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Implications of resin-based composite (RBC) restoration on cuspal deflection and microleakage score in molar teeth: Placement protocol and restorative material

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ABSTRACT

Objective. To assess the cuspal deflection of standardised large mesio-occluso-distal (MOD) cavities in third molar teeth restored using conventional resin-based composite (RBC) or their bulk fill restorative counterparts compared with the unbound condition using a twin channel deflection measuring gauge. Following thermocycling, the cervical microleakage of the restored teeth was assessed to determine marginal integrity.

Methods. Standardised MOD cavities were prepared in forty-eight sound third molar teeth and randomly allocated to six groups. Restorations were placed in conjunction with (and without) a universal bonding system and resin restorative materials were irradiated with a light-emitting-diode light-curing-unit. The dependent variable was the restoration protocol, eight oblique increments for conventional RBCs or two horizontal increments for the bulk fill resin restoratives. The cumulative buccal and palatal cuspal deflections from a twin channel deflection measuring gauge were summed, the restored teeth thermally fatigued, immersed in 0.2% basic fuchsin dye for 24 h, sectioned and examined for cervical microleakage score.

Results. The one-way analysis of variance (ANOVA) identified third molar teeth restored using conventional RBC materials had significantly higher mean total cuspal deflection values compared with bulk fill resin restorative restoration (all $p < 0.0001$). For the conventional RBCs, Admira Fusion (bonded) third molar teeth had significantly the lowest microleakage scores (all $p < 0.001$) while the Admira Fusion x-tra (bonded) bulk fill resin restored teeth had significantly the lowest microleakage scores compared with Tetric EvoCeram Bulk Fill (bonded and non-bonded) teeth (all $p < 0.001$).

Significance. Not all conventional RBCs or bulk fill resin restoratives behave in a similar manner when used to restore standardised MOD cavities in third molar teeth. It would appear that light irradiation of individual conventional RBCs or bulk fill resin restoratives may be problematic such that material selection is vital in the absence of clinical data.

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1. Introduction

Patient demand for the delivery for tooth coloured teeth has driven the development of resin-based composite (RBC) materials and today there is increased usage [1,2] and teaching [3,4] of RBCs worldwide. From a materials science perspective, one of the major disadvantages of RBCs is the excessive shrinkage stress generation on light irradiation [5]. Depending upon the compliance conditions, dental manufacturers have with relative success, developed RBCs with reduced shrinkage stress by investigating beyond methacrylate monomeric resin-blends [6] and increasing the filler volume fraction with and without nanotechnology approaches [7]. However, from a clinical perspective, RBCs are technique sensitive even for experienced operators [8] and the time required to adequately place a posterior RBC restoration can be up to two and a half times longer than an equivalent dental amalgam restoration [9]. The increased RBC restoration placement time is accounted for by the adhesive system application, incremental RBC placement and light irradiation [9]. Manufacturers have recently reduced RBC placement times by marketing 1-step adhesive bonding systems to replace 3-step (gold standard) adhesives which included a separate etch with phosphoric acid and rinse (conditioning) step, a priming step before subsequent application of the adhesive [10,11]. Conventional RBC materials, where the depth of cure is limited to a maximum of 2 mm, require an incremental restoration technique [12–14] with the number of increments dependent upon cavity size and configuration [15]. The RBC monomeric resin-formulation [16] can significantly impact irradiation times (20–40 s) such that incremental RBC restoration is time consuming and costly to the patient [17]. Therefore, manufacturers' have marketed a range of bulk fill flowable base materials [18] and/or bulk fill restorative materials [19] to the dental market with reported depth of cure of 4 mm which significantly reduce RBC placement times. It is interesting to note the departure in thinking from a focus on reducing shrinkage stress generation in RBCs to ultimately employing RBCs with lower filler volume fractions and/or increased TEGDMA as bulk fill flowable base materials [20,21] or bulk fill restorative materials with novel chemistry [22,23].

The aims of the current study were to assess the cuspal deflection of standardised large mesio-occluso-distal (MOD) cavities in human maxillary and mandibular third molar teeth restored with conventional RBCs or their bulk fill resin restorative counterparts compared with the unbound condition using a twin channel deflection measuring gauge. Following thermocycling, the cervical microleakage of the restored teeth was assessed to determine marginal integrity. The hypotheses proposed were that there would be an increase in total cuspal deflection and concomitant decrease in cervical microleakage score for conventional RBC restoratives compared with their bulk fill resin restorative material counterparts.

2. Materials and methods

Caries-free, hypoplastic defect-free and crack-free human maxillary and mandibular third molar teeth, extracted for pericorinitis, periodontal disease or atypical facial pain reasons, were used in accordance with the ethical guidelines of the Trinity College Faculty Research Ethics Committee. The inclusion criteria for third molar tooth selection was the maximum bucco-palatal-width (BPW) of the teeth varied between 10.25–10.75 mm when measured with a digital micrometer gauge (Mitutoyo, Kawasaki, Japan) reading to 0.01 mm. In the dental literature, third molar teeth have increased anatomical variances compared with premolar teeth [24] and as a result form and shape inclusion criteria were also introduced so that only maxillary and mandibular third molar teeth with four cusps (two buccal and two lingual) were included in the study. When necessary evidence of calculus deposits were removed by hand-scaling prior to random distribution of the teeth into six groups (Groups A–F) with eight individual teeth assigned to each group (n = 8). The teeth were fixed, crown uppermost with the long axis vertical, into a cubic stainless steel mould facilitated by a cold curing denture base material (ProBase® Cold, Ivoclar Vivadent, Schaan, Lichtenstein) which extended to within 2 mm below the amelo-dentinal junction (ADJ) prior to storage in high purity double distilled water (23 ± 1 °C) until required for cavity preparation [24].

Standardised MOD cavities were prepared under copious water irrigation using an established clinical protocol previously employed for maxillary premolar teeth [25–36]. The width of the approximal box was standardised at two-thirds the BPW of the third molar teeth, the occlusal isthmus was prepared to half the BPW and the cavity at the occlusal isthmus standardised to a depth of 3.5 mm from the tip of the highest cusp with the proximal boxes extended to 1 mm above the ADJ and all cavosurface margins prepared at 90° with internal line angles rounded. Following preparation, the MOD cavity dimensions were checked with the digital micrometer gauge and the teeth were stored in high purity double distilled water at 23 ± 1 °C unless moisture isolation was required for aspects of the experimental protocol.

Groups A and D third molar teeth were rinsed thoroughly with high-purity double distilled water, air-dried for 30 s and restored in the absence of a bonding agent which served as the unbound conditions (negative control) for the experiment (Table 1). Groups A teeth were restored with Tetric EvoCeram RBC (Shade A3, Lot T04946; Ref. 590314WW: Ivoclar Vivadent) using the oblique incremental technique. This involved the placement of three triangular-shaped increments (~2 mm thickness) in the mesial proximal box (up to half the mesio-distal width of the third molar teeth), three triangular-shaped increments (~2 mm thickness) in the distal proximal box (up to half the mesio-distal width of the third molar teeth) and two further triangular occlusal increments (one buccal and one palatal). The teeth in Group D were restored using Tetric EvoCeram Bulk Fill (Shade IVA, Lot T02443, Ref 638244WW; Ivoclar Vivadent) and involved the placement of one increment for both the mesial and distal proximal boxes up to a maximum increment depth of 4 mm before the application of a final occlusal increment.

The teeth in Groups B-C and E-F were prepared for bonding with a 1-step dual-curing universal adhesive (Futurabond® U SingleDose (Ref 1574, Lot 1547600; Voco, Cuxhaven, Germany)) by firstly cleaning the MOD cavity preparations with high purity double distilled water, prior to air-drying for 30 s [37].

Table 1 – Mean total cuspal deflection (μm) with associated standard deviations for the appropriate resin restorative and/or restoration protocol investigated. Groups linked with the same superscript letter are not significantly different using one-way analyses of variance and post-hoc Tukey's tests.

Resin restorative group	Number of increments	Mean total cuspal deflection (μm)
Tetric EvoCeram RBC (non-bonded control) Group A	8	4.3 ± 1.3^a
Tetric EvoCeram RBC (bonded control) Group B	8	6.0 ± 2.0^a
Admira Fusion (bonded control) Group C	8	6.4 ± 2.8^a
Tetric EvoCeram Bulk Fill (non-bonded control) Group D	3	1.3 ± 0.5^b
Tetric EvoCeram Bulk Fill (bonded control) Group E	3	3.3 ± 0.8^b
Admira Fusion x-tra (bonded control) Group F	3	3.4 ± 0.9^b

The Futurabond® U SingleDose blister was activated and following thorough stirring with the supplied Single Tim applicator (Voco GmbH), the homogeneous adhesive mixture was rubbed into the enamel and dentin surfaces for 20 s using the Single Tim applicator brush [37]. The adhesive was air-dried for 5 s and light irradiated for 10 s using a bluephase® style (Ivoclar Vivadent) light emitting diode (LED) polywave technology light curing unit (LCU) operating at a irradiance of $1125 \pm 25\,mW/cm^2$ with a spectral range of between 320–520 nm as measured with a MARC patent simulator (BlueLight Analytics Inc., Halifax, Canada).

Futurabond® U SingleDose adhesively treated third molar teeth in Groups B and C were restored using the oblique incremental technique (previously described for Group A teeth). Group B teeth were restored with Tetric EvoCeram (Ivoclar Vivadent) RBC and Group C teeth with Admira Fusion (Shade A3, Lot 1545568) RBC (Voco GmbH). The Futurabond® U SingleDose adhesively treated teeth in Groups E and F were restored using bulk fill restorative materials (Group E: Tetric EvoCeram Bulk Fill (Ivoclar Vivadent) and Group F: Admira Fusion x-tra (Shade U, Lot 1537600; Voco GmbH)). The bulk-fill restoration technique involved the placement of one increment for the mesial and distal proximal boxes up to a maximum increment depth of 4 mm before the application of a second (final) occlusal increment.

Fig. 1 – Photograph of the twin channel deflection measuring gauge showing the buccal and lingual cusps of the tooth placed in contact with two Mercer 490 probes Baseline cuspal deflection measurements between different teeth were evaluated by placing the palatal Mercer 490 probe 2.5 mm from the cusp tips and before setting the gauge to zero. Each individual RBC increment was light irradiated for 20 s with the LED LCU tip maintained ~2 mm above the cusp tips with cuspal deflection measurements recorded up to 180 s following the initiation of light irradiation (at time intervals of 30, 60, 90 and 180 s).

2.1. *Cuspal deflection*

The buccal and lingual cusps of the third molar teeth were placed in contact with two Mercer 490 probes (Engineering & Gauge Ltd., St. Alban's, Hertfordshire, UK) connected to a twin channel deflection measuring gauge (Mercer 122L Twin Channel Analogue Gauge Unit, Engineering & Gauge Ltd.). A Tofflemire matrix band was shaped and placed around each tooth prior to RBC placement with significant care taken to ensure the receptors of the twin channel deflection measuring gauge were free to contact the buccal and lingual cusps of the teeth (Fig. 1). Baseline cuspal deflection measurements between different teeth were evaluated by placing the palatal Mercer 490 probe 2.5 mm from the cusp tips and before setting the gauge to zero. Each individual RBC increment was light irradiated for 20 s with the LED LCU tip maintained ~2 mm above the cusp tips with cuspal deflection measurements recorded up to 180 s following the initiation of light irradiation (at time intervals of 30, 60, 90 and 180 s). Previous investigations highlighted no cuspal recoil of the buccal and palatal cusp deflections occurred following 180 s post-irradiation [25–36]. The sum of the buccal and palatal cusp deflection measurements were calculated for each third molar tooth in the respective groups. Statistically significant differences in mean total cuspal deflection measurements between groups ($p < 0.05$) were determined using one-way analyses of variance (ANOVA) and post-hoc Tukey's tests [38] with SPSS Statistics V22.0 software (SPSS Inc., Chicago, IL, USA).

2.2. *Cervical microleakage assessment*

Cervical microleakage assessment of the restored teeth was performed following sealing of the root apices with sticky wax and all tooth surfaces with nail varnish (Rimmel 60 Seconds, London, UK) with the exception of a 1 mm band around the margins of each resin-restoration. The teeth were thermocycled between two water-baths ($4 \pm 1\,°C$ and $65 \pm 1\,°C$ [39]) for 500 cycles in accordance with the International Organisation for Standardisation Technical specification no. 11405 [40,41]. The teeth were submerged for 10 s in each water-bath with a 25 s transfer between baths before 24 h immersion in 0.2% basic fuchsin dye. The resin-restored teeth were mid-sagitally sectioned in the mesio-distal direction using a ceramic cutting disc (Struers, Glasgow, Scotland) at 125 rpm under a weight of 100 g. The sectioned teeth were examined under a Stemi 305 stereo-microscope (Zeiss MicroImaging GmbH, Jena, Germany) at ×25 magnification. The extent of the cervical microleakage was recorded as '0'—no evidence of dye penetration; a score of '1' was superficial dye penetration not beyond the ADJ; a score of '2' was dye penetration along the gingival floor and up to the axial wall; a score of '3' was dye penetration along the axial wall and across the pulpal floor and a score of '4' was dye penetration into the pulp chamber from the pulpal floor in accordance with a previously used protocol [25–36]. A Kruskal–Wallis test followed by paired group comparisons using Mann–Whitney U tests was conducted ($p < 0.05$) using the SPSS software (V22.0) to statistically analyse the cervical microleakage scores given the semi-quantitative non-parametric scale employed [38].

3. Results

3.1. *Cuspal deflection*

The variances of the cuspal deflection values for Groups A–F were homogeneous when tested using Levene statistics ($p > 0.562$). The one-way ANOVA highlighted statistically significant differences in mean total cuspal deflection measurements ($p < 0.0001$) between the groups tested (Groups A–F). For the conventional RBCs, the total cuspal movement for Tetric EvoCeram (bonded: 6.0 (2.0) μm; Group B) and Admira Fusion (bonded: 6.4 (2.8) μm; Group C) were not significantly different ($p = 0.997$) or was the total cuspal movement for the Tetric EvoCeram (no bond: 4.3 (1.3) μm; Group A) restored teeth ($p > 0.096$). When the bulk fill resin restoratives were employed there were no significant differences ($p = 1.000$) in total cuspal movement for Tetric EvoCeram Bulk Fill Restorative (bonded: 3.3 (0.8) μm; Group E) and Admira Fusion x-tra (bonded: 3.4 (0.9) μm; Group F) or the Tetric EvoCeram Bulk Fill Restorative (no bond: 1.3 (0.5) μm; Group D) restored teeth ($p > 0.125$). Interestingly employing conventional RBC materials eight oblique increments had significantly higher mean total cuspal deflection values (Table 1) compared with bulk fill restoration when the one-way ANOVA of the mean total cuspal deflection measurements were assessed (all $p < 0.0001$).

3.2. *Cervical microleakage assessment*

The cervical microleakage scores recorded for the conventional RBCs and the bulk fill restorative RBCs placed using the oblique incremental or the bulk fill restorative RBCs, in conjunction with the 1-step bonding system and the unbound condition employing no bonding system are presented using a box and whisker plot (Fig. 2). The Kruskal–Wallis non-parametric test of the cervical microleakage scores revealed a significant difference between Groups A–F ($p < 0.001$). For the conventional RBCs, the Mann–Whitney U tests revealed no significant difference in microleakage scores reported for Tetric EvoCeram (bonded: Group B) and Tetric EvoCeram (non-bonded: Group A) restored teeth ($p = 0.230$), however, the Admira Fusion (bonded: Group C) teeth had significantly reduced microleakage scores (all $p < 0.001$). For the bulk fill

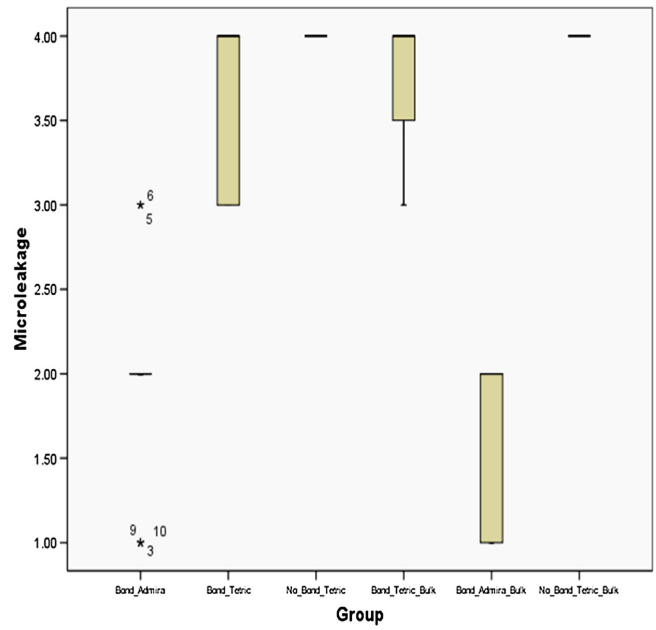

Fig. 2 – The cervical microleakage scores recorded are presented using a box and whisker plot for the conventional RBCs (Tetric EvoCeram: Group B and Admira Fusion: Group C) placed using the oblique incremental technique and the bulk fill restorative RBCs (Tetric EvoCeram Bulk Fill: Groups E and Admira Fusion x-tra: Group F), when used in conjunction with the 1-step bonding system. The unbound condition (in the absence of a bonding system) for Tetric EvoCeram (Group A) and Admira Fusion (Group D) are control groups that are also presented. Median cervical microleakage scores are indicated by the bold black line across the box, the highest and lowest cervical microleakage scores recorded are represented by the whiskers, while the box contain the inter-quartile range.

restorative RBCs, no significant difference in microleakage scores were evident for Tetric EvoCeram Bulk Fill (bonded: Group E) and Tetric EvoCeram Bulk Fill (non-bonded: Group D) restored teeth ($p = 0.540$), however, the Admira Fusion x-tra (bonded: Group F) teeth had significantly reduced microleakage scores (all $p < 0.001$).

4. Discussion

Following preparation of a large dental amalgam replacement cavity, the remaining tooth cusp(s) are susceptible to deflection during resin-restoration since a standardised MOD cavity preparation was shown to result in a significant loss in relative cuspal stiffness [42] related to the loss of marginal ridge integrity [43]. The restoration of posterior dentition in molar teeth is more difficult for dental practitioners compared with premolar teeth owing to the problems with access, moisture isolation and the increased challenges of the oral environment [8] notwithstanding the increased masticatory stresses on the restoration following placement. In the current study, human maxillary and mandibular third molar teeth were used compared with previous studies by the research group where maxillary first premolar teeth were exclusively employed [25–36]. The major advantage of employing maxillary first premolar teeth was consistency in form, shape and size [24], albeit the size was further controlled by the study inclusion criteria where the BPW of the teeth varied by <5%. Employing standardised human maxillary and mandibular third molar teeth is more of a challenge owing to the increased variances reported among third molar teeth [24]. While the inclusion criteria for the current study accommodated for size variance by selecting the BPW of the teeth which varied between 10.25–10.75 mm, additional form and shape inclusion criteria were introduced so that only maxillary and mandibular third molar teeth with four cusps (two buccal and two lingual) were included in the study to reduce the increased anatomical variances reported among third molar teeth in the literature [24].

In the oral cavity teeth, regardless of the tooth type (premolar or molar), Class II RBC restorations most frequently fail by marginal leakage [5] when the synergism of the tooth/RBC interface, mediated by the adhesive bond, is compromised [44,45]. In the current study, the 1-step 'mild self-etch' adhesive (Futurabond® DC SingleDose) was chosen based on the observations of a trend towards 'mild self-etch' adhesives which do not 'underperform at dentin' [34–36,46,47]. Groups A–C third molar teeth were restored using an oblique incremental technique with conventional RBC restoratives in eight increments [14]. The restoration of MOD cavities in the absence of the bonding agent served as a negative control for the experimental study and the reduced mean total cuspal deflection measurement reported was indicative of inadequate polymerisation of the RBC [27] or poor adhesive performance [34–36], with priority in this instance given to the latter (owing to the absence of the bonding agent). The reduced values of mean total cuspal deflection measurements for the maxillary and mandibular third molar teeth compared with the maxillary first premolar teeth previously used when employing the RBCs investigated [36] are readily explained by the anatomy of the different tooth types. When standardised by BPW, maxillary first premolar teeth have increased 'anatomic crown' length compared with maxillary and mandibular third molar teeth although the third molar teeth have a significantly wider surface area owing to their function, namely to grind the food bolus during the masticatory cycle. Therefore although the BPW of maxillary and mandibular third molar teeth and maxillary first premolar teeth are similar, standardised MOD cavities prepared in maxillary first premolar teeth have longer and thinner cusps compared with third molar teeth. Simple cantilever beam theory informs that deformation is proportional to the cubed power of the length [48–50] and therefore the reduction in the effective cusp length (between first premolar and third molar teeth) would significantly reduce the deflection in the standardised MOD cavity configuration as evidenced in the current study.

The incremental bulk fill (horizontal) restoration technique involved placing the RBC material in contact with both the buccal and palatal cusps prior to light irradiation which constrained both the buccal and palatal deflection [14] compared with the oblique incremental restoration technique where the RBC contacted a maximum of one cusp at a time [13,14]. The horizontal incremental restoration technique therefore had the advantage of reducing the effective remaining cusp length for the subsequent final increment. By eliminating monomeric RBC formulation, cantilever beam theory [48–50] can further be proposed for the significantly higher mean total cuspal deflection values obtained using conventional RBC materials (eight oblique increments) compared with the two horizontal increments for the bulk fill resin restoratives (all $p < 0.0001$).

The cervical microleakage scores presented are semi-quantitative owing to the non-parametric scale employed. As a result, care must be taken to recognise that 'microleakage' in the context of the current study is a measurement of dye ingress (along non-bonded or debonded interfaces and/or dye permeation through the 'mild self-etch' adhesive) and should not be confused as a predictor of clinical performance or a direct predictive model for microbial ingress [51]. For the conventional RBCs and bulk fill resin restoratives investigated, third molar teeth restored with Admira Fusion (bonded) and Admira Fusion x-tra (bonded) had significantly the lowest microleakage scores (all $p < 0.001$) compared with Tetric EvoCeram RBC (bonded and non-bonded) and Tetric EvoCeram Bulk Fill (bonded and non-bonded) restored teeth. The results for the non-bonded (negative) controls, where the 1-step 'mild self-etch' adhesive was omitted, resulted in a microleakage score of '4' (dye penetration into the pulp chamber from the pulpal floor), for all sixteen tooth halves examined for the third molar teeth restored with Tetric EvoCeram RBC and Tetric EvoCeram Bulk Fill. This finding was expected owing to the absence of a bond at the tooth/RBC interface and the potential for the development of a marginal gap as a result of shrinkage stress development during/following light irradiation in line with previous cuspal deflection studies [34–36]. The poor microleakage performance of third molar teeth restored with Tetric EvoCeram RBC (bonded) and Tetric EvoCeram Bulk Fill (bonded) is somewhat confusing although the literature does suggest reduced light penetration on light irradiation for Tetric EvoCeram Bulk Fill compared with Admira Fusion x-tra [52]. Indeed when the cuspal deflection of standardised large MOD cavities in maxillary premolar teeth restored with bulk fill resin restorative materials including Tetric EvoCeram Bulk Fill and Admira Fusion x-tra, no statistically significant differences ($p = 0.149$) were evident between the materials [36], in line with the results of the current study on third molar teeth. However, Tetric EvoCeram Bulk Fill had significantly increased cervical microleakage score compared with the Admira Fusion x-tra restored teeth group ($p < 0.0001$) [36]. Initially, the authors postulated that the quartz-tungsten-halogen LCU used previously [36] may have been responsible for the increased cervical microleakage score by not optimising initiation of the Ivocerin photo-initiator containing Tetric EvoCeram family of resin restoratives [20,22]. Interestingly, the Ilie and Fleming [52] polymerisation kinetics study reported reduced penetration on light irradiation for Tetric EvoCeram Bulk Fill compared with Admira Fusion x-tra, when a bluephase® 20i (Ivoclar Vivadent) light emitting diode (LED) polywave technology LCU—specifically designed for the Ivocerin photo-initiator containing Tetric EvoCeram family which nullified the QTH argument. It is increasingly likely that the compatibility of the adhesive system (Futurabond U Single-

Dose) with the Admira family of resin restoratives would have been optimised since the 1-step 'mild self-etch' adhesive was manufactured by Voco GmbH (Cuxhaven, Germany) that also manufactured the Admira resin restoratives further suggesting an explanation for the increased cervical microleakage scores for Tetric EvoCeram resin restoratives. The hypotheses proposed that there would be an increase in total cuspal deflection and associated decrease in cervical microleakage score on comparing conventional RBC restoratives with their bulk fill resin restorative material counterparts were rejected since the individual conventional and individual bulk fill resin restoratives behaved significantly differently when used to restore standardised MOD cavities in third molar teeth.

5. Conclusion

It would appear that light irradiation of some conventional RBCs or bulk fill resin restoratives may be problematic such that material selection is vital in the absence of clinical data.

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