3D optical profilometer analysis of the marginal gap of Class II restorations made with different materials for vital pulp therapy procedures

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INTRODUCTION

Vital pulp therapy (VPT) is a biologic conservative treatment aiming to preserve the vitality and function of the coronal or remaining radicular pulp tissue in vital permanent teeth1. In modern endodontics, VPT has been considered an ultra-conservative approach2. VPT can be realized with a one-stage protocol, when during a chairside session the biomaterial is positioned under the definitive restoration, or with a two-stages protocol, when the biomaterial is positioned as temporary restoration during the first session, and partially replaced with a composite material on the second stage after 30–40 days3. In the past, the gold standard material to achieve success with this treatment was calcium hydroxide4, yet with difficult handling during clinical procedure9. In the last years, several materials were introduced to improve cell vitality but with low mechanical performances, such as mineral trioxide aggregate (MTA)6-8. Other silica-based or glass-ionomeric materials were also introduced to overcome this problem9.

Microleakage, defined as the passage of bacteria, fluids and ionic substances under the restorations, is an intrinsic problem of direct filling materials and is undetectable by X-ray analysis10. Some papers evaluated microleakage with bio-active materials for VPT only in primary teeth11,12, but there are histological differences between decidual and permanent teeth10. Microleakage is obviously associated with the presence of a so-called ‘gap’ at the interface between a restorative material and the residual part of prepared dental cavities14,15. This gap determines the adhesion of bacteria and their accumulation, resulting in the long term into plaque and tartar deposition and growth. The marginal gap can finally lead to microleakage15, allowing bacterial biofilm to enter the tooth cavity, giving rise to secondary caries16,17, and eventually dental pulp contamination, with failure of VPT procedures18. It is therefore necessary to characterize the marginal gap, in order to be able to assess which materials and/or techniques are able to accomplish the best results, corresponding to absent or minimized gap.

The point of properly defining the accordance between tooth and restoration at their interface is long-standing. Holmes et al. already pointed out that defining the misfit is probably more practical than defining the fit20, from which the concept of ‘gap’ followed. Some authors tried to assess the gap indirectly in terms of the resulting microleakage, pointed out as the most relevant effect of the gap in clinical practice21. For example Kim et al. evaluated the gaps, both internal and marginal, of restorative crowns22, by focusing on the changes occurring for metal-ceramic crowns after the different processing stages of selective laser sintering and porcelain firing. They defined the gap as the average distance in the space of the whole surface misfit, based on a ‘cloud’ of 67,491 distributed points obtained by computer CAD/CAM design and processing. However, despite the advanced 3D characterization, most considerations were made on the gaps measured between the silicone replicas of a titanium master tooth model and the model itself.

However, it appears important to define the
gap according to direct geometrical analysis of the restoration interface, providing a recipe to quantitatively evaluate the gap in reproducible and universal manner. Nevertheless, whereas this gap is qualitatively evaluated by dentists according to their clinical experience, it appears not trivial to define it accurately in terms of 3D morphology parameters. Already Holmes et al. noticed the difficulty in defining this misfit, depending on the different locations between tooth and restoration, and distinguished several different figures describing the marginal gap. The most notable ones were the internal gap, viz. the distance between materials on the inner side of the interface; the marginal gap, viz. the same distance at the edge of the inmost material border at the interface; and the absolute marginal discrepancy, viz. the distance between gap edges on both opposite material sides (see casting misfit terminology, according to ). However, the last is difficult to appreciate from a projected top-view optical image of the interface, and more often the marginal gap is used for assessing the amount of misfit, assuming the over/under-extension so limited in size to be negligible.

The direct 3D information on the gap impossible to obtain with a simple microscope can be obtained with a profilometer. Until a decade ago, only stylus profilometers were available, in which a tip was set in contact with the sample at given vertical load and was scanned along a line. By assembling several 1D scans into a 2D map of heights, one could get a 3D image of the surface. Nevertheless, physical contact is affected by possible sample or tip modification, and the resolution is dictated by the tip size, ~1 µm diameter. In this work, we used an optical profilometer, which allows for fast scan without sample and/or tip damage or convolution artefacts in the resulting images.

Clinically, the risk to obtain microleakage during Class II VPT restorations under gingival margin is a very common cause of difficulty of the procedure. A proper bio-material must guarantee a complete seal to avoid secondary carious processes. The goal of this study was both to define a new effective and efficient quantity describing the marginal gap with a single numerical value, and to evaluate the gap forming after the realization of Class II direct restorations in critical tooth areas by means of four specific restorative materials, as detailed in the Experimental section. After preparing the samples, we have measured the surfaces at the gap locations with innovative technology set by optical confocal profilometry. We have also worked on devising an effective and efficient definition of gap, based on a limited number of such measurable parameters, related with extensions both on the junction plane and in the normal direction. Then, from our 3D data we have extracted the values of the defined gap, and carried out statistical analysis thereof.

MATERIALS AND METHODS

Teeth source
All procedures performed in our study involving human participants were in accordance with the ethics standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The work was approved by Ethical Committee of Department of Surgical Sciences and Integrated Diagnostic, University of Genoa with registry number P.R. 270REG2017.

Five fresh molar teeth were used, which were taken from patients of Dr. A.I. The inclusion criteria were such that the subjects had to be subjected to dental extraction for clinical reasons. Subjects that did not give their consent to the use were excluded. The population to the study consisted in four people, without distinction of gender. We avoided people older than 65 years or younger than 18, as well as women using contraceptives or pregnant or during breast feeding period, as well as patients under relevant pharmaceutical treatment. After extraction, the teeth were immersed in sodium ipochlorite for 60 min, to remove the surface residuals of biological (organic) material (i.e. the periodontal ligament), and later kept in deionized (DI) water.

Treatment of personal data
The patients who took part in the study filled in the form for the treatment of personal data according to international rules. The forms filled in by the patients about informed consent and participation of their tissues in the study have been archived in the office of Dr. A.I., according to the laws about privacy, and they can be accessed only by the medical personnel of the dental office. Neither M.S. nor his institute knew anything about the subjects participating in the study, as the samples were received by them in anonymous form, without any chances of retrieving the sources. The data have not be communicated to third bodies. The results of the present study are published here in anonymous form, without including any personal information about the patients.

Cavity preparation
After extraction, cleansing and storage, A.I. prepared all the teeth removing the superior part of the cusps to obtain a calibrated length. A cylindrical diamond bur of 0.18 mm diameter and 6 mm length (code 6836.314.018 - komet) was used on a high speed hand-piece to obtain a calibrated class II cavity one on each of the four main sidewalls of the molar tooth (See Fig. 1a, b). The cavities extended longitudinally ~1 mm under the cement-enamel junction (CEJ) (Fig. 1b), such that it was possible to evaluate the marginal gap at both the enamel-restoration and the cement-restoration interfaces.

Restorative materials
On each tooth the restorative materials were divided in 4 groups: Biodentine (B), Geristore (G), Self etch adhesive system with composite without dentin orthosporic acid pre-treatment (SE) and a total etch adhesive system with composite restoration with the role of control (C). Details about the restorative materials can be found in Table 1.
All manufacturing process has been carried out by F.V., as an expert operator, with the same or equivalent technique when using the different restorative materials, always in accordance to the directions specified by the manufacturer in the respective instructions. After the filling step completed, all the samples were polished with diamond discs (Solfex Pop-on XT) and cleansed with a vapor device (Evolution-Silfradent). After restoration, the typical tooth appeared as in the sketch of Figs. 1a, b, where, looking at the tooth from the top (Fig. 1a), the four restorations have been identified with the short code for the respective restorative material, namely Biodentine (B), Geristore (G), composite without prior etching (SE), and composite (C), in clockwise order, starting from a p letter written on the tooth as a reference mark, meaning palatal position.

Before shipping to the measurement operator, the teeth were kept in physiologic condition at 37°C for approximately 7 days; then rinsed thoroughly in DI water (to avoid deposition of salt) and blown dry with clean compressed air. The samples were then packaged in a box avoiding contact of their surfaces of interest with the box walls.

Obviously the results of both cavity preparation and filling procedures are greatly influenced by the operator. However, since our interest is focused on the differences appearing among the restorative materials according to the defined gap, we let a single operator to carry out each of the above procedures, to avoid variations in this respect. Both our operators are highly skilled, according to the best standards of training and experience among dentists in our country, and can be assumed to represents closely the typical work done in the average private practice workshops in Italy.

**Morphological measurements**

When received, the samples were stored in ambient air at room temperature. For each one, immediately before measurement, the surfaces were blown dry from ambient

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![Fig. 1 Sketch of the cavities prepared on each of the 5 teeth, and then restored with the 4 different materials, with short-form names of B (Biodentine), G (Geristore), self-etching composite system (SE), composite with prior standard etching (C). a) top-view, b) side-view.](image)

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### Table 1 Restorative materials tested in this study with respect to their marginal gap formed versus the native tooth tissue, either enamel or cement

| Material (short name) | Type | Manufacturer (Lot no.) | Procedure |
|-----------------------|------|------------------------|-----------|
| Biodentine (B) | Bio-silicate Portland cement | Septodont (B21007) | Capsules were mixed with 5 liquid drops and inserted into the cavity with a plastic carver. The matrix was removed after 20 min and the finishing and polishing procedure was completed. |
| Geristore (G) | Resin modified glass ionomer | DenMat (1602800007) | The filling material was positioned into the cavity and, after 10 s, a light curing lamp was used to complete its polymerization. The matrix was removed and the finishing and polishing procedure was carried out. |
| iBond Universal+ composite (SE) | Acetonic-based self etching bond system | Kulzer (K010008) | After the cavity preparation, self-etch bonding agent was used without Phosphoric acid and a light curing lamp was used for 20 s to complete polymerization. The matrix was removed and the finishing and polishing procedure was carried out. |
| V2+composite (C) | Water based bonding system | Kuraray (5F0004) | Phosphoric acid was used on the dentine surface for 15 s and washed for 30 s. The surface was dried for 15 s and the Primer A+B was used as per manufacturer instructions. The Bond A application was achieved and a light curing lamp was used for 20 s to complete polymerization. The matrix was removed and the finishing and polishing procedure was carried out. |
| Composite(s) used for cases SE and C | Venus Diamond Flow; Venus Pearl | Heraeus Kulzer (K000215 and 010029A, respectively) | Venus Diamond Flow was the liner placed immediately on the adhesive system, while Venus Pearl was the paste used for the bulk of restoration |

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moisture by flowing dry nitrogen for ~20 s.

The 3D maps of relative height at the tooth-restoration interfaces have been carried out by means of an optical profilometer Zeta-20 by Zeta instruments, a company of KLA (CA, USA). The instrument works based on the confocal principle, and was run with an optical objective with 20× magnification and numerical aperture. In these conditions, we had a diffraction-limited lateral resolution of ~400 nm, and a vertical resolution of ~500 nm, with a field of view (FOV) of 664×498 µm². The single 3D map was acquired in a time of ~30 s.

The acquisition scheme is represented in Fig. 2a, where an image of a restoration at a low resolution (large FOV) obtained with a stereomicroscope is shown, for illustrative purposes. The dashed yellow and red lines identify the approximate positions of the interfaces between native tooth tissues —enamel and cement— and restoration, called er and ec, respectively. The dashed black line identifies the CEJ. Because we were interested in evaluating the marginal gap at both interfaces of enamel-restoration (er) and cement-restoration (cr), we acquired our 3D images close to the ideal CEJ line, which was crossed by the restoration. For each restoration, on each type of interface we acquired four images, termed 1–4. Figure 2b shows the top-view of the one of the 3D images obtained by the Zeta profilometer, on a single restoration as in Fig. 2a (it is a ‘cr2’ region).

At the end of the study, the samples have been disposed of in the institute of M.S., according to the rules of law for biological materials of human origin.

**Analysis of raw data and operative definition of gap**

On each single tooth-restoration pair, from each of the four images representing the two interfaces (er and cr), we traced ten cross-sections across the respective interface. Each profile was ~300 µm long, and we assumed it to be ~100 µm on either side on the respective materials (e.g. 'e' on the left side and 'r' on the right side, for the 'er1' image in Fig. 1), and the central ~100 µm to be associated with the actual junction, where the gap is expected to occur. We determined the 1D RMS roughness parameter Rq, on each of the two ~100 µm-long pieces representing each material on the opposite sides of the margin. These quantities are called with the respective additional index identifying the interface, Rqe and Rqr in the considered case. Here the possible difference between
the means of the two top levels on the opposite sides of the interface (i.e. if the 'casting' restorative material can be under- or over-extended with respect to the tooth is not considered, as we cannot know the exact position of the materials in depth, under the top surface, and in any case we rather focus on the concept of gap as a local void of materials, whose depressions will favour bacterial colonization. Since the above amplitude parameters represent the variation in relative height due to the simple surface top roughness alone, obviously there is no real gap associated with the respective (er) interface, if all the steps remain within a given difference from this limit. Actually, we assumed a definition of gap occurring when the step-height at the interface edge surpasses five times the highest $R_q$ on either side of the interface. For example in the case shown in Fig. 2, the cross section no.1 showed a gap, because the $R_q$ on either sides was $R_{q1r} = 5.12 \mu m$ and $R_{q1e} = 2.36 \mu m$, so the minimum threshold for the edge step-height to be defined a real gap was assumed to be $5 \times 5.12 \mu m = 25.6 \mu m$, and the maximum depression actually visible at the edge — i.e. inside the transition region— measured ~38 \mu m. On the contrary, for profile no.5 in Fig. 2, it was $R_{q5r} = 0.92 \mu m$, $R_{q5e} = 5.06 \mu m$, and the depression at the edge was ~22 \mu m < 5 \times 5.06 \mu m = 25.3 \mu m$.

While our vertical height threshold identifies an occurring gap and also partly quantifies for its amount, it is however not considered to be sufficient to fully quantitatively describe the gap. In addition to the vertical direction, the in-plane extension perpendicular to the edge interface has to be considered as well. Obviously, a gap is more relevant and represents a more serious problem when it also extends much laterally, meaning that a gap of e.g. $30 \mu m$ depth and $10 \mu m$ width is less serious than a gap both $30 \mu m$ deep and $30 \mu m$ wide. We therefore decided to consider the product of depth $d$ and the square root of width was a figure of merit for the gap “intensity” $g$, see Fig. 3 (for deeper considerations, see Discussion).

**Statistical analysis**

For each type of interface (er and cr) and for each type of restorative material (MTA, B, G, BA), on the $g$ values obtained as described in the former Section, in the maximum number of $n=10$ profiles/image (if the gap occurs and so is defined for all profiles) $\times 4$ images/tooth $\times 5$ teeth $= 200$, the mean values have been considered representative, with error bars extending one standard deviation above and below the means. The differences among the means have been tested for statistical significance according to ANOVA, with pair comparisons based on Tukey test, and significance level $\alpha = 0.05$.

**RESULTS**

We remind here that Table 1 contains the full description of the used materials, whereas Fig. 1 shows the positions of the dental cavities filled, and identifies the respective materials placed therein. A single case of raw data in the form of a 3D profilometer image, with the consequent analysis in terms of 1D cross-section profiles, is shown in Fig. 2. Occasionally, there appeared to be some residuals of dried abrasive paste mixed with abraded material (smear layer), resulting after the polishing with rubbers. In those cases, this material, which hid the real surface, was removed by washing out in ethanol and DI water, under mild sonication in a bath for 30 s at each step, before being blown dry by nitrogen.

It should be considered that Fig. 2 is still given as a piece of information describing the method used in this work, rather than the final results. For this reason, we did not care about expanding the table of profile parameters in panel 2d up to a level allowing to read the single numbers, as the illustration is intended solely to show the flow of information being processed in the work.

The optical confocal profilometry adopted here can also be affected by artifacts such as contact profilometry or atomic force microscopy (AFM), due to different refractive index of the scanned material, in case of inhomogeneous surfaces. However, for obvious esthetical reasons the restorative materials usually match closely the optical properties of the tooth tissue, and thus major artifacts can be excluded. On the other hand, sometimes it was hard to recognize the interface between adjacent materials. However, the roughness contained in the 3D information helped us to identify the lateral position of the gaps.

On each of the profiles like those shown in Fig. 2, the analysis as described previously, to assess if a gap there exists along the same profile, was carried out. In that case, for each profile showing a gap, a $g$ value as defined in Section 2 was calculated. The numerical values are summarized in Table 2 and are presented graphically in Fig. 4. In Table 2, $n_g$ is the number of profiles —among
Fig. 4 Results of the present analysis: the columns represent the means and the error bars the standard deviations for the gap ‘intensities’ of all cases of four restorative materials and two interfaces. The pairs with statistically significant difference are identified by joining lines with * (p<0.05).

Table 2 Results of the present analysis: the means and the standard deviation (after the±sign) are reported, for the gap ‘intensities’ of all cases of four restorative materials and two interfaces. ng is the number of profiles, out of 200, which showed an actual gap.

| Material: | B (er) | B (cr) | G (er) | G (cr) | C (er) | C (cr) | SE (er) | SE (cr) |
|-----------|--------|--------|--------|--------|--------|--------|---------|---------|
| g (µm)    | 86±53  | 118±40 | 152±75 | 137±56 | 71±39  | 69±38  | 38±52   | 47±36   |
| ng        | 21     | 45     | 60     | 54     | 39     | 42     | 34      | 29      |

One of the most recently used techniques for 3D direct microscopy of dental surfaces is AFM. However, while the spatial resolution of AFM is high, the scope is limited. Therefore, the AFM is more used to obtain detailed information on uniform surfaces, such as those od implants or restorative materials, aiming to characterize the roughness. When even decreasing the resolution down to the level assumed as a target in this work, with AFM we would acquire only a maximum scan area of 100×100 µm², with a similar lateral resolution (390 nm in the case of 256×256 pixels) and much better vertical resolution (~1 nm), yet with much longer acquisition time (21 min at 0.2 Hz scan frequency requested for the given scan size). Additionally, the vertical range would be limited, typically ~10 µm, which instead is virtually unlimited on the profilometer (>100 µm). Furthermore, the physical contact between tip and surface may result invasive for both sides, and prevent measuring in recessed regions, where the tip sidewalls touch.

It should be mentioned here that we also tried 3D measurements by stylus profilometry, which is similar in concept to contact mode AFM. In Fig. 5 one can see a 3D image of a restoration edge obtained by scanning a series of 2 mm long profiles at a spacing of 5 µm, and assembling them into a single 2D map of height. Above all, the scan was so slow (~10 h) to require overnight run for a single specimen. Obviously, this approach is not viable for a large number of specimens and/or regions of interest.

Nawafleh et al. reviewed different methods to measure the marginal adaptation of crowns and fixed dental prostheses, in the period 1970–2011, for a total of 183 papers. Direct view methods were used in 47.5% of cases, while cross-sectioning methods followed (23.5% cases), and then the use of impression replicas (20.2%). Micro-CT also started to be used in the area (1.6%). The marginal gap length observed varied largely from 7.5 to around 200 µm. The authors noticed as a source of variations the type of study, if in-vivo or in-vitro. However, much variation could be due to the uneven definition of marginal gap.

More recently, Parameswari et al. compared marginal fit and tensile strength of metal crowns cemented by using different luting agents. The gap between the margin of the cast metal crown and the...
Fig. 5  a) Example of image made with a contact profilometer. Acquisition required ~10 h, so it was started in the evening and done overnight. Only assembly of the lines for rendering required ~10 min. In the same latter time (~10 min), a typical whole optical profilometer scan with similar area was taken as in b) (same image is shown as in Fig. 1b, yet rendered as 3D here). With times on 1 h scale, a much larger area than in b) can be scanned, up to the total region of a restoration as shown in c), when stitching several single FOVs (here 3x3), without loss of resolution.

finish line was measured using a travelling microscope before and after cementation. It appeared that for the cement strength: resin>zinc phosphate>glass ionomer>zinc polycarboxylate; while for the gap: zinc phosphate>resin>zinc polycarboxylate>glass ionomer. This was called cement “thickness”, as assumed to be the reason for large marginal gap. No clear negative correlation between strength and marginal gap was found.

Gamarra et al.15) investigated instead the quality of the margins of a bulk-fill composite restoration, carried out with different photo-polymerization techniques. They used Class II cavities, and a total of 40 teeth, distributed in groups after four polymerization protocols, with different irradiance and exposure time. The restoration interfaces were analyzed with SEM on replicas, for both pristine and thermally aged interfaces. Microleakage was assessed and evaluated with qualitative (rank) marks, at both enamel and dentin interfaces, similar to our work in resolution (magnification 200x) yet without 3D measurement. The values were expressed as a percentage of the continuous margin over the total margin length for the occlusal (buccal and lingual) and cervical (distal and mesial) margins. The percentage of non-continuous margin before thermos-cyclying varied between 7% and 0.7% for occlusal, and 0% and 34% for cervical, showing significant difference due to the polymerization technique. Additionally, the microleakage was evaluated, after immersing in a dye and exposing to fluorescent light to assess the extent of dye penetration, which was scored qualitatively. However, the correlation between the two types of observations was not clear.

Groten et al. aimed to identify the minimum number of misfit measurements required to possibly provide a valuable and robust evaluation thereof35). They used SEM to evaluate the gap at the margin of ceramic crowns. They used three different gap definitions all similar to the marginal gap of Holes et al., and measured them every 100 µm along the interface. By starting with 230 measurements for each tooth, assumed to be fully representative, and progressively decreasing the number, they observed at what point a deviation in apparent results emerged. It appeared that 50 measurements were still consistent with the largest number, while below 20 measurements the standard error increased exponentially, above the assumed tolerance limit of ±0.5 mm.

Cervino et al. also measured the gap by SEM at endodontic interfaces14). MTA cement, as the best current sealing material, was used for filling the root channel,
in combination with different polymeric bonding agents. Interestingly, the authors set a threshold below which no gap was assumed, corresponding to edge regions with a minimum in-plane size of 5 µm gap and 20 µm length. The observed mean gaps were between 13 and 6 µm.

With our measurements we pointed to assess the internal gap, in the absence of true marginal gap at the corner of a turning-around interface edge. However, in addition to the projected distance or real (inclined) distance (absolute marginal discrepancy), which is made possible to evaluate by the acquisition of the 3D interface morphology, we set our own definitions of gap. When one has in mind the issues of bacterial colonization, in addition to the local high spatial frequency roughness at the gap, it is assumed that also the vertical extension of the gap, a measurement of the over/underexposed joint, is of critical importance. However, there may be not a net over or underexposure, but rather a pit at the gap (as well as a mountain, eventually), which will also affect the overall surface area available for bacterial adhesion, and effective roughness or lower spatial frequency waviness or form of the margin itself. Luckily, it is possible to evaluate all these quantities — and many more, if required — when having the 3D surface of the interface zone, as obtained by 2D profilometry.

Our gap is defined as a negative vertical depression, and we do not reveal a gap in case when the edge presents an elevated ridge. While this could also give rise to bacterial adhesion and accumulation, it is speculated that a protruding asperity at the edge be less detrimental in the long term, and have a fate to be decreased after normal abrasion during mastication and during toothbrushing, which is not the case for recessed regions. On the other hand, our definition of gap takes into account also the lateral extension. Of course, the length of the gap along the interface edge is also of importance. However, this is intrinsically considered when averaging among the different profiles. Thus, we could have simply considered the product of both gap depth d and width w, as a kind of gap cross-sectional area. Nevertheless, the depth remains the key and most important quantity, which would not be accounted for when considering the dw product only, as a gap with e.g. d=30 µm and w=10 µm would in that case score the same as a gap with w=30 µm and d=10 µm. To avoid this, we defined as the single gap score g the product of d and w, yet with some depressed weight for w, obtained by including w with a power less than unity, e.g. 1/2. Therefore, our gap “intensity” was defined as g=d^w/v. In this case, a gap with d=30 µm and w=10 µm scores g=94.9 µm^1.5, while d=10 µm and w=30 µm score g=54.8 µm^1.5, little more than one half as much. If both d and w were 30 µm, it would be g=164.3 µm^1.5, obviously stronger than both cases above. The plot of g as a function of both d and w in the space of these quantities, for reasonable ranges such as d=[0.100 µm] and w=[0.100 µm], is presented in Fig. 3.

The results obtained for the four different types of restorations investigated, allowed us to make the following considerations. Whereas VPT treatment in one stage would be convenient vs the two stages treatment^38^, it is confirmed here what is in clinical evidence, namely that the risk of failure in this case is still high. Not only the used materials have to be biocompatible to avoid irreversible pulpar inflammation — and show high mechanical properties— to resist to masticatory forces during the minimum 40 days period^36,37^ necessary for formation of the dentinal bridge^38,39^, But also a minimum gap between the materials and cementum/dentine is necessary during the healing period, to avoid a new bacterial infection. In this study, both the analyzed materials (B and G) intended for VPT showed a higher marginal gap than composite materials. Therefore, clinically the suggestion is that during a deep second class carious process where a VPT is necessary, to avoid a new bacterial infection a composite build up on the margin with self-etch adhesive system is necessary, before finishing the VPT with new generation materials.

CONCLUSION

Within the limitations of the present work, we can draw the following conclusions. We defined a novel quantitative expression for the marginal gap that should account for the complexity of its shape, comprising both the longitudinal extension at the top and the vertical depth. We measured the 3D surfaces at the interfaces of both cr and er interfaces, and extracted the above mentioned figure of merit for the marginal gap. Our definition of gap does not pretend to be the conclusive one; yet, with a 3D map available of all the gap region, for sure even more refined definitions of gap, along with other useful morphological information, will be accessible, in the future, by fast-scanning non-invasive large-scope optical profilometry. Among the four restorative materials investigated, G and B were both worse than the standard composite, with etching or self-etching preparation system. As a consequence of these results, the indication is that the novel materials intended for VPT in one stage treatment are not yet mature, and during treatment of deep second carious processes, the use of composite on the margin with a self-etch adhesive system is recommended.

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