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Original Article

Evaluation of retentive strength of four luting cements with stainless steel crowns in primary molars: An *in vitro* study

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ABSTRACT

Background: Stainless steel crown (SSC) is the most reliable restoration for primary teeth with extensive caries. Retention is of great importance for a successful restoration and is provided by various factors such as luting cements. The aim of this study was to evaluate the retentive strength of SSC cemented with four different luting cements.

Materials and Methods: In this *in vitro* study, A total of 55 extracted primary first molars were selected. Following crown selection and cementation (one with no cement and four groups cemented with resin, glass ionomer, zinc phosphate, and polycarboxylate), all the specimens were incubated and thermocycled in 5°C–55°C. Retentive properties of SSCs were tested with a mechanical test machine. First dislodgement of each specimen and full crown removal were recorded. One-way ANOVA test followed by least significant difference test and Kruskal–Wallis test was used for retentive strength comparison at the level of significance of $P < 0.05$.

Results: The results of the study showed that the specimens cemented with zinc phosphate exhibited higher retentive strength as compared to glass ionomer and polycarboxylate ($P < 0.001$ and $P = 0.023$, respectively).

Conclusion: Zinc phosphate cement showed the most promising results; thus, it can be preferably used for cementation of the teeth with no grossly broken down crowns.

Key Words: Bond strength, luting cement, retentive, strength, stainless steel

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INTRODUCTION

The use of the stainless steel crown (SSC) with improved mechanical properties has become a common and reliable practice for the management of primary teeth with extensive caries.[1] Retention value plays a significant role to ensure a successful restoration when applying these crowns. Various factors contribute toward this feature, such as proper marginal adaptation within the undercuts; design of the tooth and marginal seal; crown length and surface area.[2]

One key factor on which the success of such restorations depends is utilization of proper luting cement; the material that fills the space between the tooth and the restoration, resulting in retention and adhesion.[3] The desired properties for luting cement materials are as follows: biocompatibility, low solubility in oral fluids, appropriate marginal seal, minimal film thickness, low viscosity, easy manipulation, and sufficient working time with rapid

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set. High tensile strength, maximum compressive and retentive strength, as well as proper adhesion to tooth/restoration are other crucial factors which contribute to the overall success of a luting cement.[4,5]

Four main groups of dental materials have been used for crown cementation for many years, namely glass ionomer cement, zinc phosphate cement, resin cement, and polycarboxylate cement.[4] Each type of cement has its own advantages and drawbacks.

Zinc phosphate cement is one of the most popular cements, which has been in use for many years. The success of this material has been attributed to high retentive and fatigue strength as well as its minimal film thickness of <25 μ.[3,6-8]

Polycarboxylate cement and glass ionomer cement have attracted attention due to their ability to bond chemically with various restorative materials and to tooth structure. According to some studies, glass ionomer cement seems to have higher retentive and compressive strength than other luting cements.[3,9-11]

Certain disadvantages of these cements, such as low retentive values despite several advancements, have led scientists to develop methods in an attempt to improve the essential properties of luting cements. Resin cement, for example, is particularly attractive because of its high retention, low solubility in oral fluids, and its ability to adhere to different materials.[12-14] In a study conducted by Subramaniam *et al*.,[15] they reported that retentive properties of resin cement and resin modified glass ionomer are statistically higher than those of conventional glass ionomer cement.

The disparities expressed in several conflicting studies that exist in the literature over many years have created an atmosphere of confusion among practitioners in terms of selecting a desirable cement material with improved biophysical and mechanical properties; a fact which underlines the need for the present study.

Hence, the present study has been undertaken to evaluate and compare the retentive strength of SSCs cemented with four different luting materials: glass ionomer cement (GC Gold Label 1, Luting and Lining Cement, GC Corporation, Tokyo, Japan), zinc phosphate cement (Master Dent, Dentonics, Inc., USA), polycarboxylate cement (Master Dent, Dentonics, Inc., USA), and self-adhesive resin cement (BisCem, dual-cured self-adhesive resin cement, BISCO, Inc., IL, USA). The null hypothesis was that there are no differences in retentive properties of the four experimental luting cement.

MATERIALS AND METHODS

Tooth preparation

This *in vitro* study protocol was approved by the Ethical Board of Mashhad University of Medical Sciences (IR.MUMS.REC.1391.72), and written informed and detailed consent was obtained from the parents of 10–12-year-old patients referred to the Department of Pediatric Dentistry, Faculty of Dentistry, for the purpose of primary tooth extraction. A total of 55 extracted primary first molars, intact or with minimal occlusal caries, without proximal, buccal, or lingual caries, restoration or developmental defects and with tooth root resorption rate more than one-third were selected for the study. Teeth were scaled and cleaned to remove tissue remnants and stored in a germ-free 0.1% thymol solution at room temperature for a maximum of 1 month before use. Measurement of the mesiodistal and buccolingual surfaces of the teeth was performed by a digital caliper (Series 500 Mitutoyo, Tokyo, Japan) with a level of accuracy of 0.01 mm to enhance the uniformity of the samples. Specimens may vary within the range of 1 mm in mean size.

The teeth were embedded in acrylic resin blocks measuring 1.5 cm × 1.5 cm × 3 cm to 1 mm below the cementoenamel junction (CEJ) along their long axes [Figure 1a]. Thereafter, all the teeth were prepared with a standardized protocol, the occlusal surfaces were reduced uniformly 1–1.5 mm[16] with a 169 L bur (SUNSHINE, Dental Burs, CA, USA) using an air turbine under a copious amount of water, and a circular box measuring 2.5 mm in diameter and 0.5 mm in depth was made on the occlusal surface of each tooth to receive the nail head which will be subsequently described. The crown preparation was completed by reducing mesial and distal surfaces up to 0.5 mm with the angle of convergence of 8°–10°s using[16] compasses aiding to produce the same angle of convergence for all the specimens. All mesial and distal undercuts were removed using diamond bur (#169, SUNSHINE, Dental Burs USA, CA, USA) and sharp angles were made rounded [Figure 1b].

Crown preparation

After tooth preparation, finish line of proximal surface of each tooth was surveyed again by a

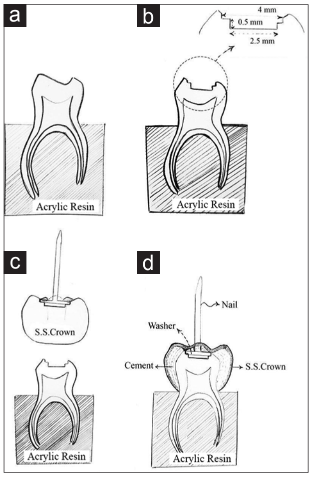

Figure 1: Steps of crown preparation. (a) Prepared tooth ready for crown selection (b) Tooth preparation for nail/washer setting (c) Prepared tooth/crown ready for cementation (d) Cemented tooth/crown.

gage. Mesiodistal length of the teeth was measured by periodontal probe, and in accordance, suitable crowns (3M. ESPE, St. Paul, USA) were selected.

After crown selection, a hole was made from the occlusal surface of the tooth through central fossa of SSCs with a 557 carbide bur's tip (1 mm wide), and a nail measuring 19 mm in height, 1 mm in shank diameter, and 2.5 mm in flattened head's diameter was put through the hole from the undersurface of the crown to facilitate the attachment of the test machine. The nail was firmly fitted into the hole. The applied load to nail was directed parallel to the long axis of the tooth during crown removal. A fine metal washer measuring 4 mm in diameter, 2 mm in diameter of the centric hole, and 0.2 mm in width was placed into the crown [Figure 1c]. After the cement was set, the washer would be rigidly fixed, and it helped to disseminate force and to avoid crown deformity [Figure 1d]. All the crowns were double-checked for consistency with CEJ and were fitted and uniformly contoured (Dental Instruments, Ball and Socket Plier, Pakistan) and crimped (Dental Instruments, Ball and Socket Plier, Pakistan).

Cementation

Samples were randomly divided into five groups of 11 teeth each group, i.e., zinc phosphate cement, polycarboxylate cement, resin cement, glass ionomer cement, and no-cement group. All specimens were cemented according to the manufacturer's instructions [Table 1]. Two-third of the inner surface of each crown was filled with the cement and was firmly placed on the tooth with finger pressure. To ensure an even seating pressure, no excessive force was applied to the crowns during the primary setting of the cement. Excess cement was removed according to the manufacturer's specifications.

Table 1: Powder-liquid ratios and mixing times of dental cements

Cement	Normal proportion	Mixing time (s)
Zinc phosphate	32 g/17.5 ml	20
Polycarboxylate	25 g/15 ml	20
Glass ionomer	15 g/8 ml	20
Self-adhesive resin	Base/catalyst 8 g mixed	-

One minute after setting time, all the specimens were placed in artificial saliva, which consists of albumin, methyl cellulose, sodium carboxymethyl cellulose, potassium chloride, sodium fluoride, magnesium chloride, glucose, and methyl paraben (Faculty of Pharmacy, Mashhad University of Medical Sciences, Mashhad, Iran) and then incubated (Incubator Machine, Shin Saeng Scientific Co., Ltd) for 24 h at 37°C and subjected for 72 h to 5000 rounds of thermal cycling (Thermocycling Machine, Nemov Co.) between 5°C and 55°C with a dwelling time at 30 s [Figure 2].

Retention measurements

Retentive properties of SSCs were tested with a Universal Test Machine (Santam STM-20, Tehran, Iran), while the applied force was done by directly engaging the specimen to lower cross-head and the nail was fixed between two surfaces of upper cross-head of the universal machine. The force was directed parallel to the long axis of the tooth, at a cross-head speed of 0.05 inch/min. The retention force was sketched automatically in *N* using Santam software (STM Controller Software, Santam, Tehran, Iran). First dislodgement of each specimen was recorded as retentive strength; testing proceeded until the SSC was fully debonded from the tooth. This figure was recorded as peak force. Readings were noted separately in kg/cm^2 [Figures 3 and 4].

Statistical analysis

Mean (standard deviation) was used as descriptive statistics of normal variables and quartiles for nonnormal variables. Normality of variables was evaluated by Kolmogorov–Smirnov test. To compare the means of first dislodgement and peak force among study groups, one-way ANOVA test was used. *Post-hoc* test of Tukey was done for pairwise comparisons between groups. Kruskal–Wallis test was done for comparison of distribution of delta, among groups. Statistical analysis was performed by means of

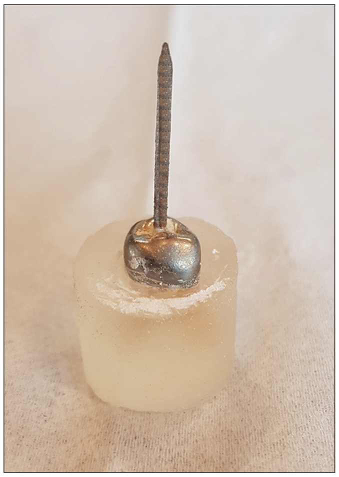

Figure 2: Prepared/cemented crown ready for pull-out test.

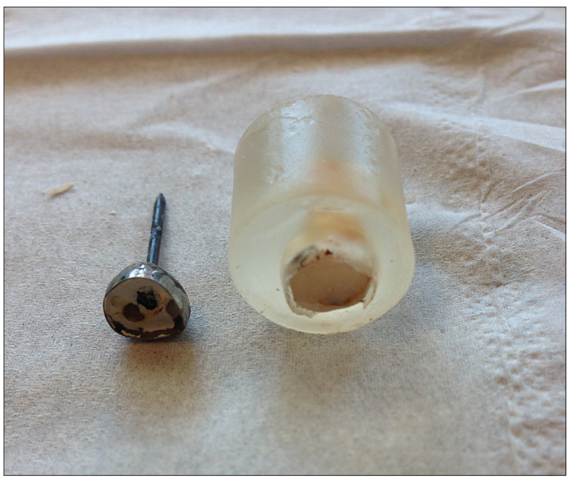

Figure 3: A picture of fully debonded crown from the tooth.

SPSS 21.0 for Windows software (SPSS Inc., Chicago, IL, USA) at the level of significance of $P < 0.05$.

A flowchart of method steps is shown in Figure 5.

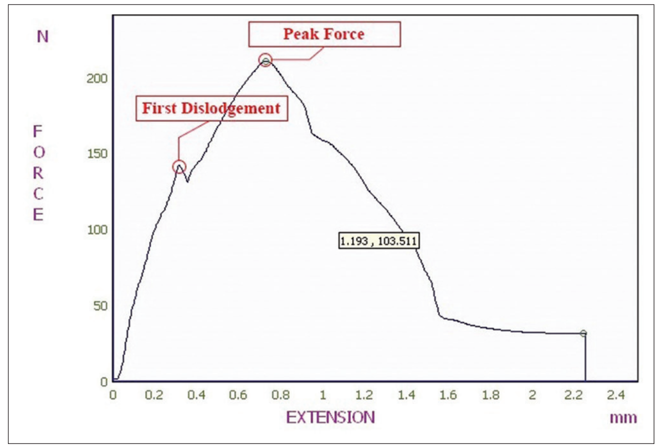

Figure 4: A graph of relationship between force and extension, depicting the first dislodgement and peak force.

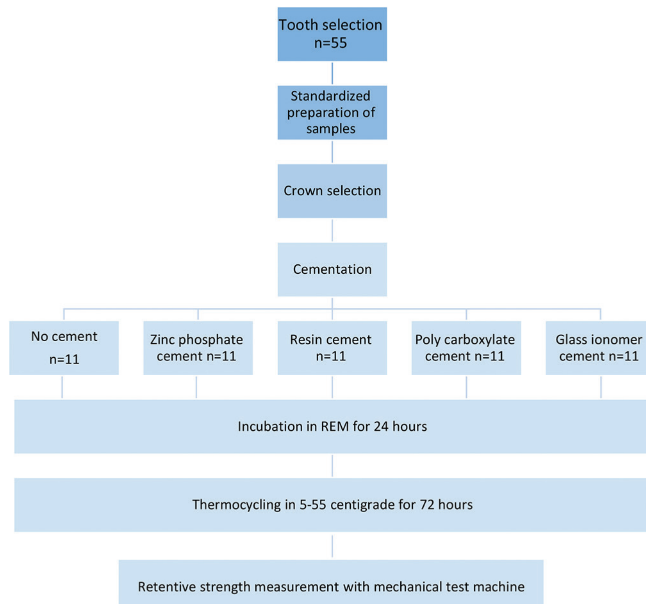

Figure 5: A flowchart of method steps.

RESULTS

The results obtained from the measurement of retentive strengths of SSCs luted with four different cements are categorized into three groups.

First dislodgement of the crowns

Polycarboxylate cement and zinc phosphate cement showed maximum and minimum retentive strength values, respectively. Statistically, significant difference was observed among the means of the first dislodgement of the study groups using one-way ANOVA test ($P = 0.003$).

As shown in Table 1, the mean value of zinc phosphate cement group was statistically higher than other groups in terms of retentive strength according to the pairwise comparison of the groups done by least significant difference (LSD) test (glass ionomer cement $P = 0.003$, resin cement $P = 0.044$, and polycarboxylate cement $P = 0.001$). There were no significant differences among other groups.

No results from uncemented group were demonstrated for the first dislodgement.

Fully separation of the crown from tooth (peak force)

According to one-way ANOVA test, crowns cemented with polycarboxylate cement and zinc phosphate cement yielded the lowest and highest mean values of peak force, respectively. The results clearly indicate that there were significant differences among the study groups ($P < 0.001$).

The pairwise comparison of the specimens using LSD test revealed that the mean values of peak force in zinc phosphate cement were significantly higher than those of glass ionomer cement and polycarboxylate cement ($P = 0.023$ and $P < 0.001$). On the contrary, there were no significant differences between zinc phosphate cement and resin cement and between resin cement and glass ionomer cement in terms of retentive strength. Resin cement and glass ionomer cement showed statistically higher retentive strength means than polycarboxylate cement ($P = 0.004$ and $P = 0.009$).

All cemented SSCs demonstrated significantly higher retentive strength values than uncemented specimens ($P < 0.001$).

The difference between first dislodgement and peak force (delta)

Although no statistically significant differences were noted among study groups in this category using Kruskal–Wallis test, the maximum value was for glass ionomer cement and the minimum value was for polycarboxylate cement in terms of the difference between the first dislodgement and peak force [Table 2].

DISCUSSION

SSC continues to be used to restore fairly damaged deciduous teeth as a result of pulpal or periapical diseases. An important consideration to improve clinical success of such restorations is luting cement with characteristics within clinical acceptability. This study was performed to check the facts and compare the retentive properties of four different luting cement within the limits of available resources.

Tooth selection/preparation

Standardization in the study was done by selecting and preparing all the specimens among first primary molars with similar sizes and conditions. Second molars were removed due to their extreme deformity following pull-out test and to limit the defects that may creep into the study.

Preparation of the samples was done with occlusal convergence angle of 8°–10°. Some studies show that maximum retention of the crowns is achieved when preparation is set at this degree.[3,8]

A nail and a fine metal washer were used in the present study to remove the crowns by Instron Test Machine. Using first primary molars with their small sizes alongside, a washer can both help to disseminate force during force application and to avoid focused force and crown deformity. In oral cavity, sticky and chewy food may create some kind of pull-out force similar to our method.

Yilmaz *et al.* used the same procedure as ours for crown removal test; however, washer was not used in their study.[17] In a study done by Gorodovsky and Zidan,[8] metal crowns were cast with a high noble gold ceramic alloy and then pull-out test was performed.

In the present study, with all these considerations, sample lost was reduced to zero, despite the fact that crown deformity seemed inevitable.

Force application test evaluation (first dislodgement and peak force)

First dislodgement

This record is of importance because of:

1. To determine which cement shows first dislodgement among the study groups
2. To determine the difference between this record and complete crown removal (delta). The higher this difference is, the more capable the cement is to tolerate intraoral forces. It is equally important that microleakage increases when first dislodgement happens and allows cement dissolution. If delta is low and is accompanied by delayed visit to a dentist, it may lead to failure in crown.

Results of the study were subjected to statistical analysis. Zinc phosphate cement yielded

Table 2: Comparison of first dislodgment, peak force, and delta among groups

Variables	Groups					P
	Glass ionomer (*n*=11)	Resin (*n*=11)	Poly-carboxylate (*n*=11)	Zinc phosphate (*n*=11)	Un-cemented (*n*=11)	
First dislodgment (Kg/Cm^2)	196.12 (50.13)^{a}	228.86 (83.72)^{b}	179.25 (57.48)^{c}	293.07 (85.34)^{a,b,c}		0.003†
Peak force (N)	286.75 (54.12)^{a,e,h}	297.97 (55.12)^{d,g}	210.90 (70.21)^{b,d,e,f}	352.04 (75.07)^{a,b,c}	29.07 (5.57)^{c,f,g,h}	<0.001†
Delta	68 (35, 120)	74.25 (17.42, 121.03)	11.93 (0.27, 63.16)	34.05 (0, 92.13)		0.067‡

Mean (SD) for normal variables and Q2 (Q1, Q3) for non-normal variables (quartiles) Within each row, means with the same superscript letters a, b, c, d, e, f, g or h are statistically different from each other.†One-way ANOVA ‡Kruskal-Wallis test SD: Standard Deviation significantly higher mean value than other study groups, and there were no significant differences among other groups.

The higher first dislodgement of the crown occurs, the more probable the cement cracks by strong forces, leading to more suitable cement. This consideration in our study shows how detailed we looked into the matter. However, other researchers merely evaluated complete crown removal and failed to signify delta,[3,8,9,17,18] while microleakage and cement dissolution occur after first dislodgement and affect overall success of the prosthesis. Microleakage and the loss of marginal integrity may allow cement dissolution, plaque accumulation, and postoperative sensitivity which may result in crown failure.[19] Hence, selection of a cement that can provide reasonable hermetic seal at the tooth structure-restoration for the clinical use is essential.

Complete separation of the crown from tooth

Based on the results of the present study, polycarboxylate cement exhibited the lowest retentive strength and zinc phosphate cement showed the highest value. In pairwise comparison, retentive capability of zinc phosphate cement was significantly higher than those of glass ionomer cement and polycarboxylate cement but not so between zinc phosphate cement and resin cement. As expected, all cemented groups showed higher values than our control group, uncemented specimens, due to crown crimping. These observations are in accordance with the results found by Raghunath Reddy *et al*.[20] in 2010, who showed that zinc phosphate cement and glass ionomer cement have higher retentive properties than their counterparts cemented with resin cement and polycarboxylate cement. The probable reason zinc phosphate cement offers the highest retention can be attributed to low solubility although water contamination should be avoided during setting process. Low initial pH of this cement has etching effect on enamel which can improve bond strength.[8] The main advantage of zinc phosphate cement is its thin film thickness of $<25\ \mu$. This creates intimate adaptation in interfaces and better sitting of the crown.[9,21] What has to be kept in mind is that film thickness is of significance when tooth structure is quite healthy and caries free, thus the tooth can be prepared in a standardized manner. However, in clinical term, there is usually extended caries area in teeth and conditions do not exactly coincide with those seen in an *in vitro* situation.

In the present study, it was inferred that specimens cemented with resin cement produce better retentive features following zinc phosphate cement. On the contrary, Krunić and Tonić presented that resin cement exhibits the highest bond strength.[22] This difference could be due to dissimilarity in the tooth used and crown type, tooth preparation, and study method. The authors have quoted that dentin bonding agents can promote adhesion of resin cements to tooth and other restorative materials.[8] Our study would have produced different results if we had applied bonding agent. However, according to manufacturer's instruction, we did not use any bonding. Browning *et al.* also demonstrated that resin cement shows significantly higher retentive force than glass ionomer cement and zinc phosphate cement.[23]

Difference between first dislodgement and complete crown removal (delta)

Regarding our results, good cement is the one with high value for first dislodgement, so as for delta (difference between first dislodgement and complete separation of the crown from tooth). Not only it gives adequate time to the patient for his visit to dentist, but also it shows the cement can enable intimate contact between tooth and crown. In the present study, glass ionomer cement exhibited the highest mean value for delta although no significant findings were observed. From these results, it can be suggested that glass ionomer cement may be a wise choice for crown cementation in pediatrics due to its advancements such as fluoride release, anticariogenic property, adhesion to tooth and base metal, proper mechanical characteristics, and high compressive strength.[21,24] In addition, because resin cement has high compressive and tensile strength and it can adhere to different surfaces, it was expected to show better retentive values.[25] However, disadvantages despite various advancements in resin cement such as high technique sensitivity, high cost, and high film thickness may be the reasons why this cement is not widely used for cementation of the SSCs in primary teeth.[26]

Hence, the use of zinc phosphate cement is advisable in pediatric clinical practice besides glass ionomer cement for crown cementation.

The present *in vitro* study was performed to check the retentive properties of luting cement while the association of marginal fit and dissolution with retention needs to be investigated in the future studies to simulate the clinical reality. While the future studies may assess the retentive properties from different angles such as scanning electron microscope, our main objective was to test it via pull-out technique mainly in primary teeth.

Limitations

- Caries-free teeth or with small occlusal cavities in first primary teeth were hard to find
- In clinical term, SSC is usually applied on teeth with extensive caries; thus, the retention strength might be different
- Our study lacks long-term results
- Clinical evaluation of such studies is limited due to ethical and mechanical issues.

CONCLUSION

Within the limitation of this study, it is concluded that zinc phosphate cement is the most acceptable material for luting SSCs to teeth with no extensive caries.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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