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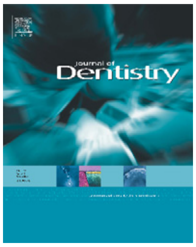

Cuspal deflection and microleakage in premolar teeth restored with bulk-fill flowable resin-based composite base materials

A. Moorthy [a], C.H. Hogg [a], A.H. Dowling [a], B.F. Grufferty [b], A.R. Benetti [c], G.J.P. Fleming [a,]*

[a] *Materials Science Unit, Division of Oral Biosciences, Dublin Dental University Hospital, Trinity College Dublin, Ireland*
[b] *Division of Restorative Dentistry & Periodontology, Dublin Dental University Hospital, Trinity College Dublin, Ireland*
[c] *Department of Dental Materials, School of Dentistry, University of Copenhagen, Denmark*

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ABSTRACT

Objectives: To assess the cuspal deflection and cervical microleakage of standardised Class II cavities incrementally filled with a dimethacrylate RBC or bulk-fill flowable RBC bases.

Methods: Twenty-four sound upper premolar teeth with Class II cavities were allocated to three groups ($n = 8$). Restoration of the teeth involved the placement of an RBC (GrandioSO) in eight oblique increments (Group A) or Groups B and C were restored to within 2 mm of the palatal cusp in a single increment with bulk-fill flowable RBC bases (SDR and x-tra base) before the two occlusal cavity increments were placed with GrandioSO. Buccal and palatal cusp deflections were recorded postirradiation using a twin channel deflection measuring gauge. Following restoration, the teeth were thermocycled, immersed in 0.2% basic fuchsin dye for 24 h, sectioned and examined for cervical microleakage.

Results: The mean total cuspal deflection for the oblique incremental restoration technique was 11.26 (2.56) μm (Group A) and 4.63 (1.19) μm (Group B) and 4.73 (0.99) μm (Group C) for the bulk-fill flowable RBC bases. A significant increase in the mean total cuspal deflection for the incrementally filled GrandioSO compared with the SDR ($P = 0.007$) and x-tra base ($P = 0.005$) restored teeth was evident. No significant difference in the cervical microleakage scores was recorded between groups AC ($P > 0.05$).

Conclusions: The bulk-fill flowable RBC bases significantly reduced cuspal deflection compared with a conventional RBC restored in an oblique incremental filling technique with no associated change in cervical microleakage recorded.

1. Introduction

Since the first successful resin-based composite (RBC) material was reported by Bowen in the early 1960s,[1] manufacturers have attempted to improve the physical and mechanical properties of RBC materials.[2,3] The free radical polymerisation of methacrylate RBC materials is associated with a post-gel contraction[4] which is constrained by the adhesive bond at the tooth/RBC interface, manifest as shrinkage stress.[5] The synergism at the tooth/RBC interface may be compromised by the shrinkage stress generated on light irradiation[4] thereby increasing the potential for mechanical failure by allowing the ingress of bacteria,[5] ultimately leading to secondary caries,[5–7] pulpal inflammation,[6] necrosis[7] or postoperative sensitivity.[3] RBC manufacturers have made significant developments to

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* *Corresponding author at*: Materials Science Unit, Dublin Dental University Hospital, Lincoln Place, Trinity College Dublin, Ireland. Tel.: +353 1 612 7371; fax: +353 1 612 7371.
E-mail address: garry.fleming@dental.tcd.ie (G.J.P. Fleming).

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reduce the shrinkage stress generated on light irradiation and today dentistry boasts RBC filler technology that encompass nanotechnology[8] and non-methacrylate based monomeric resin formulations.[9]

The filler loading of modern day RBCs often exceed 60% filler volume fraction[10] by employing nanoparticles in conjunction with larger filler particles which results in reduced shrinkage stress generated following light irradiation.[11] Prior to the development of non-methacrylate based monomeric resin formulations in 2000,[9] manufacturers tended to concentrate on reducing the shrinkage stress by limiting or eliminating the diluent (triethyleneglycol dimethacrylate (TEGDMA)) from the monomeric resin formulations.[12] Alternative methacrylate resin-based monomers were used in RBC formulations resulting in RBCs with reduced volumetric shrinkage[13] compared with Bowens original formulation[1]. However, whilst the mechanical properties (strength and elastic modulus) of the recent RBC formulations have improved steadily with increasing filler volume fraction[14] and the volumetric shrinkage has been reduced over time by the elimination of TEGDMA,[12] doubts still exist as to the clinical relevance of a reduction in volumetric shrinkage in terms of RBC performance in the ‘real-world’ of dentistry.[15] Shrinkage strain and/or shrinkage stress measurements[16] are routinely employed during and following light irradiation of RBCs[3,5,11] and the techniques used include the linometer[17] or ‘bonded-disk’[18] methods. However, none of these in vitro methods provide a prediction of clinical performance[19] and the important question is how the measurement of polymerisation shrinkage stress in vivo at the tooth/RBC interface could be performed in a ‘clinically meaningful context’?[20]

The assessment of cuspal deflection during RBC restoration of Class II, mesio-occlusal–distal (MOD), cavities has been extensively investigated in the dental literature using a variety of techniques including photography,[21] microscopy with cuspal indices alignment,[22–24] strain gauges,[25–27] linear variable differential transformers,[28–30] interferometry,[31] profilometry,[32–34] digital-image-correlation[35] or electronic speckle pattern interferometry.[20] Mean cuspal deflections of up to 50 μm were recorded using the range of techniques highlighted,[20–35] however, difficulties were apparent in the methodological approaches employed most notably in the size of the teeth (maximum bucco-palatal-width: BPW), tooth type (molar or premolar) and restoration technique (bulk or incremental) which were often not standardised.[20–35] Therefore, variations in the previously reported cuspal deflection measurements were often due to non-standardised MOD cavity preparations in non-standardised teeth[36–41] since contraction of the cusps is dependent upon the remaining tooth structure following cavity preparation.[30,35,42]

Previously, one of the authors assessed the cuspal deflection of a range of RBC materials following light irradiation using a standardised experimental methodological approach.[36–41] Light irradiation technologies (quartz tungsten halogen (QTH)[37] or light emitting diode (LED)[39]), light irradiation techniques (conventional[37] or soft-start[40] QTH irradiation), RBC placement techniques (bulk fill[36] or incremental placement[37–40] or the use of an intermediary flowable layer[41]) were considered using the standardised methodological approach. The oblique incremental restoration technique[36–41] involves three triangular-shaped increments (approximately 2 mm thickness) for the mesial approximal box, three increments for the distal approximal box and two increments for the occlusal cavity. However, the restoration of large Class II MOD restorations with RBC materials using the oblique incremental restoration technique is time consuming in terms of the time taken to place and light irradiate each increment notwithstanding the operator time required for separate etching, priming and bonding techniques.[36]

Recent advances by manufacturers have resulted in bulk-fill flowable RBC bases being marketed for use beneath conventional RBC materials,[43,44] with a reported depth of cure in excess of 4 mm.[45] Whilst the manufacturers claims that the modified methacrylate resin has a slow polymerisation rate[46] through the use of a polymerisation modulator,[47] the filler content is reported as 68 wt% for SDR (Dentsply Caulk, Milford, DE, USA)[47] and 75 wt% for x-tra base (Voco GmbH, Cuxhaven, Germany).[44]

Technically, the three triangular-shaped increments for both the mesial approximal and distal approximal boxes could be completed in a single increment with the bulk-fill flowable RBC bases and the remaining two increments for the occlusal cavity would be performed as normal with the conventional RBC. Therefore, the aims of the current study were to assess the cuspal deflection of standardised large MOD cavities incrementally filled with a conventional dimethacrylate RBC or with bulk-fill flowable RBC bases using a twin channel deflection measuring gauge. The cervical microleakage of the restored teeth following thermocycling was also assessed to determine marginal integrity. The hypothesis proposed was the bulk-fill flowable RBC bases would have reduced cuspal deflection and cervical microleakage compared with the conventional dimethacrylate RBC light irradiated in eight oblique individual increments using a QTH light curing unit (LCU).

2. Materials and methods

On visual examination, 24 maxillary premolars free from caries, hypoplastic defects or cracks, had all calculus deposits removed with a hand-scaler. The maximum buccal–palatal-width (BPW) of each maxillary premolar was measured with a digital micrometre gauge (Mitutoyo, Kawasaki, Japan) with a tolerance of 10 μm and the teeth were distributed into three groups ($n = 8$) such that variance of the mean BPW between groups was less than 5%.[36–41] The maxillary premolars were fixed crown uppermost and long axis vertical using a chemically activated orthodontic resin (Meadway Rapid Repair, MR Dental Supplies Ltd., Surrey, UK) into a cubic stainless steel mould (15 mm^3 dimensions with a central hole of 12 mm diameter). The orthodontic resin extended to within 2 mm of the amelocemental junction (ACJ) and the maxillary premolars were stored in 0.5% chloramine solution 23 ± 1 °C until they were required for cavity preparation.

Each tooth was prepared with copious water irrigation for a large standardised MOD cavity in accordance with the cavity preparation technique reported previously[36–41] where the width of the approximal box was two-thirds the BPW of the maxillary premolar. The occlusal isthmus was prepared to half the BPW with the cavity depth at the occlusal isthmus standardised to 3.5 mm – from the tip of the palatal cusp and 1 mm above the ACJ at the cervical aspect of the approximal boxes. The cavosurface margins were prepared at 90° and all internal line angles were rounded. The prepared maxillary premolar teeth were stored in high purity double distilled water at 23 ± 1 °C unless aspects of the experimentation required moisture isolation.

Following cavity preparation the tooth surfaces were prepared for bonding with a three-step adhesive (All-Bond 2® Dual-Cured Universal Adhesive System, Bisco Inc., Schaumburg, IL, USA).[48] Firstly, the MOD cavity preparation was air-dried for 30 s, prior to the application of 37% phosphoric acid etching gel (Preparator, Ivoclar Vivadent, Schaan, Lichtenstein) for 15 s before rinsing with water. Following a light drying with compressed air for 1 s, five consecutive coats of the primer (a mixture of All-Bond 2® Universal Dental Adhesive System Primer A (Ref B-2511, Lot 1000007217) and All-Bond 2® Universal Dental Adhesive System Primer B (Ref B-2512, Lot 1000007218)) was applied with a saturated brush tip until the surface appeared glossy. The primer mixture was lightly dried with compressed air for 2–3 s. A thin layer of bonding resin (D/E Resin, Ref B-2502A, Lot 1000007219) was applied to the primed enamel and dentine and light irradiated for 20 s with a QTH LCU (Optilux 501, Kerr Mfg. Co., Orange, CA, USA) operating in standard mode at a light intensity of 670 ± 36 mW cm^{-2}.

Group A maxillary premolar teeth were incrementally restored with GrandioSO (Shade A3, Lot 1103238) RBC (Voco GmbH, Cuxhaven, Germany). The oblique incremental restoration involved three triangular-shaped increments (approximately 2 mm thickness) for the mesial approximal box, three increments for the distal approximal box and two increments for the occlusal cavity.[36–41] The maxillary premolar teeth in Groups B and C were restored to within 2 mm of the palatal cusp in a single increment with SDR or x-tra base. The remaining two increments for the occlusal cavity were placed as triangular-shaped increments (approximately 2 mm thickness) with the GrandioSO RBC.

2.1. *Cuspal deflection*

Prior to RBC placement a Tofflemire matrix band was shaped and placed around the tooth such that the buccal and lingual cusps of the maxillary premolar teeth freely contacted the receptors of a twin channel deflection measuring gauge (Twin Channel Analogue Gauge Unit, Thomas Mercer Ltd., St. Alban's, UK). The palatal measuring gauge was placed 2.5 mm from the palatal cusp tip[36–41] and a baseline measurement was recorded. For Group A maxillary premolar teeth, each increment was irradiated for 20 s with the LCU tip diameter maintained 2 mm above the cusp tips. Cuspal deflection measurements were recorded at the end of the 20 s irradiation (at 0 s) and further measurements were made at 30, 60 and 180 s. Eight cuspal deflection measurements (one for each increment) were recorded for the buccal and palatal cusp of each premolar tooth in Group A. For the maxillary premolar teeth in Groups B and C, a single bulk-fill flowable RBC base increment was irradiated for 20 s with the LCU tip diameter again maintained 2 mm above the cusp tips. Cuspal deflection measurements were recorded at the end of the 20 s irradiation (at 0 s) and following additional measurements at 30, 60 and 180 s. Two additional cuspal deflection measurements (one for each occlusal cavity increment) were made for the buccal and palatal cusp of each tooth in the SDR (Group B) and x-tra base (Group C) restored teeth.

The authors assumed no cuspal recoil of the buccal and palatal cusp deflections beyond 180 s for each increment and the combined total cuspal deflections, namely the sum of the buccal and palatal cusp deflections, was calculated for each maxillary premolar tooth examined. A one-way analysis of variance (ANOVA) was conducted ($P < 0.05$) using SPSS 12.0.1 software (SPSS Inc., Chicago, IL, USA) to determine differences in the mean total cuspal deflections between groups.

2.2. *Cervical microleakage assessment*

The restored maxillary premolar teeth were polished using a slow hand-piece under water with Sof-Lex Finishing discs (3M ESPE, St. Paul, MN, USA) and 15 μm grit Composhape finishing diamond burs (Intensiv, Viganello-Lugano, Switzerland). The tooth surfaces were sealed with nail varnish (Rimmel 60 Seconds, London, UK) with the exception of a 1 mm band around the margins of each restoration surface. The root apices were sealed with sticky wax and the teeth were thermocycled. Thermocycling involved submerging the teeth for 10 s in water-baths maintained at 4 ± 1 and 65 ± 1 °C[49] with a 25 s transfer between water-baths for 500 cycles. The thermocycled teeth were immersed in 0.2% basic fuchsin dye for 24 h, before sectioning mid-sagitally in the mesio-distal plane using a ceramic cutting disc operating at a speed of 125 rpm (Struers, Glasgow, Scotland) with an applied load of 100 g. Sectioned restorations were examined under a stereo-microscope (Wild M3C, Heerburg, Switzerland) at 25× magnification. The extent of the cervical microleakage was recorded[36–41] where '0' was no evidence of dye penetration; '1' was superficial dye penetration not beyond the ADJ; '2' was dye penetration along the gingival floor and up to the axial wall; '3' was dye penetration along the axial wall and across the pulpal floor and '4' was dye penetration into the pulp chamber from the pulpal floor. A non-parametric one-way ANOVA (Kruskal–Wallis) test followed by paired group comparisons using Mann–Whitney *U* tests was conducted ($P < 0.05$) using the SPSS software to statistically analyse the cervical microleakage scores.

3. Results

3.1. *Cuspal deflection*

The mean BPW of the maxillary premolar teeth did not vary significantly between specimen groups ($P > 0.05$). Individual cuspal deflections for each tooth/RBC increment for the maxillary premolar teeth incrementally restored with GrandioSO (Group A) were combined for the data analysis. The mean total cuspal (buccal and palatal) deflection for the oblique incremental restoration technique[36–41] (three triangular-shaped increments (approximately 2 mm thickness) for both the mesial and distal approximal boxes and two increments for the occlusal cavity) was 11.26 ± 2.56 μm. Maxillary premolar teeth restored to within 2 mm of the palatal cusp in a single increment with SDR (Group B) or x-tra base (Group C) had mean total cuspal (buccal and palatal) deflections of 4.63 ± 1.19 μm and 4.73 ± 0.99 μm, respectively. The one-way ANOVA showed a significant increase in the mean total cuspal deflection for the incrementally filled GrandioSO compared with the SDR ($P = 0.007$) and x-tra base ($P = 0.005$) restored teeth. No significant difference in total cuspal deflection was evident for the SDR and x-tra base restored teeth ($P = 1.000$).

3.2. *Cervical microleakage assessment*

The cervical microleakage scores recorded for the conventional dimethacrylate GrandioSO RBC light irradiated in eight oblique individual increments and the two bulk-fill flowable RBC bases (SDR and x-tra base) are illustrated graphically using a box and whisker plot (Fig. 1) based on the median, quartiles, and extreme values. The box represents the inter-quartile range which contains 50% of the values, the whiskers represent the highest and lowest microleakage values and the bold black line across the box indicates the median microleakage score. The cervical microleakage scores recorded (Table 1) were subjected to a Kruskal–Wallis non-parametric one-way ANOVA and revealed no significant difference between groups A and C ($P > 0.05$).

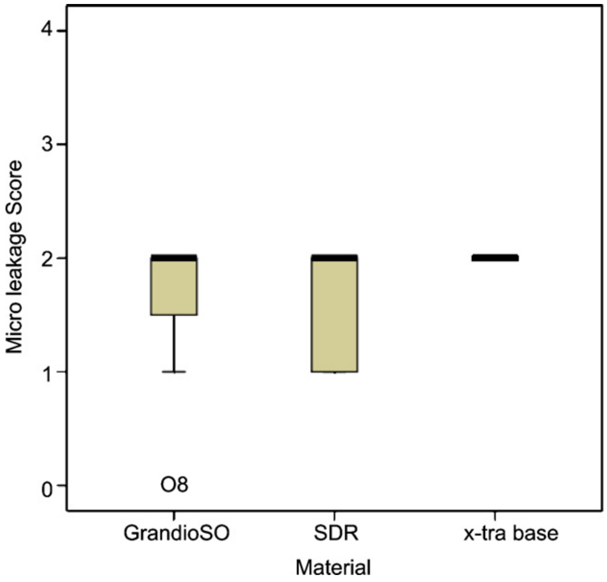

Fig. 1 – A box and whisker plot of the microleakage scores following cuspal deflection and thermocycling of the MOD cavities incrementally restored with GrandioSO compared with the SDR and x-tra base restored teeth. The plot illustrates a summary of the microleakage scores based on the median, quartiles, and extreme values. The box represents the inter-quartile range which contains 50% of the values, the whiskers represent the highest and lowest microleakage values and the bold black line across the box indicates the median microleakage score.

4. Discussion

In the current study, the Class II cavity design was chosen for RBCs[50–53] as it would weaken the remaining tooth structure to favour cuspal deflection and the cavity design was also indicative of a dental amalgam replacement cavity. The BPW of the premolar teeth in the study were standardised to within differences of a maximum of 5% between the teeth and were also standardised to within 5% differences of the teeth used in previous investigations[36–41] to ensure comparisons with previous cuspal deflection studies. The mean total cuspal (buccal and palatal) deflection for the maxillary premolar teeth incrementally restored with the RBC GrandioSO (Group A) was 11.26 ± 2.56 μm. GrandioSO RBC has similar monomeric resin constituents to Filtek™ Z250 and Filtek™ P60 (3M ESPE, St. Paul, MN, USA) and the cuspal deflection measurements reported previously[37] were 12.34 ± 2.18 μm for Filtek™ Z250 and 13.41 ± 4.43 μm for Filtek™ P60 which are higher than the 11.26 ± 2.56 μm reported for GrandioSO in the current study. It is suggested that the increased filler loading of GrandioSO (71.4% filler volume fraction)[54] resulted in the reduction in cuspal deflection measurement compared with Filtek™ Z250 and Filtek™ P60 which have filler volume fractions of 61 and 60%, respectively. The ability of the experimental approach to reproduce cuspal deflection measurements demonstrates the accuracy and reproducibility of the experimental set-up.

Interestingly, when the bulk-fill flowable RBC bases were used to restore the Class II cavities to within 2 mm of the palatal cusp in a single increment the mean cuspal deflections recorded were significantly reduced (SDR ($P = 0.007$) and x-tra base ($P = 0.005$)) compared with the oblique incremental filling technique when GrandioSO was employed. This finding is agreement with the groundbreaking paper of Versluis et al.[32] which dispelled the widely accepted belief of the time that an incremental filling technique reduced polymerisation stress generation[21,26,27] compared with bulk-filling MOD cavities. Not only did the paper by Versluis et al.[32] challenge the conventional wisdom regarding stress generation on polymerisation but the finite element calculations identified the oblique incremental technique to

Table 1 – The gingival microleakage scores for the eight MOD cavities restored in the current investigation with GrandioSO (Group A) compared with the SDR (Group B) and x-tra base (Group C) restored teeth.

Tooth	Degree of microleakage		
	GrandioSO RBC	SDR	x-tra base
1	2	2	2
2	2	1	2
3	2	2	2
4	1	2	2
5	2	2	2
6	2	2	2
7	2	2	2
8	0	2	2

produce the 'most severe stress concentration' at the tooth/restoration interface compared with a gingivo-occlusal incremental filling technique. Therefore the oblique incremental technique used to restore the MOD cavities with GrandioSO would have been expected to produce significantly higher cuspal deflection compared with the bulk-fill flowable RBC bases investigated.

One advantage of employing the bulk-fill flowable RBC bases to restore the Class II cavities, to within 2 mm of the palatal cusp in a single increment, is that the remaining cusp length is significantly reduced. Hood[42] suggested that an MOD cavity could be treated as a modified cantilever beam where the deformation is a cubed power of the length.[30,35,42] Reducing the cusp length therefore significantly reduces the deflection in a similar manner to where a resin-modified glass-ionomer is placed beneath a RBC.[25,55] Additionally, the placement of a large horizontal gingivo-occlusal increment also constrains both cusps simultaneously during light irradiation which further limits the overall mean deflection as suggested by Velsuis et al.[32] The authors suggest that the combination of the bulk-filling with the bulk-fill flowable RBC bases to within 2 mm of the palatal cusp in a single horizontal increment and the overall reduction in the cusp length for the remaining two oblique increments were responsible for the reduced cuspal deflection measurements (SDR ($P = 0.007$) and x-tra base ($P = 0.005$)) recorded compared with the oblique incremental technique used to restore the MOD cavities with GrandioSO. The authors also suggest that employing bulk-fill flowable RBC bases will reduce the operator time significantly owing to the reduction in the individual increments that are required to be placed and light irradiated during tooth restoration. However within the restrictive term bulk-fill, the materials (SDR and x-tra base) are essentially base layers[46] being mandatorily covered by a 2 mm thick surface layer of a methacrylate-based universal/posterior RBC.[56]

The Kruskal–Wallis non-parametric one-way ANOVA revealed no significant difference between groups A and C regarding the extent of the cervical microleakage recorded following sectioning of the restored premolar teeth mid-sagitally in the mesio-distal plane. This finding suggests no deleterious effect in employing the bulk-fill flowable RBC bases on the tooth/RBC restoration interface. Previously, when a similar experimental approach was examined to assess the extent of the cervical microleakage in bulk-filled RBC materials[36] the authors identified dye penetration into the pulp chamber from the pulpal floor which suggested the packable RBCs used[36] could not adequately be irradiated to 4 mm for the times specified by the manufacturers.

5. Conclusion

The current study showed that the bulk-fill flowable RBC bases investigated (SDR and x-tra base) significantly reduced cuspal deflection during light irradiation compared with a conventional RBC (GrandioSO) restored in an oblique incremental filling technique with no associated change in cervical microleakage recorded.

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