Comparison of Fracture Strengths among different Commonly Placed Anterior Esthetic Restorations for Primary Dentition: An *in vitro* study

Brent Lin* / Amit Khatri**/ Michael Hong ***

The purpose of this study was to determine and compare the shear force (N) required to fracture or dislodge an all-ceramic zirconia-based crown using different luting cement with those of polycarbonate crown and strip crown for the primary anterior teeth in vitro. ***Study design:*** *Four groups of esthetic restoration for primary anterior teeth were tested for fracture strength: 1) Fifteen all-ceramic zirconia-based crowns cemented with glass ionomer cement, 2) Fifteen all-ceramic zirconia-based crowns bonded with a self-adhesive resin cement, 3) Fifteen polycarbonate crowns cemented with a polymer reinforced zinc-oxide eugenol and 4) Fifteen resin strip crowns. All restorations were placed and cemented on reproductions of dies in an independent laboratory at Delhi, India. All samples underwent loading until fracture or dislodgement with the Universal Testing Machine. The force in Newton (N) required to produce failure was recorded for each sample and the type of failures was also noted and characterized. One-way analysis of variance (ANOVA) test and the Tukey and Scheffe's post hoc comparisons were used for statistical analyses.* ***Results:*** *In this invitro study, results were measured in Newtons (N). Group 1 (410.9±79.5 N) and Group 2 (420.5±57.8 N) had higher fracture strength than Group 3 (330.3+85.6 N) and Group 4 (268.4+28.2 N). These differences were statistically significant at P≤.05 among the sample groups. No significant difference was found between groups 1 and 2 (P = 0.984) nor between groups 3 and 4 (P =0.104). Among type of failures, majority of restoration fractures for zirconia-based crowns and resin strip crowns were due to cohesive failures and polycarbonate crowns had predominantly mixed failures.* ***Conclusions:*** *Under the limitations of this in vitro study, it could be concluded that all-ceramic zirconia-based crowns attained the highest fracture strength among all restorative samples tested regardless of the type of luting agent employed (P<.01). Cohesive failures were commonly observed in the zirconia crowns and resin strip crowns, whereas polycarbonate crowns revealed predominately mixed failures.*

Keywords: *Fracture strength, Esthetic restorations, Primary teeth, Full coverage crown*

INTRODUCTION

With current raising awareness of dental disease prevention and a systematic approach on caries risk assessment, dental professionals possess a tool and protocol to determine the caries risk level and have an opportunity to prevent the extent and severity of dental caries in children. However, early childhood caries (ECC) is still prevalent among children who exhibit recognized factors and indicators of high caries risk. Early childhood caries (ECC) remains a significant problem challenging our diagnostic, preventive and restorative skills[1-2]. Due to the nature of ECC and area of affected dental structure, a restoration with full coronal coverage is usually indicated[3]. Various options are available having its advantages and disadvantages that provides full coverage restoration for anterior primary dentition[4]. The polycarbonate crown is fabricated from heat-molded acrylic resin and has provided an esthetic treatment alternative for primary and permanent teeth[5].

*Brent Lin, Clinical Professor, Division of Pediatric Dentistry, UCSF School of Dentistry, San Francisco, CA.
**Amit Khatri, Professor, MDS, Department of Pedodontics and Preventive Dentistry, University College of Medical Sciences, Guru Teg Bahadur Hospital, University of Delhi.
***Michael Hong, Lecturer, Department of Developmental Biology, Harvard school of Dental Medicine, Boston, MA.

Corresponding author:
**Amit Khatri, Department of Pedodontics and Preventive Dentistry, University College of Medical Sciences, Guru Teg Bahadur Hospital (University of Delhi), Delhi-110095 , India
Mobile:+ 9999954120
E-mail : Khatri9804@rediffmail.com

There were limited studies done on evaluating the polycarbonate crown, and published reports have shown frequent dislodgement and fracture associated with the use of polycarbonate crown[6-7]. This may be due to the physical property of material and its inability to be crimped and hence its retention is depended on luting cement. In addition, its strength and effectiveness as a primary tooth restoration has not been evaluated. Another esthetic and popular choice for restoring primary anterior dentition is resin strip crown utilizing celluloid crown forms to provide a clear, rigid mold for composite restoration. Resin strip crowns offer one of the most esthetic restorative alternatives and have been widely used in restoring anterior primary teeth worldwide [5]. In long term clinical study by Kupietzky, resin strip crowns demonstrated a high retention rate with fair color match and color stability. This study finding suggested strip crowns may be indicated as an excellent treatment choice for carious primary incisors with adequate tooth structure after caries removal, especially if esthetic concerns predominate [8].

Recently, zirconium dioxide ceramic pre-fabricated crown has been used in treatment of anterior primary teeth. All-ceramic zirconium crown is a viable option in providing esthetic, durable restoration with ease of placement [9]. In Larsson's study, of zirconium dioxide based dental restoration in permanent dentition the material has demonstrated high wear resistance, excellent biocompatibility, and superior corrosion resistance [10.] Unlike other ceramic materials, zirconia can withstand tensile stress as well as metals and can defy crack propagation through phase transformation at the crack tip (transformation toughening) or the introduction of microcracks of particles (microcrack toughening)[11]. Although zirconium crown has shown promise, limited study has been done in comparison of its clinical effectiveness and durability with other commonly placed esthetic restorations for primary teeth. The purpose of this *in-vitro* study was to investigate the fracture strength of all-ceramic zirconia-based crowns and compare it with other similar and commercially available anterior non-metallic esthetic crowns in a laboratory setting. Shear force strength and durability will be quantified for each sample group and type of failures will be noted and be characterized.

MATERIALS AND METHOD

Sixty samples of three commonly placed, full-coronal coverage, primary tooth restorations were tested and consisted of four groups.

Group 1: Fifteen all-ceramic zirconia-based crowns (EZ Pedo, Loomis, Calif., USA) cemented with glass ionomer cement (Fuji I, GC America, Alsip, IL., USA).

Group 2: Fifteen all-ceramic zirconia-based crowns (EZ Pedo, Loomis, Calif.,USA) bonded with a self-adhesive resin cement (RelyX Unicem,3M ESPE., St. Paul, Minn., USA).

Group 3: Fifteen polycarbonate crowns (PedoNatural, Valencia, Calif., USA) cemented with a polymer-reinforced zinc oxide-eugenol cement (IRM Dentsply / Caulk,Milford, DE,USA).

Group 4: Fifteen conventional Pedo strip crowns (3M ESPE, St. Paul., Minn., USA).

Typodont teeth of the maxillary primary anterior incisor were prepared according to the standard preparation design for each type of restorations, and a negative replica was fabricated with mold of polyvinylsiloxane impression material (Aquasil, Dentsply/ Caulk, Milford, DE., USA) using self designed Jig. Crowns were placed in the mold and cemented or bonded onto the aged reproduction of dies based the manufacturer's instructions.

All samples were then placed in distilled water and stored in an incubator at 37 °C for 48 hours. The crowns were thermal cycled at 4°C and 55 °C for 500 1-min cycles[12]. Each die was then placed into a custom holder on the Universal Testing Machine. With a crosshead speed of 1 mm/min, force was applied to the incisal edge at 148° (the primary inter-incisal angle) until the crown fractured or was dislodged. The force in Newton (N) required to produce failure was recorded, and type of failures (adhesive, cohesive, or mixed) was noted and characterized for each sample.

Data was entered into the Excel spread sheet and was analyzed with SPSS statistic program. One-way analysis of variance (ANOVA) test was used to detect whether a significant difference existed among the mean fracture strengths of each sample group. Tukey and Scheffe's post hoc comparisons were also performed, and the differences were statistically significant when P-value ≤ 0.05.

RESULTS

Sixty samples of commonly placed anterior esthetic restorations were tested and fracture strengths were determined. The means, Standard deviation, minimal and maximal values of the fracture strengths measured in Newton (N = Force in Newton) of the four different groups are shown in Table 1. The mean fracture strength is highest in all-ceramic zirconia-based crowns with mean force required to fracture of 410.9 ± 79.5 N in group 1 and 420 ± 57.8 N in group 2 compared to the mean fracture forces of polycarbonate crowns and conventional resin strip crowns, which are 330.3+85.6 N and 268.4+28.2 N respectively. The comparative bar graph of the means and standard deviation for each group are presented in Figure 1.

The one-way ANOVA test was performed and indicated significant difference between groups at P-value <.0001 (Table 2). The Tukey and Scheffe's post hoc comparisons showed both groups of zirconia-based crowns have significant higher mean fracture strengths than those in sample groups of polycarbonate crowns and conventional resin strip crowns. These differences were statistically significant at $P \leq .05$ among the sample groups.(Table 3). However, among two groups of zirconia-based crowns, restorations bonded with self-adhesive resin cement tend to have higher fracture strength than restorations cemented with glass ionomer cement, although the differences were not statistically significant (P-value =.984). Conventional resin strip crowns have lower mean fracture strength than polycarbonate crowns. However, this difference was not statistically significant (P-value =.104).

In the present study, after fracture strength analysis, all the samples were analyzed to evaluate the nature of bond failure. Adhesive failure occurred along the adhesive interface. Cohesive failure occurred within resin composite or zirconia and mixed failure occurred within adhesive joint with failure within the resin composite or zirconia.[12]

Table 4 reveals that the majority of restoration fractures for zirconia-based crowns and resin strip crowns were due to cohesive failures (13, 12 and 14 samples in group 1, 2 and 4 respectively) Adhesive failure was observed only in one sample in group 4. Within the group of polycarbonate crowns (Group3), more mixed failures (11 samples) were observed among test samples than cohesive failures.

Figure 1–Comparison of mean fracture strength among 4 groups of Esthetic restoration

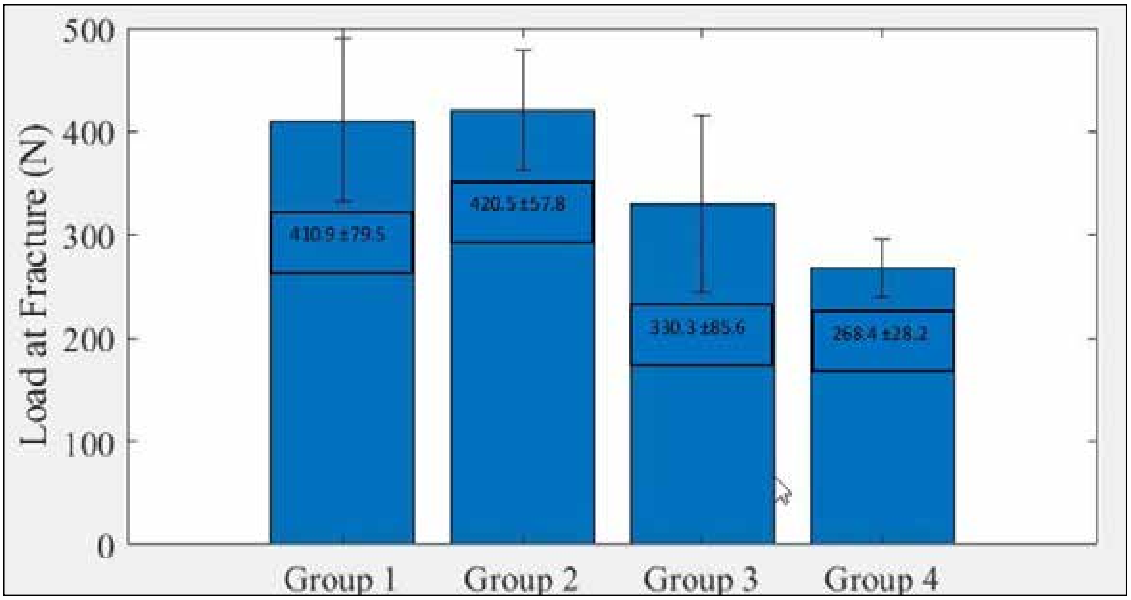

Table 1. Force required to fracture among 4 groups of three anterior esthetic restoration

Crown Type	No. of Crowns	Force Required to Fracture (N)					
		Mean	SD	SE	Min	Max	95% CI
Group 1	15	410.9	79.5	20.5	207	528	370.7-451.2
Group 2	15	420.5	57.8	14.9	300	514	391.3-449.8
Group 3	15	330.3	85.6	22.1	223	474	287.0-373.7
Group 4	15	268.4	28.2	7.3	221	325	254.1-282.7

Group 1: all-ceramic zirconia-based crowns cemented with glass ionomer cement

Group 2: all-ceramic zirconia-based crowns bonded with a self-adhesive resin cement

Group 3: polycarbonate crowns cemented with a polymer-reinforced zinc oxide-eugenol

Group 4: conventional resin strip crowns utilizing celluloid crown forms

*N = Force in Newton

Table 2. One-way ANOVA for fracture strength

Source of Variation	Sum of Squares (SS)	degree of freedom(df)	Mean Square(MS)	F Ratio= MSB / MSW	P-value
Between Groups	232577.3	3	77525.75	17.3	P<.0001
Within Groups	249779.6	56	4460.35		
Total	482356.9	59			

Between Groups degrees of freedom: df = k − 1, where k is the number of groups, Within Groups degrees of Freedom: df = N − k, where N is the total number of samples, Total Degrees of Freedom: df = N – 1, Mean Square Between Groups: MSB = SSB / (k − 1), Mean Square within Groups: MSW = SSW / (N − k)

Table 3. Result of multiple comparisons for fracture strength

Group (M_1)	Group (M_2)	Mean Difference (M_1-M_2)	Tukey's HSD(Honest Significant differanc) (q)	*P* value
Group 1	Group 2	-9.6	-0.5	.984
Group 1	Group 3	80.6	4.6*	.018*
Group 1	Group 4	142.5	8.2*	.000*
Group 2	Group 3	90.2	5.2*	.006*
Group 2	Group 4	152.1	8.8*	.000*
Group 3	Group 4	61.9	3.59140741	.104

*Statistical significance at *P*≤.05

Table 3. Result of multiple comparisons for fracture strength (continued)

$$HSD = M_1 - M_2 / \sqrt{MS_W \left(\frac{1}{n}\right)}$$

Where HSD-Honestly significant difference, M1, M_2 are mean values, MSw-Mean square within groups, n-Number per mean.

Table 4. Type and number of observed failures

Crown Type	Number of Adhesive Failures	Number of Cohesive Failures	Number of Mixed Failures
Group 1	0	13	2
Group 2	0	12	3
Group 3	0	4	11
Group 4	1	14	0

DISCUSSION

Restorative options of full coronal coverage for primary anterior teeth are few and have inherited shortcomings and limitations. Several esthetic treatment options (such as strip crowns, polycarbonate crowns, and zirconia crowns) are reported in the literature for restoring decayed primary anterior teeth[5, 6,7,8,9, 13,14].

Recently, all-ceramic zirconia-based crowns have garnered attention as an excellent alternative in providing full coronal coverage. While a number of studies testing the strength and durability of these various crowns focus on permanent dentition[15], studies on the all-ceramic crowns for primary dentition are limited[16-17]. Study has shown that the force required to fracture primary anterior zirconia crown ranged from 751.43±102.103 to 937.36±131.69[16]. The fracture strength of anterior zirconia crown tested in this study are lower and ranged from 410.9±79.5 N to 420±57.8 N.Our current study investigated and compared the mean force in Newton (N) required to fracture different full-coverage coronal restorations of primary anterior teeth and characterized type of failure of these materials in a controlled environment.

Overall, the all-ceramic zirconia-based crowns withstood significantly more stress loading than polycarbonate crowns and strip crowns at the time of fracture or dislodgement. Similar failure rates were observed in the zirconia crowns cemented with the glass ionomer cement and zirconia crowns cemented with resin cements, and no statistically significant difference is noted. It is consistent with the study by Palacios and Wahadni that types of cement may not significantly affect treatment outcomes[18-19].The two groups of zirconia crowns and the resin strip crown group also demonstrated nearly identical fracture patterns with predominately cohesive failure, although the resin strip crowns failed at a significantly lower fracture load than the zirconia crowns. The polycarbonate crown group, however, demonstrated random failure patterns with the vast majority of mixed failures with some cohesive failures and fractured at a significantly lower stress load of force.

Similar to the study by Roman-Rodriguez, our study demonstrated a relationship between failure patterns, observed fractures, and the loading forces[20].The cohesive failures appeared to occur at higher loads than adhesive failures. Zirconia crowns of Group 1 and 2 demonstrated their cohesive failures at an average of 420.5N and 410.9N respectively. Group 3 polycarbonate crowns averaged their mixed failures at 330.3N. Group 4 is exempt from this analysis due to the use of etch and bond to develop a hybrid layer at the dentin-resin interface and resin tags with adhesive lateral branches, which aid in fabricating microscopic aspects of an affective bond[21]. However, Groups 1, 2 and 3 relied strictly on luting agents and mechanical bonding for adhesion. In addition, the lack of adhesive failure in the zirconia and resin strip prostheses can be attributed to their superior bonding. Lack of adhesive failure in the zirconia and resin strip prostheses may be attributed to superior bonding strength. While studies postulate that zirconia crowns do not bond well to dentin due to their high purity crystalline structure[22-23], the zirconia crowns in our study have added retention feature with luted Zirlock (surface roughened micromechanical retention grooves within the internal walls of the crown) to improve the adhesion property[24]. This addition to our cementational interface may lead to reduced occurrence of adhesive failure, compared to other zirconia crowns.

Mastication and biting force in primary teeth are also less compared to the permanent dentition, as the child's muscle strength is still developing[25]. Studies have shown the mean maximum occlusal bite force of children in the late primary dentition is 240.37±92.56 N[26]. The fracture strengths of all materials tested in this study are more superior and higher than the occlusal bite force of average children in the late primary dentition. As the deciduous teeth exfoliated and replaced by the permanent teeth, the ensuing masticatory forces increase. The occlusal bite force tends to increase with age as masticatory muscle develops and reaches peak in males at the age of 20 years and females at the age of 17[27]. As a child approaches the late mixed dentition stage, the fracture strength of zirconia crowns among all materials tested in our study is the only one demonstrated a comparable strength to the mean maximum occlusal bite force of 432.62 N in children at the late mixed dentition[26].

The advantage of this study as being an *in vitro* fracture strength test was that the limiting confounding variables can be achieved with stringency and relative ease and hence offered sound internal validity. Performed in a controlled laboratory environment, this study was able to prevent biases from testing, instrumentation, regression, and other factors. Multiple loads of fracture test were performed in duplicate dies, this study evaluated the basic mechanical property in fracture strength while providing additional insight on the stress distribution. Similar to the Waggoner's study design[12], the incisal bite force was determined by setting the universal machine to 148 degrees to emulate the primary interincisal bite force.

The limitation of this laboratory study is the small sample size and its challenge to duplicate the *in-vivo* clinical scenarios. For example, in fracture to failure tests, instead of considering the first failure, the restoration was overloaded until catastrophic fracture occurred. The results could be misleading and overestimated failure load that is not plausible under normal chewing cycles[28].In addition, intra-oral factors such as the intricate functioning of the masticatory cycle, the nature of occlusion, presence of intra-oral fluid and saliva, and the complex composition of teeth and their surrounding tissues are simply not reproducible, thus limiting the external validity of the study[29].

In a zirconia study by Aboushelib *et al*, results showed that not only differences in the failure types were observed between clinically fractured zirconia veneered all-ceramic restorations and their laboratory fractured counterparts, but the estimated failure stresses were also significantly different[29]. Nevertheless, within the limitations of this study, we were able to evaluate the fracture strength of different types of esthetic materials in restoring anterior primary teeth and demonstrated monolithic zirconia crowns to sustain the highest fracture loading among other materials tested in a controlled laboratory setting.

However, the clinical situation cannot be reproduced through the test performed in this study. This study intended to set up an *in vitro* platform to evaluate the restorative materials that amalgamate esthetics and strength. Fracture strength is perhaps one of several but critical factors in determining the durability of a restoration. Consequently, further studies are required to evaluate the effectiveness and treatment outcome of esthetic, restorations for primary anterior teeth in a clinical setting are warranted at this time.

CONCLUSIONS

Based on the study results, the following conclusions can be made:

1. In a laboratory study, all-ceramic zirconia-based crowns have higher mean fracture strength and can withstand higher fracture load than polycarbonate crowns and resin strip crowns.
2. No statistical difference in the mean fracture force was observed between zirconia-based crowns cemented with glass ionomer cement and zirconia-based crowns bonded with self-adhesive resin cement.
3. Restoration fractures for zirconia-based crowns and resin strip crowns are mainly due to cohesive failure, while majority of restoration fractures for polycarbonate crowns are due to mixed failure.

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