Survival of Direct Posterior Composites With and Without a Bulk Fill Base

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ABSTRACT

Objectives: Direct composite restorations are increasingly popular and a flowable bulk-fill base material (SDR, Dentsply) claims to minimise stress through a more flexible polymerisation process. This retrospective audit of restorations placed in general practice compares SDR based restorations with conventional composite restorations. Methods: Restorations were all placed by one operator using a similar clinical technique and were audited as Group G, placed with a conventional layering composite (G-aenial, GC) and Group S which had a bulk-fill base of SDR (Dentsply) and then were covered with G-aenial (GC). Data regarding survival, post-operative sensitivity and mode of failure were recorded and analysed. Results: In total 54 Group S restorations and 71 Group G restorations were followed for a minimum of 24 months. Group S had a 92.6% survival and Group G 93%. Group S was more prone to failure by tooth fracture (p=0.033). In both groups failure was more likely in larger cavities, in both those with an increased number of surfaces (p<0.001) and cuspal coverage (p=0.004). Conclusions: There appears to be similar survival of the two techniques in the short-term although there were significantly more tooth fractures in teeth restored with SDR.

INTRODUCTION

Dental resin composite materials are in common use and manufacturers seek to overcome their limitations such as by managing the polymerisation contraction stress. Early studies identified that contraction leads to stresses within the restoration, tooth and adhesive interface resulting in decreased bond strengths or even localised loss of adhesion, causing voids.[1,2] Polymerisation stress is a function of elastic modulus (Emod) and the polymerisation contraction. Composite Emod develops during the polymerisation reaction, which can be considered in two distinct phases. In the pre-gel phase the resin component has not developed significant Emod, molecules are free to flow and contraction does not result in any resultant stress.[3] Further contraction during the post-gel shrinkage generates stress.[4] Other factors such as characteristics of the light cure, the resin formulation and volume are also important in polymerisation stress and therefore low-shrinkage composites do not necessarily produce reduced stress.[5]

Efforts have also been made to modify the resin component of composite in order to reduce polymerisation stress. This includes changes to the Bis-GMA molecule to reduce viscosity or the introduction of other monomers[6,7] More flexible polymer chains have been designed and incorporated into materials such as SDR (Dentsply); these do not reduce the polymerisation contraction but rather aim to minimise stress caused by the contraction.[8,9] The cross-linkage of the polymer chains incorporating this polymerisation modulator allows conformational flexibility around the central modulator leading to decreased stress accumulation within the tooth-restoration system.

Bulk-fill lining is not a new concept; traditionally zinc-oxide eugenol, GIC, RMGIC were used and more recently Biodentine, each with individual merits and disadvantages. Resin-based bulk-fill lining materials, such as SDR, have been developed with improved depth of cure and reduced polymerisation stress to enable composite placement with fewer increments. As with all lining materials they need to be covered due to longevity limitations usually in relation to their strength and lack of wear resistance. Other methods of bulk-filling while reducing the effect of shrinkage are under investigation including the use of self-cure resins.[10]

The aim of this retrospective audit was to compare the clinical survival of direct posterior composite restorations that were placed in a general dental practice. The clinical outcomes of two techniques were analysed and compared; SDR composite used as a bulk-fill base and a conventional nano-hybrid composite used in an oblique incremental layering technique.

METHODS

The records of patients who were regular attenders in a UK dental practice for routine examination and follow up treatment were assessed for potential use in the analysis. As this was a retrospective analysis using historical dental notes only, and not a prospective research study with randomisation, ethical approval was not required. All class 1 or class 2 direct composite restorations in premolars and molars placed between 1st March 2012 and 30th June 2012 inclusive were identified and selected for further investigation. Restorations were placed by one clinician, to eliminate operator variability, in adult patients in a private dental practice in the UK. Record searches were performed by hand, looking at every appointment booked during the time period and identifying restorations that met with the inclusion criteria. A single investigator performed the searches, assessed the type of restoration placed and collated the information.

Restorations were identified for potential use in the study if they had been performed according to one of the methods being evaluated. The SDR restorations (group S) consisted of a closed sandwich protocol using a SDR base to replace dentine and a conventional nano-hybrid composite (G-aenial posterior, GC, Tokyo, Japan) to restore the superficial enamel layer at the proximal (for class 2 cavities) and occlusal aspects. The conventional group was a direct posterior composite restoration performed with a conventional, restorative nano-hybrid composite (G-aenial posterior) in an anatomical oblique layering method (Group G). These materials were selected as they were commonly used in UK general practice at the time. It is useful to directly compare properties of the materials used in this audit (SDR and G-aenial posterior nano-hybrid composite). G-aenial uses a predominately UDMA resin with fillers of three sizes including relatively large 16-17μm prepolymerised particles, a fluoroaluminosilicate glass and fumed silica (of size greater than and less than 100nm respectively). Table 1 compares physical properties of G-aenial and SDR taken from manufacturers' data.[11,12] The data shows that G-aenial has a higher filler load and correspondingly higher compressive strength, higher Emod and lower polymerisation shrinkage. The SDR has improved fracture toughness.

Table 1. Table to compare properties of SDR and G-aenial using manufacturers' data.[11,12]

	SDR bulk fill	G-aenial Composite
Filler Load (%volume)	45	65
Emod (GPa)	4.7	8.3
Fracture toughness	4.63	1.6
Compressive strength (MPa)	218	288
Volumetric shrinkage (%)	3.5	2.3

The reported polymerisation shrinkage for SDR of 3.5% is higher than reported for most modern materials. This reflects that SDR is not designed to be a low-shrinkage material but rather a low-stress material. SDR utilises flexible polymer chains and altered polymerisation kinetics that are proposed to decreased polymerisation stress. An independent laboratory study found SDR had an extended pre-gel phase and created the lowest polymerisation stress when compared to conventional and flowable composites.[13]

The records were assessed and a standardised protocol was apparent. Within the specified time period all posterior composite restorations were performed with a similar technique, bonding protocol and materials. This audit included restorations as follows:

1. Class 1 or class 2 restorations placed in a vital premolar or molar tooth under rubber dam.
2. A standardised bonding procedure was followed using the etch and rinse, 2 stage bonding protocol with Optibond FL (Kerr) in line with the manufacturers' instructions. This involved etching of enamel for 30sec, dentine for 15sec, wash for 15sec, removal of excess moisture, application of primer, air thinning of primer, application of adhesive, air thinning of adhesive and light activation for 20sec.
3. For both groups, class 2 cavities were restored by creating the proximal contact and wall with G-aenial before the internal aspects of the cavity were restored. This technique may have an effect on polymerisation dynamics of the subsequent restoration.

4. Following bonding and proximal wall build-up, the dentine replacement was performed with either an SDR bulk-fill base (SDR group) or G-aenial in an anatomical, oblique incremental technique (conventional group). SDR and G-aenial materials were placed into cavities and cured according to manufacturer's instructions.
5. Both groups used G-aenial composite for the enamel replacement layer.
6. Primary or replacement restorations were included and cavity size in terms of number of surfaces was noted.
7. Patients must have attended for routine examination and any recommended treatment at least annually following intervention and the most recent appointment must have been at least 24 months after the intervention.
8. Patients were 18 years old or older at the time of the restoration.

Restorations were excluded from the analysis if the restoration procedure varied or if other materials were used as a bonding agent, a base or a superficial layer. Patients were excluded if they failed to maintain regular examination appointments (maximum interval of 12-months) during the evaluation period or if records were incomplete. Non-vital teeth with previous endodontic therapy were excluded from the analysis.

Group S restorations (54) and Group G restorations (71) were observed for a range of 24-26 months.

Details recorded included: patient's age and gender, tooth and cavity restored, type of previous restoration, material and bonding system used, survival at most recent review with mode of failure where appropriate, further interventions required and any post-operative biological complications.

Data was entered into a statistical software package (SPSS) and analysed using Fishers Exact Test to determine differences between interventions. When considering the number of surfaces there were 5 values recorded. With such few values this variable was not considered as continuous and therefore a Mann-Whitney test was used. Cuspal coverage is binary and therefore chi- square test was used.

RESULTS

There was no significant difference between the gender or mean age of the patients in the two groups G and S. There was only one cavity per patient. Cavity size was assessed only by the presence or absence of cuspal coverage and the number of surfaces involved as shown in Table 2. This difference is due to clinical decisions at time of placement and was determined once the audit was completed. The mean follow-up duration was 24.5 months for group S and 24.8 months for group G.

Due to the retrospective nature of this audit photographic records are not available for all cases as these were not taken as standard at this time. An example of the conventional layering technique with G-aenial is illustrated in Figure 1 and an example of the SDR bulk-fill technique with a G-aenial covering layer is illustrated in Figure 2. Two examples of restorations reported on in this paper are given in Figures 3 and 4.

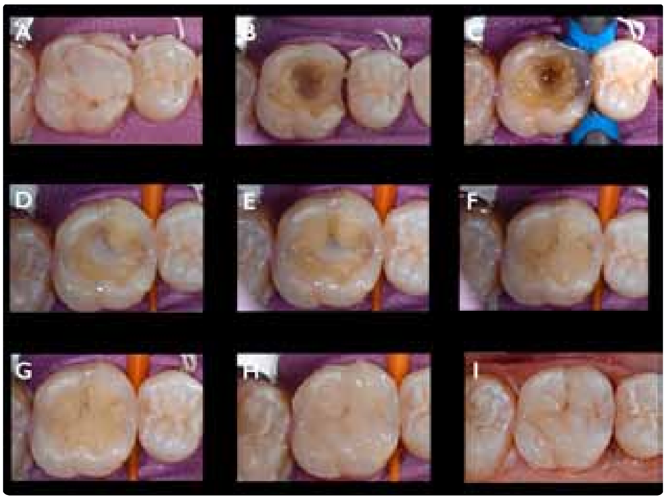

Figure 1: An example of the conventional layering technique used. A. Preoperative situation with failing composite restoration due to recurrent caries. B. Cavity preparation. C. Initial composite to recreate mesial wall. D-G. Cuspal composite increments to build to full contour. I. Completed restoration after, in this case, application of surface tinting.

Table 2. Distribution of cavity size between the two groups and modes of failure.

ALL RESTORATIONS	Surfaces						Failure		
	1	2	3	4	5	failure	Tooth #	Restoration #	Caries
G-aenial group G	7	23	28	11	2	5	0	4	1
SDR group S	6	23	19	6	0	4	4	0	0

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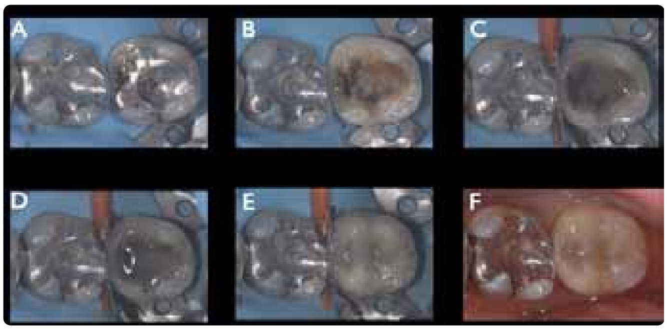

Figure 2: An example of the sequence used in the extended bulk fill base technique. A. Initial situation with failing amalgam due to wear and chipping. B. Cavity prepared. C. Initial restorative composite increment to recreate mesial wall. D. Flowable bulk fill base used leaving space for the final increment of restorative composite. E. Restorative composite used to complete restoration to full contour. F. Completed restoration.

Figure 3: A large mesio-occlusal cavity in the audit restored with using the extended bulk-fill base technique.

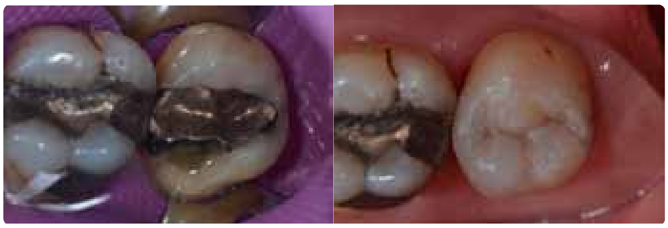

Figure 4: A large mesio-occlusal cavity with buccal cusp extension from this audit restored using the conventional layering technique.

At the end of the observation period 92.6% of Group S and 93.0% of Group G survived. There were 9 failures in total: 4 of 54 in the SDR group and 5 of 71 in the conventional group. Fishers Exact Test revealed no significant differences (p=1). The Annual Failure Rate (AFR) was 3.6% and 3.4% for groups S and G respectively. Fishers Exact Test was used to explore any differences in the mode of failures. The 4 failures in Group S were all due to tooth fracture whereas none failed in this way in Group G, this is statistically significant (p=0.033). Restoration fracture was found to be 0 and 4 in groups S and G respectively but this was not statistical significance (p=0.133). Symptoms of sensitivity related to 3 teeth in the conventional group and 0 in the SDR were identified. Fishers Exact Test found this did not reach statistical significance (p=0.26).

The data was analysed to determine whether the number of surfaces and the presence of cuspal coverage influenced survival irrespective of which intervention was chosen. Results (see Table 3) show a trend for increasing number of surfaces leading to increased failure. Using a non-parametric test (Mann-Whitney) this was found to be statistically significant for the restorations as a whole (p<0.001), the SDR group individually (p=0.002) and the conventional group individually (p=0.019).

Twenty-eight restorations had cuspal coverage and when all these restorations were considered together a total of 6 of 28 (21.4%) of the cuspal coverage restorations failed in comparison to 3 of 97 (3.1%) without cuspal coverage. This difference was found to be statistically significant (p=0.004). This trend is also evident in the both groups when considered individually. In the conventional group 4 of 21 (19.0%) with cuspal coverage failed in comparison to 1 of 50 without (2.0%). This reached statistical significance (Mann-Whitney, p=0.025). In Group S, 2 of 7 (28.6%) with cuspal coverage failed compared to 2 of 47 (4.3%) without cuspal coverage. This did not reach statistical significance (Mann-Whitney, p=0.077).

Table 3. Table to show the influence of increasing number of surfaces on survival of the restorations when both groups are considered together. The number of surfaces was found to be statistically significant in failure (p<0.001).

ALL RESTORATIONS	Surfaces					
	1	2	3	4	5	total
Failed	0	1	1	6	1	9
	0.0%	2.2%	2.1%	35.3%	50%	7.2%
Survived	13	45	46	11	1	116
	100%	97.8%	97.9%	64.7%	50.0%	92.8%
Total	13	46	47	17	2	125

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DISCUSSION

The survival of restorations from both groups in this audit is comparable to published data concerning posterior class 2 restorations placed with conventional layering techniques. Manhart *et al*'s review[14] of restoration survival found that posterior composite restorations had a mean AFR of 2.2% and a range of 0-9%. The large range reported may indicate that material selection is not the sole consideration in restoration survival as has been concluded by Demarco *et al.*[15] The findings in the present study are well within this range and close to the mean value with AFR of 3.4% for the conventional and 3.6% for the SDR groups. However, due to the short-term nature of this study we cannot assume that observed trends would continue in terms of long-term survival.

The results do however indicate that increasing number of surfaces leads to an increased failure rate. The presence of cuspal coverage also produced an increased failure rate when all restorations were considered as a whole and for both groups individually. Due to the retrospective nature of the study it was not possible to measure size of cavity directly; however, recording the number of surfaces and the presence of cuspal coverage could be considered to be indirect measurement of size and extent of the cavity. It therefore appears that the size and extent of cavity are related to survival; appropriate case selection is important in minimising failures. This may be more important than the choice of restoration technique.

In the current evaluation restorations failed by restoration fracture (n=4), tooth fracture (n=4) and caries (n=1). SDR restorations failed exclusively by fracture of tooth structure whilst conventional composite failed mainly by fracture of the restoration. This is despite more of the larger cavities being restored with conventional resin. Had an equal number of large cavities been restored with SDR then the cusp fracture rate may well have been higher. The SDR group experienced a statistically significant increase in tooth fracture which is in agreement with Van Dijken *et al.*, [16] who also found that restorations performed with SDR as a bulk-fill base layer failed exclusively by cusp fracture (sometimes in conjunction with secondary caries) whereas a control group restored solely with a restorative ormocer failed by restoration fracture. The SDR bulk-fill resin composite technique showed good durability during the 3 and 5-year follow-ups but the main reason for failure was tooth fracture, followed by resin composite fracture.[17-19] Two separate clinical trials showing statistically significantly increased tooth fracture where an SDR base was used suggest caution should be exercised where cusp fracture is considered to be a risk. Burgess and Munoz[20] state that most complications were related to fractures or voids in the superficial restorative composite overlying the SDR base.

Material properties affect the ability of the restoration to reinforce the tooth. Cuspal deformation can lead to cusp fracture. Tooth rigidity can be restored by using a bonded composite restoration.[21,22] Morin *et al.*,[21] measured lateral cusp displacement to applied load for teeth with a slot cavity (mesial, distal and occlusal surfaces) that was unrestored, restored with non-bonded amalgam or restored with bonded composite; only the bonded restoration reinforced tooth structure. However, further investigation by Fissore *et al.*,[23] found that the reinforcement effect is only present whilst the bond is intact and that with increased magnitude and cycles of loading the reinforcement effect may be lost. The study identified a sudden reduction in tooth rigidity suggesting that at a critical point, the bond between tooth and restorative material is lost and this results in loss of reinforcement. The quality and durability of bond to tooth is therefore critical in providing long-term cusp reinforcement with adhesive restorations.

It is well-known from *in-vitro* studies on extracted teeth that the polymerisation of composite can cause cusp deflection.[24] One such study showed that the bulk-fill flowable SDR base did significantly reduced cuspal deflection following polymerisation compared with a conventional composite restored with a conventional technique.[25] While this suggests that the polymerisation contraction stress conveyed to the cusps is reduced due to the more flexible monomer present it may also result in reduced restoration rigidity and support of the cusps in *vivo.*

These laboratory findings are supported by clinical studies. Opdam & Roeters[26] found that placement of an intra-coronal bonded composite restoration for the treatment of a tooth with CTS appears to produce reasonable short-term results. However, after seven-years of observation it was found that restorations with cuspal coverage produce a more predictable outcome.[27] It seems likely that the bond is compromised by cyclical loading. Further, it is known that the dentine bond is prone to degradation with time due to hydrolysis by matrix-metallo proteinases and other enzymes.[28]

The reinforcement ability of composite restorations depends on the Emod of the material.[29] The relatively rigid enamel shell has an important role in determining stress transfer through the tooth and reinforcing tooth structure.[30] However composite has an Emod more comparable with dentine than enamel. Despite emerging evidence to support the use of direct composite in cracked teeth and extensive cavities in the short and medium-term,[26,27,30] this approach has been questioned in the longer-term. Composite has a decreased Emod in comparison to enamel and may lead to increased deformation under masticatory load, limited ability to reinstate tooth-rigidity and the potential to lead to more catastrophic failure.[26,27,31]

The effect on cusp reinforcement of using SDR as a bulk-fill base is currently not fully known. El Safty *et al.*,[32] found SDR to have significantly lower Emod values than the majority of conventional composites tested. In the present study SDR has been used as a dentine replacement with a nano-hybrid material as the enamel replacement. The reduced Emod of SDR is likely to reduce the reinforcement effect and allow increased flexural stress to be transmitted to the tooth structure; as this is already weakened it may explain the higher incidence of tooth fracture for this group in comparison to Group G. There is currently no evidence regarding the stability of SDR in the oral environment however it is likely that, as with most composites, the material will experience a deterioration in mechanical properties due to fatigue and water uptake.

The conventional composite has a higher Emod than SDR however the value is still comparable with dentine. There was no tooth fracture in the Group G despite a greater proportion of more extensive cavities; the conventional material therefore appears to have satisfactory tooth reinforcement performance in the cavities tested in the short-term, supporting findings of previous studies.[26,27,29,33] The bulk-fill base technique with a more flexible SDR base-material did not reinforce tooth structure to a suitable level in some cases.

This is concerning, as long-term evidence is emerging to support the use of composites in more extensive cavity configurations including for cusp replacement,[33] for the management of cracked teeth,[26, 27] and CTS.[34] The composites demonstrating promising long-term results however are likely to be older hybrid materials that were popular at the time and these differ significantly from the materials being used today.

The results obtained in the present audit are specific to the operator and patient base; both features have the potential to affect success rate.[14] There are limitations to the study as a single dentist planned and performed all treatments which may create a bias; cases are therefore likely to share certain features consistent with the decision making process and the skill of that dentist. This will alter the way the results should be interpreted for clinical practice as other clinicians may have made different decisions and/or have executed the restorations differently. This retrospective audit obtained data from a general practice but as restorations are placed without prospective study controls the results must be interpreted with caution. A single operator does however lead to a degree of standardisation for the study. Inclusion criteria were well defined to enable selection of similar restorations. To achieve reasonable sample size, the restorations were any size of class 1 or 2 cavity. Root canal treated teeth were excluded due to potential differences in behaviour and survival.

A single data collector ensured standardisation in collection and analysis of data. The data collector was also the operator. This introduces risk of bias as the operator may have an interest in obtaining high success rates. It was not possible to blind the operator from the results of the study as they were clearly written in the notes being inspected and only one operator was involved.

Both materials provided reasonable survival rates over the observation period with no significant difference in survival between the groups. There are only two other available reports of using SDR as a bulk-fill base; Burgess and Munoz[17] had eighty-six restorations with follow-up of up to three-years and showed 99% survival however there appears to have been a high drop out rate of the original participants. Van Dijken[16] and van Dijken & Pallesen[17-19] reported several times from one prospective study performed under controlled conditions within a university setting utilising strict inclusion-criteria and therefore may differ from regular dental practice. The results from this current audit may therefore be more representative of the performance of SDR within the general dental practice setting. While a longer study period would be desirable the two year outcomes deserve consideration as they confirm the clinically significant increased incidence of cusp fracture with the bulk-fill base material SDR in use.

CONCLUSIONS

The current study has limitations related to the retrospective nature, limited sample size and follow-up duration. However, SDR is a new material and as such early clinical studies will tend to be limited until sufficient data becomes available. Our results show no differences in the restoration survival however there seems to be a difference in mode of failure.

Larger restorations are more prone to failure irrespective of whether conventional or extended bulk-fill base techniques are used. The mode of failure may differ between groups due to differences in physical properties and tooth reinforcement. When failure occurred in the SDR restorations tooth fracture occurred which is more damaging than restoration fracture.

REFERENCES

1. Bausch JR, de Lange K, Davidson, CL, Peters A, De Gee AJ. Clinical significance of polymerization shrinkage of composite resins. *J Prosthet Dent* 1982;**48**:59-67.
2. Nayif MM, Nakajima M, Foxton RM, Tagami J. Bond strength and ultimate tensile strength of resin composite filled into dentine cavity; effect of bulk and incremental filling technique. *J Dent* 2008;**36**:228-234.
3. Davidson CL, Feilzer AJ. Polymerization shrinkage and polymerization shrinkage stress in polymer-based restoratives. *J Dent* 1997;**25**:435–440.
4. Kleverlaan CJ, Feilzer AJ. Polymerization shrinkage and contraction stress of dental resin composites. *Dent Mat* 2005;**21**:1150–1157.
5. Tantbirojn D, Pfeifer CS, Braga RR, Versluis A. Do low-shrink composites reduce polymerization shrinkage effects? *J Dent Res* 2011;**90**:596-601.
6. Moszner N, Salz U. Recent developments of new components for dental adhesives and composites. *Macromolecular Materials Engineering* 2007;**292**:245–271.
7. Weinmann W, Thalacker C, Guggenberger R. Siloranes in dental composites. *Dent Mat* 2005;**21**:68–74.
8. Ilie N, Hickel R. Investigations on a methacrylate-based flowable composite based on the SDR™ technology. *Dent Mat* 2011;**27**:348-355.
9. Gill R, Millar B J, Deb S. Properties of a bulk-fill flowable composite resin with high depth of cure. *Open J Stomatol* 2017 in press.
10. Millar BJ, Deb S. An in vitro study of microleakage comparing total-etch with bonding resin and self-etch adhesive luting cements for all-ceramic crowns. *Open J Stomatol* 2014;**4**:126-134.
11. Dentsply International. Surefil® SDR flow Product Brochure. 2010. Online information available at http://www.surefilsdrflow.com/sites/default/files/ SureFil_Brochure.pdf (accessed September 2014).
12. GC Europe. G-aenial anterior and posterior technical manual. 2014. Online information available at http://www.gceurope.com/pid/145/manual/en_Manual.pdf (accessed September 2014).
13. Ilie N, Hickel R. Investigations on a methacrylate-based flowable composite based on the SDR™ technology. *Dent Mater* 2011;**27**:348-355.

14. Manhart J, Chen H, Hamm G, Hickel R. Buonocore memorial lecture. Review of the clinical survival of direct and indirect restorations in posterior teeth of the permanent dentition. *Op Dent* 2004;**29**:481–508.

15. Demarco FF, Correa MB, Cenci MS, Moraes RR, Opdam NJM. Longevity of posterior composite restorations: Not only a matter of materials. *Dent Mat* 2012;**28**:87-101.

16. Van Dijken JW. Randomised 2-year follow-up of posterior bulk-filled resin composite restorations. Presented at the 46th Meeting of the Continental European Division of the International Association for Dental Research with the Scandinavian Division (NOF). *Florence*. 2013. Available from: http//www.dentsply.co.uk/products/restorative/composites/SDR (accessed September 2014).

17. van Dijken JWV, Pallesen U. A randomized controlled three year evaluation of bulk-filled posterior resin restorations based on stress decreasing resin technology. *Dent. Mater*, 30 (2014), pp. e229–e237.

18. van Dijken JWV, Pallesen U. Randomized 3 year clinical evaluation of Class I and Class II posterior resin restorations placed with a bulk-filled resin composite and a 1-step self-etch adhesive. *J. Adhes. Dent.*, 17 (2015), pp. 81–88.

19. van Dijken JWV, Pallesen U. Posterior bulk-filled resin composite restorations: A 5-year randomized controlled clinical study. *Journal of Dentistry*, 51 (2016), pp. 29-35.

20. Burgess J, Munoz C. 36-Months clinical trial results (document on the internet). *Dentsply*; 2013 (cited 2014 Sept 7). Available from: http//www.dentsply.co.uk/products/restorative/composites/SDR (accessed September 2014).

21. Morin DL, Douglas WH, Cross M, DeLong, R. Biophysical stress analysis of restored teeth: experimental strain measurement. *Dent Mat* 1988;**4**:41-48.

22. MacPherson LC, Smith BG. Reinforcement of weakened cusps by adhesive restorative materials: An in-vitro study. *Brit Dent J* 1995;**178**:341–344.

23. Fissore B, Nicholls JI, Yuodelis RA. Load fatigue of teeth restored by a dentin bonding agent and a posterior composite resin. *J Prosthet Dent* 1991;**65**:80-85.

24. Causton B, Millar BJ, Sefton J. The deformation of cusps by bonded posterior composite restorations : An in vitro study. *Brit Dent J.* 1985 159 397-400

25. Moorthy A1, Hogg CH, Dowling AH, Grufferty BF, Benetti AR, Fleming GJ. Cuspal deflection and microleakage in premolar teeth restored with bulk-fill flowable resin-based composite base materials. *J Dent.* 2012 Jun;**40**(6):500-5. doi: 10.1016/j.jdent.2012.02.015. Epub 2012 Mar 3.

26. Opdam NJ, Roeters JJ. The effectiveness of bonded composite restorations in the treatment of painful, cracked teeth: six month evaluation. *Op Dent* 2003;**28**:327-33.

27. Opdam NJ, Roeters JJ, Loomans RA, Bronkhorst E. Seven year clinical evaluation of painful cracked teeth restored with a direct composite restoration. *J Endodont* 2008;**34**:808-11.

28. Tjäderhane L, Nascimento, FD, Breschi L, *et al*. Optimizing dentin bond durability: control of collagen degradation by matrix metalloproteinases and cysteine cathepsins. *Dent Mat* 2013;**29**:116–135.

29. Yap AUJ, Wang X, Wu X, Chung SM. Comparative hardness and modulus of tooth-colored restoratives: a depth-sensing microindentation study. *Biomat* 2004;**25**:2179–85.

30. Magne M, Belser U. Rationalization of shape and related stress distribution in posterior teeth: A finite element study using nonlinear contact analysis. *Int J Periodont Rest Dent* 2002;**22**:425–433.

31. Magne P, Belser U Porcelain Versus Composite Inays/Onlays: Effects of Mechanical Loads on Stress Distribution, Adhesion, and Crown Flexure. *Int J Periodont Rest Dent* 2003;**23**:543-555.

32. El-Safty S, Silikas N, Watts DC. Creep deformation of restorative resin-composites intended for bulk-fill placement. *Den Mat* 2012;**28**:928-935.

33. Fennis WM, Kuijs RH, Roeters FJ, Creugers NH, Kreulen C M. Randomized Control Trial of Composite Cuspal Restorations Five-year Results. *J Dent Res* 2014;**93**:36-41.

34. Banerji S, Mehta SB, Kamran T, Kalakonda M, Millar BJ. A multi-centered clinical audit to describe the efficacy of direct supra-coronal splinting – A minimally invasive approach to the management of cracked tooth syndrome. *J Dent* 2014;**42**:862-871.