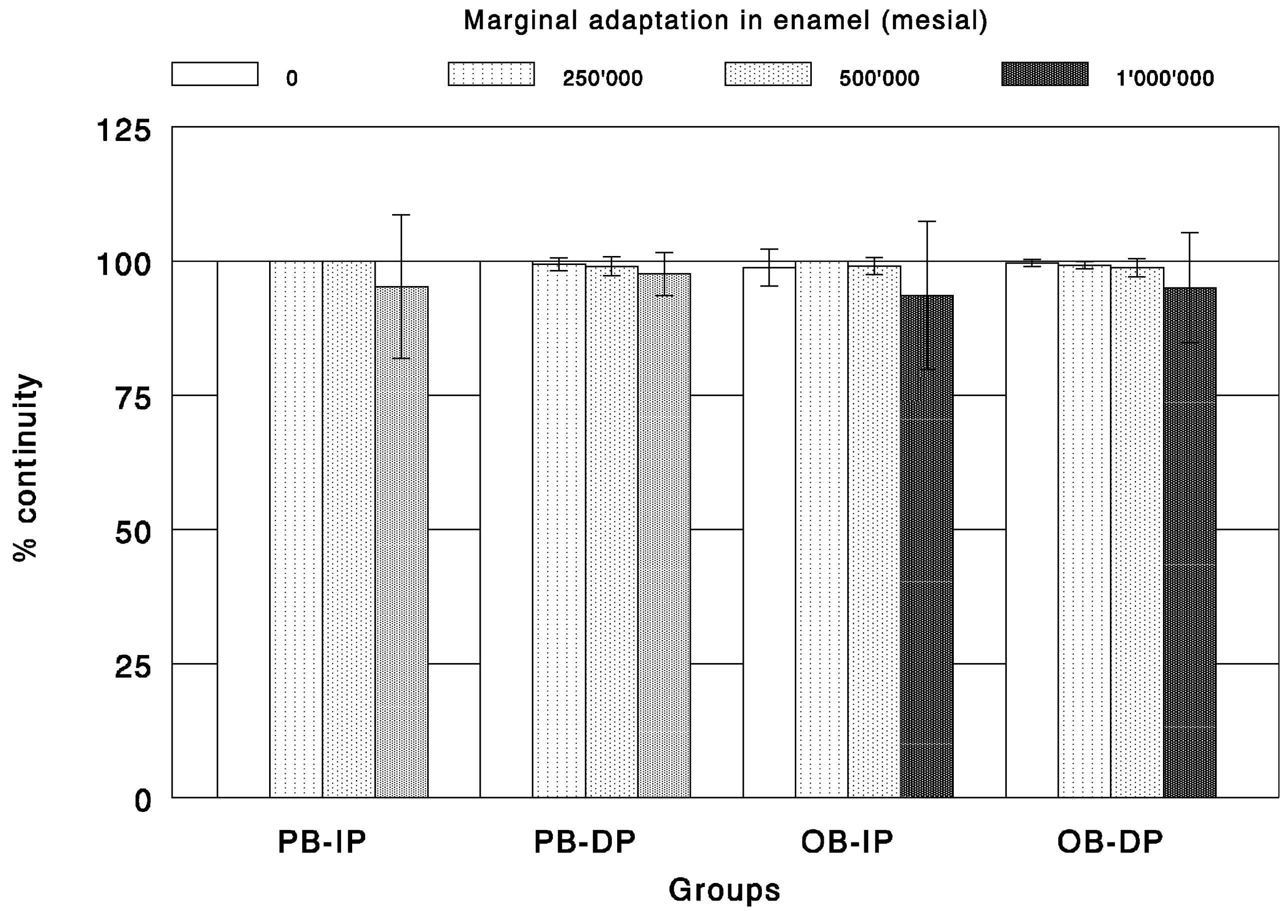

Fig. 3. Results of the marginal adaptation evaluation, in enamel, at the sample mesial surface, before and after the different loading phases.

3.1. Marginal adaptation

The adaptation to enamel proved satisfactory before, as well as after mechanical loading, on both restoration sides. Actually, percentages of enamel margins in continuity varied between 98.7 and 100% before loading and 87.2 and 97.6% after loading, with no significant difference among the experimental groups (Table 2). The only type of defect which was observed on enamel margins with, however, low percentages, was the 'marginal tooth fracture' (Fig. 7).

Following mechanical loading and as a result of marginal opening, the proportion of margins in continuity at the dentin level decreased in all groups (percentages of continuity ranging from 88.8 (OB-IP) to 100% (PB-IP) at baseline and from 55.1 (PB-IP) to 89% (OB-DP) after mechanical loading) with a significant change for PB-IP (between 0 and 500,000 or 1,000,000 cycles) and OB-DP (between 0 and 1,000,000 cycles). After 500,000 and 1,000,000 loading cycles, the use of Prime & Bond, together with an immediate composite insertion (PB-IP), resulted in a marginal adaptation on dentin significantly worse than following a delayed composite application, whatever adhesive was applied. Where adhesive failure were observed, the separation usually occurred between the restoration and the hybrid layer.

3.2. Internal adaptation

The restoration adaptation to enamel was excellent in all groups (ranging from 96.9 (OB-DP) to 100% (OB-IP)). Regarding adaptation to dentin, the overall quality was also satisfactory ("total" percentages ranging from 79.2 (PB–DP) to 98.3% (OB–DP)). Regarding the influence of the different locations on internal restoration adaptation, significant differences in continuity values were found only between the dentin occlusal area for PB samples, or the gingival dentin area for PB-DP, and gingival enamel. Optibond samples showed a better internal adaptation than Prime & Bond samples, at the gingival and occlusal interfaces.

3.3. Micro-morphological observations of internal interfaces

In most of the samples, an acid resistant layer of 5–10 μm thickness was present between the restoration and the intact dentin, likely corresponding to the hybrid layer. Resin tags showed a variable penetration in the tubules, usually between a few to 50 μm (Fig. 8). The protocol applied to the samples of this study did not allow to identify the bonding resin layer. No specific morphological feature

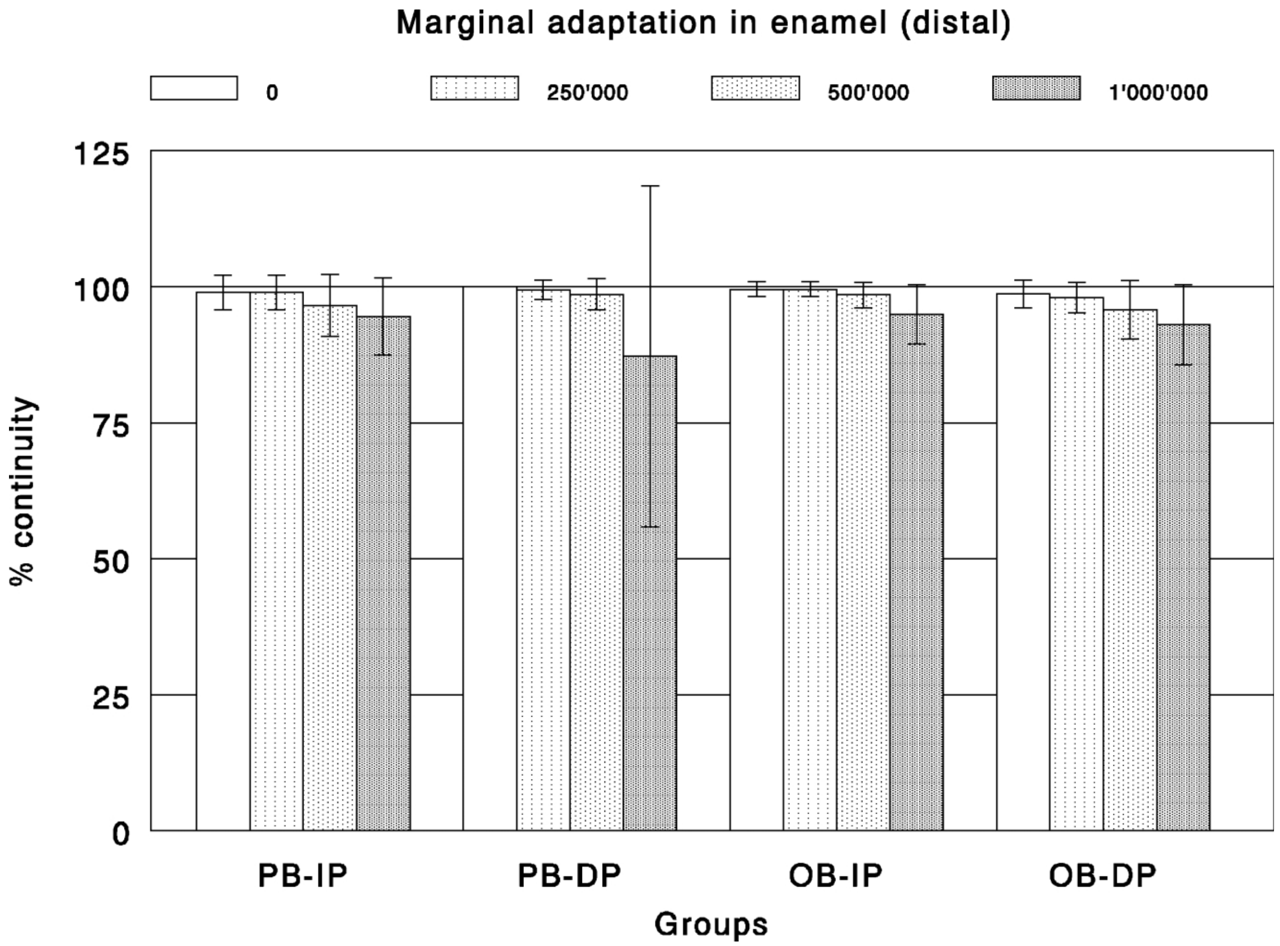

Fig. 4. Results of the marginal adaptation evaluation, in enamel, at the sample distal surface, before and after the different loading phases.

could be attributed to any of the adhesives under evaluation; they both revealed similar variations in tag length and density or hybrid layer thickness.

Adhesive failures were found to occur at the top of the hybrid layer, in particular where no tag formation was visible (Fig. 9). The separation also predominantly occurred at the occlusal and gingival surfaces in the Prime & Bond samples. Other failure mechanisms such as cohesive fractures in dentin, within the hybrid layer, or a detachment of the hybrid layer at its base were virtually not found.

4. Discussion

4.1. Materials and method

The ultimate goal for a restoration, besides any aesthetic concern, is to ensure the biomechanical integrity of the tooth; this implies achieving a proper function and maintaining over time a satisfactory marginal and internal adaptation. Consequently, a SEM observation of internal adhesive interfaces was judged necessary to supplement the information resulting from the standard margin quality evaluation [34,35,37]. This additional evaluation, performed on replicas of sample sections, proved useful to study the micro-morphology and failure modes of class II adhesive restorations [26,38]. A modification of the basic method of surface replication [60] was also applied, in order to improve the accuracy of the SEM observation; it consisted in shortly acid etching the restoration margins or sample sections, prior to making the impression.

The same restorative composite resin, a fine hybrid (TPH Spectrum), was used in all groups in order to reveal the influence on restoration quality of the adhesive type and the delay between adhesive placement and composite build-up.

4.2. Marginal adaptation to enamel

The restoration adaptation to mesial or distal enamel proved satisfactory in all groups, despite a severe mechanical fatigue test. Actually, very low proportions of defects were found at enamel margins, initially as well as after loading. Those observed proved to be mainly tooth micro-fractures. This very favourable finding likely reflects the influence of prism orientation in bonding efficiency to acid-etched enamel; it is known that a bevelled margin with enamel prisms cut roughly perpendicular to their long axis is

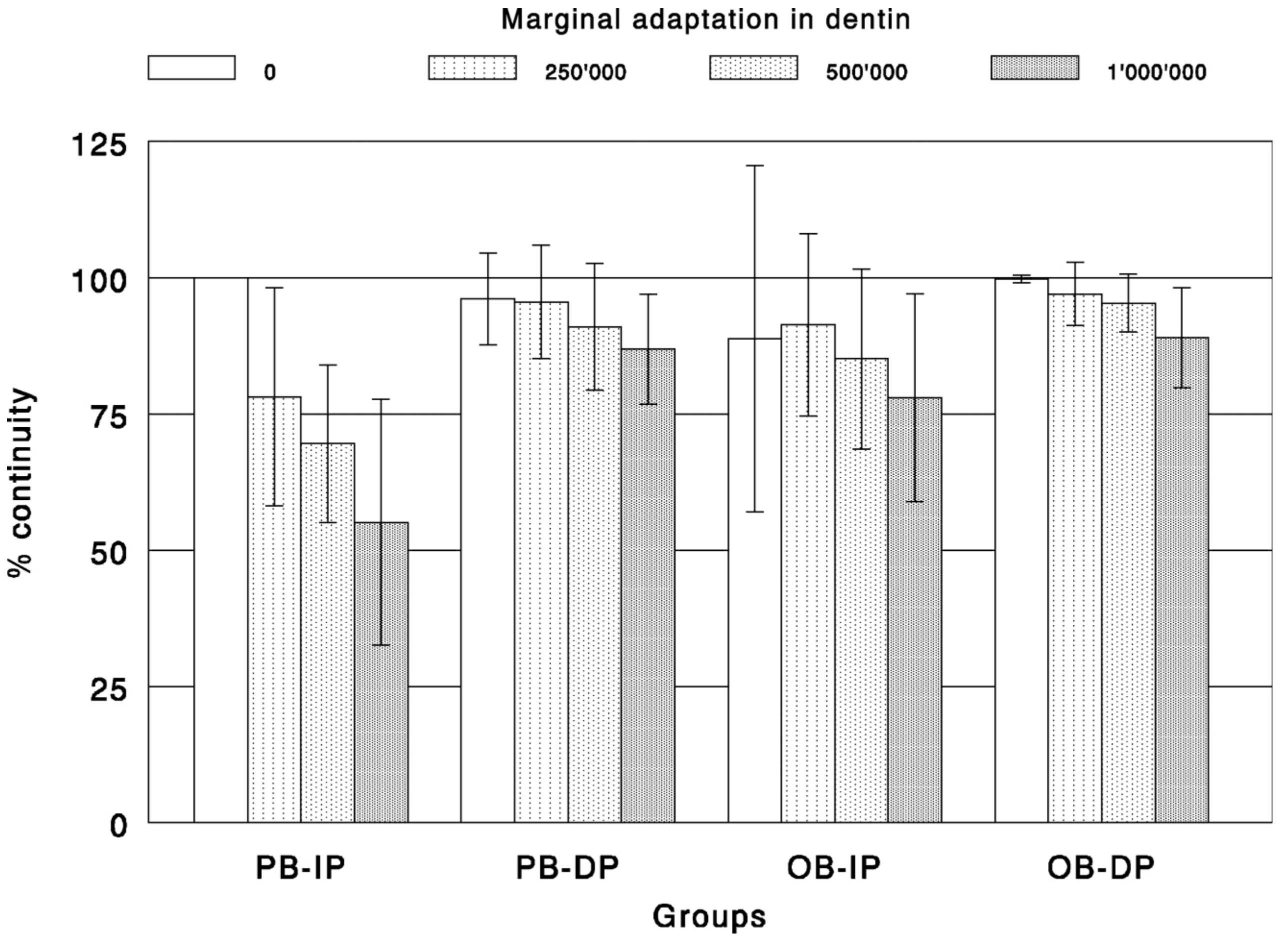

Fig. 5. Results of the marginal adaptation evaluation, in dentin, at the sample mesial surface, before and after the different loading phases.

a configuration more favourable than a butt margin [18,39]. Actually, larger proportions of enamel micro-cracks were observed in in vitro mechanical loading tests conducted on cavities with a butt margin design [25,26,38,40]. This speaks again in favour of placing a bevel around cavities to be filled with a direct technique, wherever enamel thickness is 1 mm or more [41,58].

4.3. Adaptation to dentin

In dentin, significant differences in margin quality were observed, between placement methods and adhesives; the test hypothesis, namely that different types of adhesive or a delayed composite placement may influence restoration adaptation, was then confirmed. This difference in margin quality proved, however, significant only after 500,000 cycles. With consideration of the high initial percentages of continuous margins, this proves that both DBA were equally efficient in preserving interface integrity, but following simulated functional stresses. This stress the influence of mechanical loading in such in vitro evaluations and the primary importance of fatigue tests in pre-clinical testing of adhesive techniques.

The samples of the PB-IP group, with immediate composite insertion and making use of the so-called one-bottle non-filled adhesive system (Prime & Bond 2.1), showed the smallest proportion of excellent margins. As well, the assessment of internal adaptation in dentin revealed more interfacial defects with this adhesive, compared to the filled system (Optibond FL). Different phenomenon, probably relating to each other, explain these findings. The first one is certainly the positive influence of the delay, before submitting the interface to polymerization or functional stresses. Actually, the bond strength is known to develop progressively, reaching its maximal value only after several hours [27–29]. The co-polymerization process of the different monomers involved in the formation of the adhesive interface as a whole, necessitates time for completion. The potential for immediate adhesion being then limited, one has to expect disappointing results in unfavourable configurations, such as deep and large cavities restored with a direct technique. As well, because most of data found in publications or manufacturer documents regarding maximal bond strength of dentin adhesives result from tests performed after 24 h, clinicians tend to under-estimate the occurrence of adhesive failures. Undoubtedly, more attention should be paid to this fact. For this reason, it can be advantageous to place a stress breaker layer in the

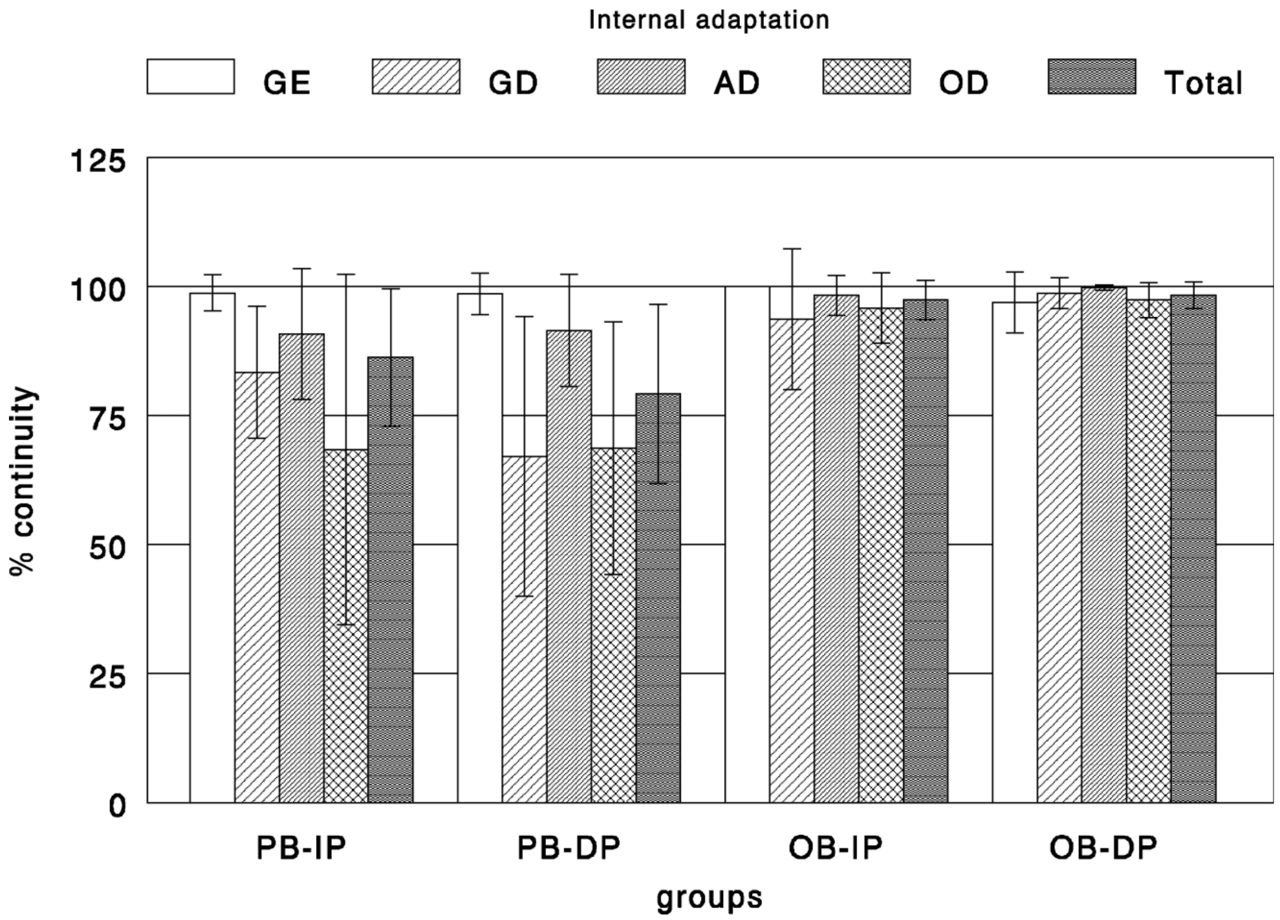

Fig. 6. Results of the internal adaptation evaluation, after mechanical loading.

system, which relates to the second explanation of the present results. Actually, the elastic deformation of a more 'flexible' material (e-modulus lower than the restorative material) [4,22] placed close to or within the adhesive interface might help to absorb immediate (resin polymerization shrinkage) and delayed strains (spontaneous post-polymerization and functional forces). The importance of the elastic layer has been shown as early as 1990 [21,22]; since then, several studies confirmed the validity of this concept [10,12,40,42,43].

A last potential explanation for the inferior efficiency of such a one bottle adhesive is an insufficient or total lack of polymerization of the very thin resin layer left after adhesive placement and solvent evaporation (only a few microns) [44]. Actually, the inhibitory effect of oxygen is known to affect resin polymerization to a depth of 100 μm or more and to create a layer of totally non-polymerized resin of about 15 μm [45]. As resin penetrates the demineralized dentin to a depth of only 0–10 μm and considering the extremely thin resin coating normally persisting on the dentin surface [46,47], a complete resin polymerization within the adhesive interface prior to composite placement is unlikely. As a consequence, the collagen network might be disturbed by composite placement, which generally results in a higher proportion of adhesive failures at the hybrid layer-bonding resin interface [48,62]. Therefore,

Table 3
Results of the internal adaptation evaluation, according to the different interface segments and the whole dentin interface (total) (percentages of continuity ± SD)

Groups	GE	GD	AD	OD	Total
PB-IP	98.8 a (3.5)	83.4 A,B,a,b (12.8)	98.0 a,b (12.6)	68.4 A,b (34)	86.3 (13.3)
PB-DP	98.6 a (4)	67.1 A,b (27.1)	91.5 a,b (10.9)	68.7 A,b (24.5)	79.2 (17.4)
OB-IP	100 (–)	93.7 B (13.6)	98.3 (3.8)	95.9 A,B (6.8)	97.4 (3.8)
OB-DP	96.9 (5.9)	98.7 B (3)	99.8 (0.5)	97.4 B (3.4)	98.3 (2.6)

For comparison between products (columns), means with same lower case letter are not statistically different at $p = 0.05$ using the Scheffé F-test. For comparison between locations (rows), means with same capital letter are not statistically different at $p = 0.05$ using the Scheffé F-test. No significant difference was found for rows and columns without letter.

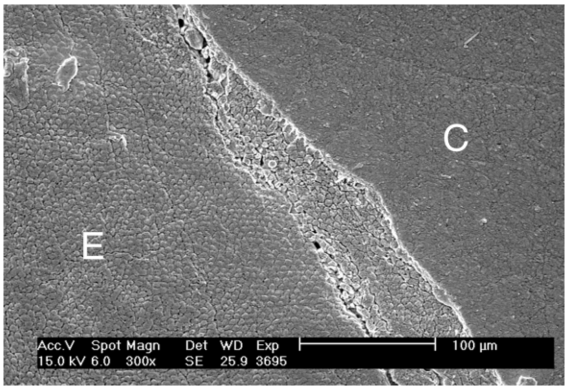

Fig. 7. SEM observation of a marginal tooth fracture. This illustrates the typical defects found at the level of enamel, after mechanical loading. (Prime & Bond sample-immediate placement-1,000,000 cycles).

in a clinical class II configuration and in the absence of hybrid layer stabilization, the resistance to stress of the adhesive interface promoted by a thin uncured resin layer is probably reduced. This sustains the findings of Frankenberger et al. [49] who showed that a pre-curing of the bonding resin was mandatory to maximize the quality of indirect and direct class II restorations.

In the present study, the restorations were realized

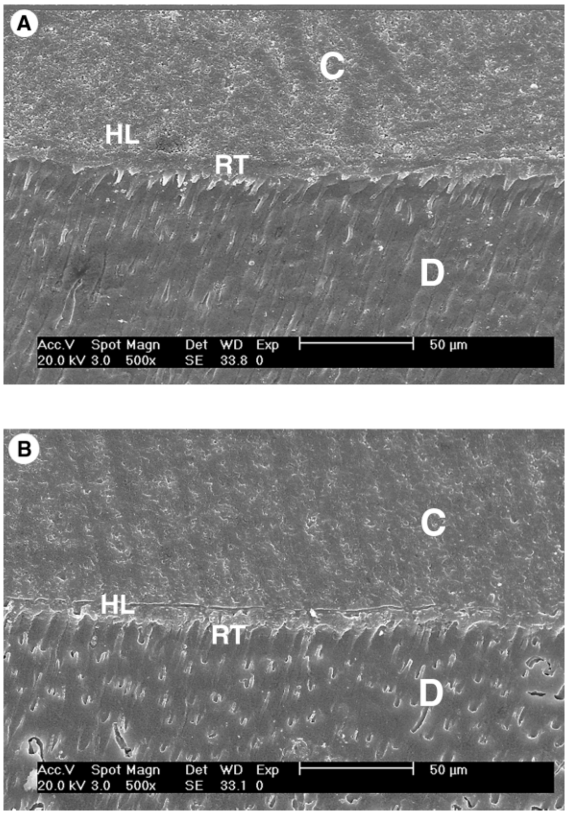

Fig. 8. (a) Section of an Optibond FL sample—immediate composite placement. The adaptation is in continuity with a well organized hybrid layer and resin tags clearly visible; (b) section of a Prime & Bond sample—delayed composite placement. The micro-morphology of the adhesive interface is very similar to the one of Optibond FL, showing a well organized hybrid layer and resin tags.

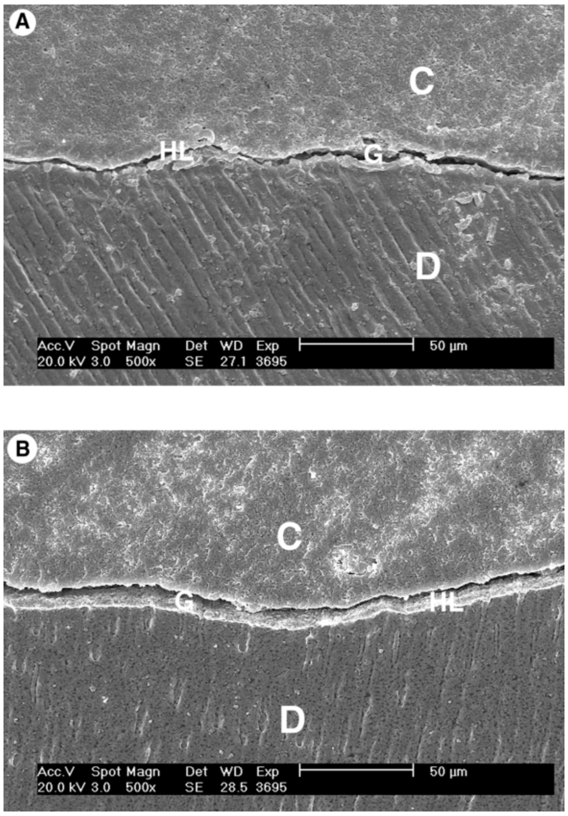

Fig. 9. (a) Section of a Prime & Bond sample—immediate composite placement. The gap clearly occurred over the hybrid layer, in an aera with no resin tag formation. This points out the importance of tags in bonding efficiency; (b) optibond FL sample—immediate composite placement. Similar observation were made underneath gap in this groups.

following the total bonding concept [50], which requires adhesion to be established on all cavity surfaces. The rationale behind this concept is to provide an even stress distribution within the tooth-restoration system, assuming on the long term a behaviour alike natural teeth. Contrarily, with the concept of selective bonding, as described in 1986 by the group of Lutz et al. and Krejci and Stavridakis [6,11,50] adhesion is established only at the margins, providing a large internal free surface. In a critical class II configuration, when polymerization stresses might develop faster and higher than adhesion, excessive internal stress build-up is prevented by separation at a pre-determined interface. The separation takes place between a base-lining made of glass–ionomer and the next composite layer, while following the original technique [11], or between two different kinds of dentinal adhesives [50]. The selective bonding efficacy is based on the preservation of dentin biological seal by either glass–ionomer or dentin adhesive and, as well, by the lack of direct stress on the tooth-lining interface. The concept of delaying stress development follows the same objectives, when the total bonding concept is applied to a critical cavity configuration. In this situation, the indirect technique is to be favoured, which allows postponing and reducing stresses developing at the tooth-restoration interface. As a concentration of functional stresses along the margins, as resulting from the strict application of the selective bonding concept, might be detrimental to restoration quality [51], the use of indirect or semi-direct techniques [24] for large and deep class II cavities still appears suitable.

4.4. Micro-morphology of the internal adhesive interface

The micro-morphology of the internal adhesive interface, as shown on the gold-sputtered resin replicas, is compatible with the description made by Nakabyashi, Pashley and Van Meerbeck [44,52,53]. SEM observation of sample sections at higher magnification revealed that adhesive failures chiefly occurred above the hybrid layer and predominantly where resin tag formation was insufficient. This sustains the importance of tags in improving bond to dentin [53].

In other areas of debonding, the influence of the substrate cannot be totally excluded. However, the use of non-carious intact teeth, as well as the absence of clear differences in gap percentages between the different cavity zones, do not make it a likely variable. Although cohesive fractures in dentin were observed after bond strength tests, especially micro-tensile bond strength tests [20,54,55], this failure mode was not pertinent to the present study. This confirms the idea that actual bond strength of modern dentin adhesive do not surpass the yield strength of resin composites or the ultimate tensile strength of dentin [56], especially in a clinically relevant configuration.

5. Conclusions—clinical relevance

In the present experimental conditions, it can be concluded that:

- adaptation to enamel of direct composite class II restorations was satisfactory with bevelled proximal margins
- the marginal adaptation to dentin was better after a delayed placement of the restorative material, showing that the resistance of the adhesive interface to polymerization and functional stresses is not optimal immediately after DBA application
- the internal adaptation to dentin proved better when creating a thick adhesive layer (Optibond FL), confirming the importance of a stress-releasing layer within the adhesive interface
- debonding took place predominantly over the hybrid layer; this interface was again identified as the weak link of dentin adhesion.

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