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Research Article

How Efficacious are Stainless Steel Crown Luting Cements: An *Ex Vivo* Comparative Study

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Abstract

The most common ailment of the teeth affecting the people world over is dental caries. If left untreated and unattended, results in large cavitated defects, periapical pathology and in cases of primary teeth, the infection further transcends down to the underlying permanent tooth bud causing various malformations including hypoplasia in the successors deeming it necessary to place stainless steel crowns (SSCs) on them after definitive therapy.

Besides several advantages that SSCs offer, there are certain disadvantages viz; recurrent decay, inflammation of vital pulps, and reinfection of previously treated root canal. To overcome these problems and to increase longevity of SSCs, several types of luting cements have been used to cement stainless steel crowns for primary molars.

To assess which type of luting cement would be effective in increasing the longevity of stainless steel crown by reducing incidence of microleakage, demineralization inhibition and improve its retention, this study was planned. Standardized preparations were made on one hundred eighty extracted primary teeth and stainless steel crowns were adapted and cemented using zinc phosphate (ZP), glass ionomer (GIC), resin-modified glass-ionomer cement (RMGIC) and resin cement (RC). Specimens were tested for retention, microleakage and demineralization inhibition. The data for retentive force assessment was analysed by one way ANOVA with post-hoc Bonferroni test for group comparisons. While the data for demineralization inhibition and microleakage assessment was analysed using Chi-square test, Kruskal-wallis test and mann-whitney U test using the statistical package for social science (SPSS version 18.0) software.

Based on test results groups were ranked from least to most microleakage as RC, RMGIC, GIC, ZP. Ranking for retention from least to most was found to be as ZP, GIC, RMGIC, RC while ranking for demineralization inhibition potential from least to most was ZP, RC, RMGIC, GIC.

Keywords: *Stainless Steel Crown; Primary Teeth; Luting Cements; Microleakage; Retention; Demineralization Inhibition*

Abbreviations

SSC: Stainless Steel Crown; ZP: Zinc Phosphate; GIC: Glass Ionomer Cement; RMGIC: Resin Modified Glass Ionomer Cement; RC: Resin Cement

Introduction

Dental caries is one of the most common ailment affecting people world over. When left untreated and unattended it leads to formation of large carious defects.

Primary teeth are believed to be the best space maintainers of the oral cavity and efforts should thus be made to preserve them. It thus becomes important for us to treat the carious primary teeth by restoration and endodontic therapy unless extraction is unavoidable.

Traditionally, silver amalgam restorations were done to restore the grossly carious teeth, however, the stainless steel crowns are found to have several advantages over silver amalgam restorations. These include low cost, less chair time, protection of tooth from further decay, availability of many sizes, durability, resistance to tarnish, absence of mercury, the ability to regain vertical dimension and retain occlusion, maintenance of morphologic form to preserve the health of gingival tissues, and the ability to preserve arch length [1].

SSCs were introduced in 1950 by Humphrey and Engel for restoration of badly broken down primary molars and for their use with space maintainers. Stainless steel crowns were also used for restoration of teeth with extensive decay, teeth which are deformed by developmental anomalies and hypoplastic defects etc.

Despite many advantages of stainless steel crowns, these had some reasons of failure too like poor retention of the crown, increased incidence of microleakage around the cervical margin and resultant cervical caries, which compromise their longevity.

The SSCs derive their retention from primary factors and secondary factors. Primary factor includes the morphology of the tooth (buccal prominence) while the secondary factor includes the use of various luting agents [2,3]. If primary factors are made standard, then role of secondary factors in increasing their retention becomes important.

Till date, there are just a handful of studies conducted so far to evaluate the efficacy of luting cements for cementing stainless steel crowns on primary teeth in terms of their retention, microleakage and demineralization inhibition potential.

This study was thus planned to comparatively evaluate zinc phosphate cement, type 1 GIC, RMGIC and pure resin cement to assess their efficacy in retention, demineralization inhibition potential and microleakage inhibition when used for cementing stainless steel crowns in primary teeth.

Materials and Method

A total of one hundred eighty extracted human primary teeth were included in this study and called as samples. Soft tissue deposits and calculus removal was done with an ultrasonic scaler, carious lesions, if any were restored after excavation with light cure composite.

Each sample was mounted on an acrylic block. The block was made by putting self cure acrylic in a vinyl tube of 30 mm long and 1.5 cm in diameter.

After mounting the teeth in self cure acrylic, tooth preparation was done and SSC of appropriate size adapted as per guidelines mentioned in Mc Donalds and Avery's dentistry for the child and adolescent, 10th edition.

Samples were then equally and randomly divided into following 3 groups:

1. **Group 1**: 60 samples to be used for retentive force assessment.
2. **Group 2**: 60 samples of this group were to be used for demineralization inhibition assessment.
3. **Group 3**: Remaining 60 samples were to be used for microleakage assessment.

Each group was further divided into 4 subgroups: a to d according to the luting cements to be used for cementing SSCs viz subgroup a: zinc phosphate cement (ZP), subgroup b: glass ionomer cement (GIC), subgroup c: resin modified glass ionomer cement (RMGIC) and subgroup d: resin cement (RC).

Artificial Saliva solution was prepared using 20 Mm of sodium bicarbonate ($NaHCO_3$), 3 Mm sodium dihydrogen phosphate (NaH_2PO_4), 1 Mm calcium chloride($CaCl_2$).

Artificial caries solution was also prepared using 2.2 Mm calcium phosphate ($Ca_3(PO_4)_2$), and 50 Mm acetic acid (CH_3 COOH).

Retentive Force Assessment

After removing the adapted SSCs from all the 60 samples of group 1, a round class I cavity was prepared in the centre of occlusal surfaces of samples using a wheel bur of 0.5 cm diameter. Then a hole was made in the selected SSC corresponding to the prepared cavity for a nail to pass through and then the crowns were cemented as per the following:

- **Subgroup 1a:** SSCs in 15 samples cemented using ZP cement.
- **Subgroup 1b:** SSCs in 15 samples cemented using GIC.
- **Subgroup 1c:** SSCs of 15 samples cemented with RMGIC.
- **Subgroup 1d:** SSCs of 15 samples cemented using pure RC.

Demineralization inhibition potential assessment

60 samples of group 2 were selected randomly and divided into following 4 subgroups of 15 each as follows:

- **Subgroup 1a**: 15 samples cemented using ZP cement.
- **Subgroup 1b**: 15 samples cemented using GIC.
- **Subgroup 1c**: 15 samples cemented using RMGIC.
- **Subgroup 1d**: 15 samples cemented using pure RC.

All the remaining exposed surfaces of the samples were coated with nail varnish leaving a window (2 mm X 2 mm) at the cervical margin of the proximal surface (mesial/distal) that was uncoated. The samples were then placed in artificial saliva for a period of 90 days, during this period, the samples were exposed to caries solution daily for a period of 35 minutes every 8 hours and brushed with fluoridated tooth paste twice daily. After a period of 90 days, the samples were sectioned from the middle of the exposed surface in mesiodistal direction and studied under stereomicroscope for demineralization. The samples were assessed using the following modified Kidd's criteria:

- **Grade 0**: No dye penetration.
- **Grade 1**: Dye penetration till 1/3rd or less from the prepared outer surface.
- **Grade 2**: Dye penetration more than 1/3rd but till 2/3rd or less from the prepared outer surface.
- **Grade 3**: Dye penetration more than 2/3rd from the prepared outer surface.

Microleakage Assessment

60 samples of group 3 were selected randomly and divided into 4 subgroups of 15 each as follows:

- **Subgroup 1a**: Cemented using ZP cement.
- **Subgroup 1b**: Cemented using GIC.
- **Subgroup 1c**: Cemented using RMGIC.
- **Subgroup 1d**: Cemented using pure RC.

The samples were then thermocycled at 5 and 55°C with a dwell time of 30 seconds and a transfer time of 15 seconds. The samples after thermocycling were dipped in a solution of methylene blue for 24 hours before they were sectioned mesiodistally and observed under stereomicroscope for dye penetration. The samples were then assessed according to the following criteria:

- **Grade 0**: No micro leakage.
- **Grade 1**: Continuous band of dye seen until 1/3rd of axial wall of the tooth from the cervical area.
- **Grade 2**: Continuous band of dye seen in more than 1/3rd but less than 2/3rd of axial wall of the tooth from the cervical area.
- **Grade 3**: Continuous band of dye seen in more than 2/3rd of axial wall of the tooth from the cervical area.
- **Grade 4**: Continuous band of dye over the occlusal surface.

Statistical analysis

The data for retentive force assessment was analysed by one way ANOVA with post-hoc Bonferroni test for group comparisons. While the data for demineralization inhibition and microleakage assessment was analyzed using Chi-square test, Kruskal-wallis test and mann-whitney U test using the statistical package for social science (SPSS version 18.0) software.

Results and Discussion

Although SSCs have high success rates, a significant number of clinical failures do occur due to cement loss, periapical pathology and defective margins [4-7] which has profound effect on the retention of the crowns and may result in increased incidence of microleakage around the cervical margin and resultant cervical caries.

Retention loss has been found to be one of the most common causes of restoration failure [8]. Crown's retention has been attributed to various primary and secondary factors. The primary factors include the morphology of the tooth and the crown preparation, while the secondary factors include the use of various cementing agents, placing retentive grooves, pretreatment of inner surface of crown etc.

Several researchers have conducted studies on the factors that contribute to retention of stainless steel crowns. Savide NL, Caputo AA (1979) reported that apart from preservation of as much tooth structure as possible especially on the buccal and lingual side, use of cementing agents additively increase the retention capacity of all preparations, thereby increasing the longevity of the restoration [9].

Similar findings were reported by Myers., *et al.* who stated that crown retention with cement was significantly higher than mechanical retention alone [3,10].

The 60 samples of group 1 were evaluated for retentive force. The mean retentive force value in subgroup 1a (ZP) was 148.27 N, for subgroup 1b (GIC) it was 177.40 N, for subgroup 1c (RMGIC) the mean retentive force was 178.33 while for subgroup 1d (RC) it was 223.80 N revealing that the mean retentive force was the highest for subgroup 1d (RC) and least in subgroup 1a (ZP) (Figure 1). The comparison was drawn using One-way ANOVA Test. There was a significant difference (p-value < 0.05) in mean retentive force (N) between subgroup 1a (ZP) and subgroup 1d (RC).

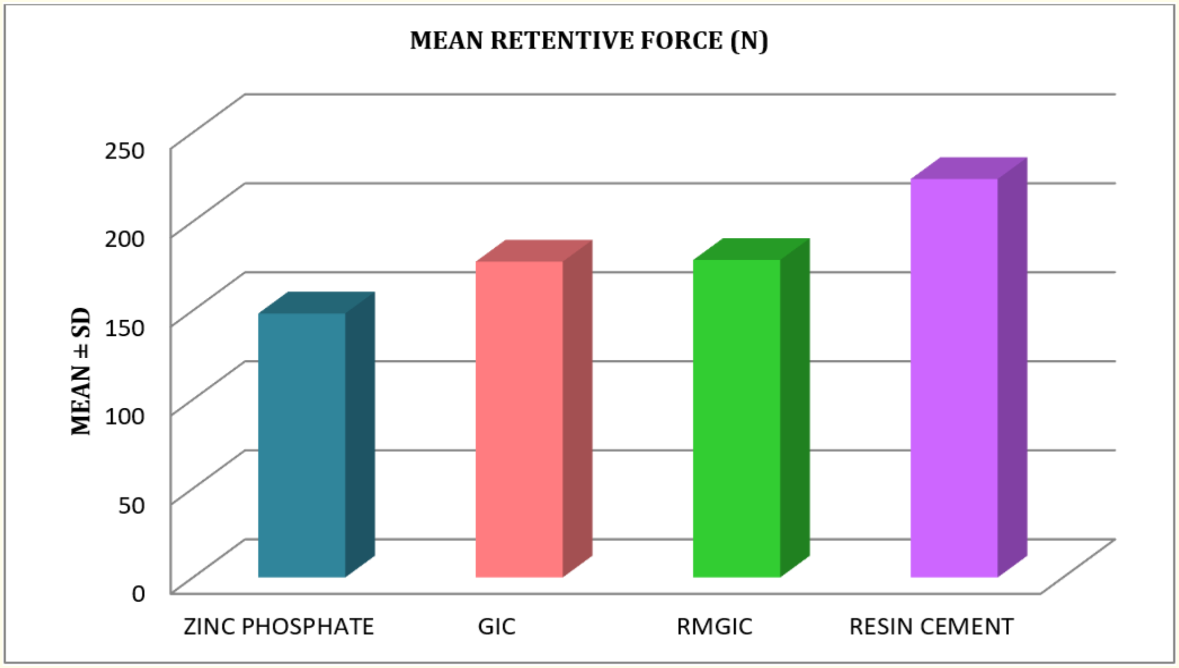


Figure 1: *Mean retentive force (N) comparison amongst subgroup 1a (ZP), subgroup 1b (GIC), subgroup 1c (RMGIC), subgroup 1d (RC).*

The superior retentive force of pure RC could be attributed to the fact that the RC used in our study, RelyX U200, is a dual cure self-adhesive cement in which the setting reaction is started by light and/or by a chemical reaction of the initiator system (dual cure). The setting reaction is a radical polymerization during which the single monomer molecules are chemically cross-linked to form a three-dimensional polymer network. Simultaneously, neutralization reaction takes place, which enhances the long-term stability [11,12]. Also, the phosphate esters present in cement decalcify the dentin or enamel, thus improving the micromechanical bonding between tooth's hard tissue and resin cement [13]. In addition, ionic interactions may also contribute to bonding between tooth structure and cement. Ionic bonding between negatively charged phosphate ester monomer and the positively charged calcium ions on tooth may have enhanced the retention.

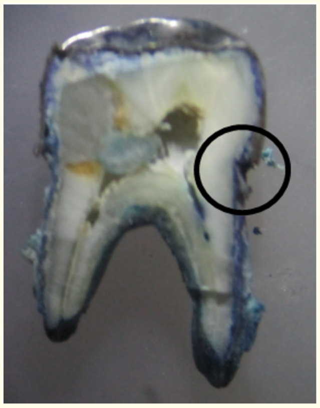
In case of RMGIC, tags are formed at the dentin-cement interface from penetration of RMGIC polymer into the dentinal tubules resulting in them displaying increased retentive force. In our study, the mean retentive force of RMGIC was found comparable to GIC. This finding is in contrast to a clinical trial done by Almuammar MF, Schulman A, Salama F who showed increased strength of RMGIC [14].

Zinc phosphate, even though is the oldest of the luting cements, used widely for cementation of stainless steel crowns, displayed the least retentive force amongst all the 4 tested luting cements due to the fact that its retentive properties are purely mechanical in nature. Mechanical nature of bonding occurs due interlocking at the interface as zinc phosphate cement does not involve any reaction with surrounding hard tissue or restorative material [15]. Additionally it is brittle, has a relatively high solubility in the mouth, and does not adhere to the tooth structure.

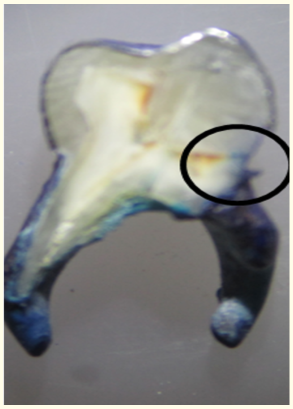
Another common problem with the use of stainless steel crowns is the development of demineralization at cervical region underneath the crown that results in cervical caries [16]. This problem was highlighted by Henderson., et al. in their clinical trial in which they noticed that clinically and radiographically, no matter how accurately the crowns were trimmed, adapted and polished, some inflammation was bound to be observed due to the differences in form and contour between the tooth and the crown [11]. This was in turn associated with caries around the cervical margin. Similar findings were reported by Myers who found a clinically significant association between crown defects and gingivitis and resultant caries [12].

Demineralization inhibition potential was assessed by dye penetration under stereomicroscope using the following criteria (Figure 2):

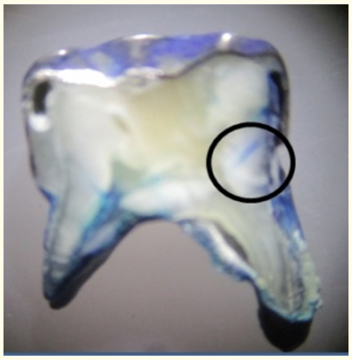
- **Grade 0**: No dye penetration.
- **Grade 1**: Dye penetration till 1/3rd or less from the prepared outer surface.
- **Grade 2**: Dye penetration more than 1/3rd but till 2/3rd or less from the prepared outer surface.
- **Grade 3:** Dye penetration more than 2/3rd from the prepared outer surface.



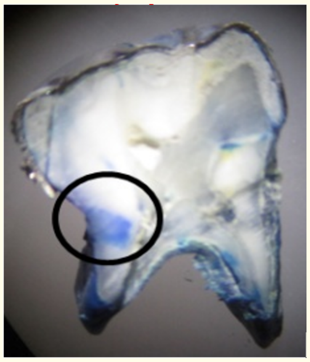
Score 0: *No dye penetration.*



Score 1: *Dye penetration till 1/3rd or less from the prepared outer surface.*



Score 2: *Dye penetration more than 1/3rd but till 2/3rd or less from the prepared outer surface.*



Score 3: *Dye penetration more than 2/3rd from the prepared outer surface.*

Figure 2: *Demineralization inhibition scoring using stereomicroscopic images of samples.*

Mean values for demineralization were assessed and the data analysed using Kruskal-wallis test and found that GIC showed maximum demineralization inhibition potential while ZP group showed minimum demineralization inhibition potential (Table 1).

	Number	Mean	STD. Deviation	Mean rank	p-value
Subgroup 2a (ZP)	15	2.80	0.56	45.13	0.001
Subgroup 2b (GIC)	15	1.00	1.00	17.63	
Subgroup 2c (RMGIC)	15	1.47	0.74	23.27	
Subgroup 2d (RC)	15	2.20	1.15	35.97	
Kruskal-wallis test *** Very Highly Significant difference (p-value ≤ 0.001)					

Table 1*: The mean values of demineralization for different subgroups.*

The maximum demineralization inhibition potential exhibited by GIC could be attributed to the fact that it is composed of fluoride-containing silicate glass and polyalkenoic acids which are set by an acid-base reaction between the components. During the setting reaction, a variety of ionic constituents are released from the glass, including fluoride. Two mechanisms have been proposed by which fluoride is released from glass-ionomers into an aqueous environment. One mechanism is a short-term reaction, which involves rapid dissolution from outer surface into solution, whereas the second is more gradual and results in a sustained diffusion of ions through the bulk cement. These processes are presented by the right-hand first and second terms of the equation:

$[F]_c = [F]_I t/(t + t_{1/2}) + \beta\sqrt{t}$.

The parameter $t_{1/2}$ is the 'half-life' of the process I to reach one-half of its maximum value which is given by F. Parameter $\beta \sqrt{t}$ is material dependent and can be considered as a measure for the driving force of process 2 [16].

An initial high release from glass-ionomers over the first 24 hours is likely due to the burst of fluoride released from the glass particles when reacting with the polyalkenoate acid dsuring the setting reaction.

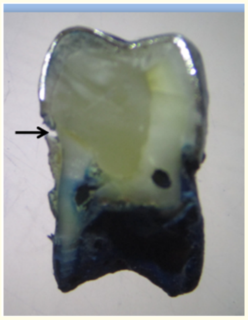
In vitro, it is proven that the maximum release occurs during the first 24 - 48 hours ranging from 5 to 155 ppm for different brands of glass-ionomer cements (1 - 1.5 mm thick, 6mm in diameter) [17].

Long term fluoride release by glass ionomer cement and the resultant demineralization inhibition can also be attributed to the fact that glass-ionomers are mostly found to have significantly better capability to act as a fluoride reservoir due to fluoride rechargeability than composite resin-based materials [18-21]. This could be explained by the loosely bound water and the solutes in the porosities in the glass-ionomer, which may be exchanged with an external medium by passive diffusion [22].

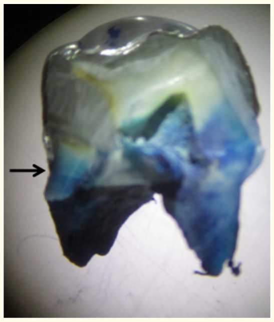
Anti-cariogenic ability of zinc containing materials such as zinc phosphate cement has been attributed to its ability to release zinc ions that inhibits the growth of caries causing bacteria. Zinc's antibacterial action has been reported to be similar to fluoride, but is reported to work better in neutral pH [23,24]. Researchers have also found that the zinc phosphate cement that is instantly mixed displays strong antibacterial properties, however this reduces considerably after setting as seen from the results of the present study.

Third important factor assessed in this study was cementing agent's ability to have low solubility in order to prevent seepage of fluids thereby reducing the chances of secondary caries, for which microleakage assessment was done by visualizing stereomicroscopic images of the samples as per the following criteria (Figure 3):

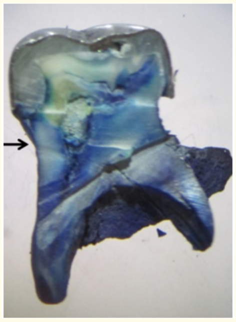
- **Grade 0**: No micro leakage.
- **Grade 1**: Continuous band of dye seen until 1/3rd of axial wall of the tooth from the cervical area.
- **Grade 2**: Continuous band of dye seen in more than 1/3rd but less than 2/3rd of axial wall of the tooth from the cervical area.
- **Grade 3**: Continuous band of dye seen in more than 2/3rd of axial wall of the tooth from the cervical area.
- **Grade 4**: Continuous band of dye seen in more than 2/3rd of axial wall of the tooth from the cervical area.



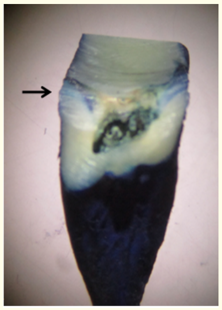
Score 0: *No micro leakage.*



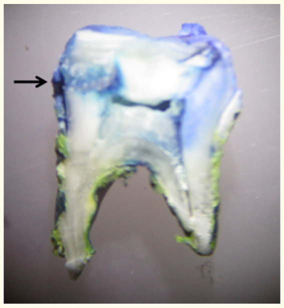
Score 1: *Continuous band of dye seen until 1/3rd of axial wall of the tooth from the cervical area.*



Score 2: *Continuous band of dye seen in more than 1/3rd but less than 2/3rd of axial wall of the tooth from the cervical area.*



Score 3: *Continuous band of dye seen in more than 2/3rd of axial wall of the tooth from the cervical area..*



Score 4: *Continuous band of dye over the occlusal surface.*

Figure 3: *Microleakage scoring using stereomicroscopic images of samples.*

The mean microleakage values of the 4 luting cements; ZP, GIC, RMGIC and RC were assessed and found to be 3.87, 3.07, 2.40, 1.20 respectively which means that microleakage was least with RC followed by RMGIC, GIC and then ZP.

Subgroups	Number	Mean	STD. Deviation	Mean Rank	p-value
Subgroup 3a (ZP)	15	3.87	0.35	45.47	$p < 0.001$
Subgroup 3b (GIC)	15	3.07	1.03	33.90	
Subgroup 3c (RMGIC)	15	2.40	1.45	27.77	
Subgroup 3d (RC)	15	1.20	1.32	14.87	
Kruskal-wallis test *** Very Highly Significant difference (p-value ≤ 0.001)					

Table 2*: Mean values of luting cements as obtained from microleakage scoring.*

Microleakage may occur as a result of poor marginal seal along the interface between the tooth and SSC. Poor marginal seal of SSC may allow microleakage of bacteria and their toxic metabolic waste products into the tooth structure. Such microleakage can lead to recurrent decay, inflammation of vital pulp, or reinfection of previously treated root canal by coronal microleakage [25-27]. This phenomenon is especially significant in prefabricated SSCs because achieving optimal marginal adaptation is difficult with these crowns. Thus, luting cements play an important role in obtaining a suitable marginal seal and reducing microleakage through the crown margin [28] aiding in retention of crown.

The least microleakage observed in pure resin cement could be explained by the fact that adhesion to enamel occurs through the micromechanical interlocking of resin to the hydroxyapatite crystals and rods of etched enamel. Dentin adhesion is obtained by infiltration of resin into etched dentin, producing a micromechanical interlock with partially demineralised dentin, which underlies the hybrid layer or resin inter diffusion zone [29].

Less microleakage can also be attributed to the ability of resin cement in generating an effective seal at the interfaces between restorative alloy, cementing agent and dental tissue without requiring pretreatment of the prepared tooth surfaces. The resin cement contains specific multifunctional phosphoric acid methacrylates able to interact with the tooth surface in multiple ways, such as by forming complex compounds with calcium ions or by different kinds of physical interaction like hydrogen bonding or dipole-to-dipole interactions [11,12].

Probable reason why ZP displayed maximum solubility might be the nature of its dentin bond which is exclusively mechanical. Zinc-phosphate, together with polycarboxylate and glass-ionomer cement, belongs to the group of acid-base cements. All the cements contain acid as a component which is responsible for high acidity of mixture during cementation. The pH of the zinc-phosphate cement at the moment of application to the dental tissues remains 1.6, which subsequently increases during the cement setting. Acid component of the cement may demineralize smear layer and intact dentin. Cement mixture consistency is creamy and it is not capable of diffusing through the demineralized dentin. Exposed collagen fibres surrounded by empty spaces of demineralized dentin undergo hydrolysis in due course of time under the influence of oral fluids and water, which impair the accomplished bond and lead to the development of micro cracks and microleakage [30].

Conclusion

Based on the results of the present study, the following conclusions were drawn:

1. Pure resin cement proved the best in retaining the SSC as it provided the maximum resistance against its dislodgement while zinc phosphate cement proved to be least efficacious in retaining the SSC. The retentive force assessment of different luting cements could be summarized as:

   Resin cement > RMGIC > GIC > Zinc phosphate cement
2. Glass ionomer cement faired the best out of other cementing agents used in the present study in preventing demineralization around the SSCs and thereby preventing cervical caries while zinc phosphate cement was found to be least effective in preventing demineralization. The efficacy of different cements in terms of demineralization inhibition potential could be summarized as:

   GIC > RMGIC > Resin cement > Zinc phosphate cement
3. Pure resin cement was also found to be the most effective in reducing microleakage while zinc phosphate cement did not prove efficacious enough to prevent microleakage. The efficacy of various cements in reducing microleakage could be summarized as:

   Resin cement > RMGIC > GIC > Zinc phosphate cement

After evaluating all the luting cements under study for all the three parameters, resin cement was found to exhibit the best retentive force and least microleakage while glass ionomer cement was found to be the best in inhibiting demineralization.

However, further exhaustive studies with larger sample size are needed to be conducted to authenticate the results of the present study.

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Volume 17 Issue 11 November 2018