Determination of Load to Failure of Three Commercially Available Pre-veneered Primary Molar Stainless Steel Crowns

Improved standards of living and better dental education over the past thirty years have given rise to higher expectations for esthetic dental treatment .[1,2] The higher esthetic standard demanded by adults is also being expected for their children. The demand for esthetics, durability, and evidence based restorative care is a challenging balance that dentists must manage.

For over fifty years, stainless steel crowns (SSC) have proven to be some of the most durable and successful posterior restorations for primary teeth. The SSC is used following pulp treatment, for teeth with developmental defects, and caries that involve multiple surfaces.[3] Dawson studied 114 patient records over a minimum of two years and determined that stainless steel crowns were the treatment of choice for primary molars, especially on first primary molars. [4] The results of a Meta analysis of published clinical data on stainless steel crowns spanning 27 years came to the conclusion that preformed crowns were superior to Class II amalgam restorations for multi surface cavities in primary molars. [5] Crowns placed in 4-year-olds and younger show a success rate that is twice that of Class II amalgams for each year up to 10 years of service. [6]

Stainless steel crowns have proven to be durable. Stainless steel crowns are not an esthetic restoration. Parents have expressed that they do not like the way that stainless steel crowns look. [7] The crowns on the lower first primary molars have the most negative comments. [8,9]

There have been several attempts at improving the esthetics of the stainless steel crown. The open-faced SSC was an attempt to use composite inserted into a cut window in the crown. [10,11] The disadvantage of this method is that they are time consuming and the metal window with blood can cause discoloration of the composite, which reduces the esthetic value. [12,13]

Stainless steel crowns with bonded composite veneers have been developed as an alternative to open faced crowns and were first introduced in the mid 1990's. Composite can be bonded effectively to the metal of stainless steel crowns using a bonding agent. [14] Fuks et al. 1999, presented some subjective findings regarding veneered crowns. They reported that although esthetics are improved, occlusal reduction has to be more aggressive, crimping is more difficult, the crowns have to fit passively to avoid facing fracture, the final esthetic result is not always pleasing, and they are expensive. [15]

If the crowns are being chosen for esthetic value, the durability of the composite veneer is of clinical importance. A study by Ram et al, evaluated the clinical performance of 10 NuSmile ™ veneered posterior crowns after four years of service in the mouth .[16] They reported that after 4 years, all the esthetic crowns presented chipping of the facing and consequently, a very poor esthetic appearance.

Laboratory studies have evaluated the shear bond strength of esthetic facings and report shear forces that range from 36.9 kg to 107.2 kg. [13,17] No laboratory studies published to date have evaluated the shear bond strength of composite veneered posterior stainless steel crowns.

The purpose of this study was to compare the fracture resistance of three types of veneered SSC's and to compare the values with the documented maximum masticatory force of children.

Methods

Samples

A total of 75 pre-veneered SSC's from three different companies were used. The crowns were obtained from Orthodontic Technologies Inc. (NuSmile^{TM} crowns, Houston, TX), Mayclin Dental Studio (Kinder Krowns ^{TM}, Minneapolis, MN), and Peter Cheng Orthodontic Laboratory (Cheng Crowns ^{TM}, Drexel Hill, PA). All crowns were primary mandibular left second molar size #4.

A preliminary experiment was conducted using 5 crowns from each manufacturer to determine sample size by power analysis (UCLA Statistic Calculator). The minimum sample size required to detect a significant difference was 15 crowns of each type. Each crown was inspected using light microscopy at 10X to determine if there were any preexisting fractures in the crown surface. There were no preexisting fractures and each crown was accepted for testing.

Testing methods

A symmetric cylindrical stainless steel die was fabricated (figure 1) allowing a passive fit of the crowns, which is recommended by the manufacturers to prevent stress on the veneer.

The stainless steel die was machined and sharp edges were rounded to mimic a standard stainless steel crown preparation. A total of 25 dies with identical dimensions were fabricated.

Each crown was individually cemented with glass ionomer cement (Ketac, 3M ESPE, St. Paul, Minn) to the die. The Ketac cement was used per manufacturers recommendation. It was activated and mixed for 10 seconds. The crown was filled with cement and placed over the die. A 205 (g) standard weight was centered on the occlusal surface for 7-minutes (figure 2). This weight was used to insure that each crown was cemented identically with a consistent light force. The time of 7-minutes was based on the documented time to total cure of the Ketac cement as listed in the package instructions.

A stainless steel chisel shaped rod was centered to make contact with the maximum convexity of the buccal cusp tip (figure 3). This was determined by marking the crown with a felt tip marker on the cusp tip and visually aligning the chisel rod. Each crown was axially loaded along the long axis in a universal testing machine (QTEST, SINTECH , a division of MTS Systems Corporation, NC) at a crosshead speed of 0.01 in/minute until there was fracture and loss of veneer (figure 4).

This point of failure was detected by Test Works QT (version 3.1). Visual failure was defined as the point at which any portion of the veneer delaminated from the SSC as this would indicate clinical esthetic failure.

The pilot experiment proved that visual failure corresponded with a dip in the load to displacement curve (figure 4). The load to displacement was recorded until failure was detected by the computer with simultaneous visual confirmation of loss of veneer . The increase in fracture load values was recorded continuously in kilograms (kg) starting at 0 kg. The load at which the failure occurred was recorded in kilograms. The pilot experiment also demonstrated that the cement was able to hold the crowns during loading without any rocking or change in the crown-die orientation.

The crown was then removed from the die and the process was completed for the next crown. SN curves were generated that identified load at failure. Each Specimens was photographed before and after testing using a digital camera (Canon 20D) to help document chisel placement and failure type. The mode of failure was characterized with regard to location of the failure. A cohesive failure was noted if the resin broke within itself and a veneer was left on the stainless steel. An adhesive failure was noted if the entire facing was dislodged without breakage. If a mixed failure occurred, only part of the veneer chipped and there was some veneer remaining.

The load at failure for each crown was recorded, and a one-way analysis of variance (ANOVA) and a Scheffe's post hoc comparison was analyzed to look for significant differences between the crowns. The level of significance was set at (α=0.01).

Results

Load required for veneer failure

Table 2 shows the mean load to failure of each crown type with a total of 75 crowns tested, 25 per type. ANOVA indicated a significant difference between the three manufacturers, $P<0.001$ F=8.689. Figure 6 depicts the distribution of load to failure values for the three different manufacturers.

A Scheffe's post hoc test revealed that the NuSmile crowns were able to withstand significantly ($\alpha = 0.01$) greater loads than Kinder Krowns $P<0.001$. This was the only significant difference. The Kinder Krowns required the least amount of force, but this was not significantly different from the Cheng crowns. There was no significant difference between NuSmile and Cheng crowns.

Table 3 depicts the type of failure observed for each crown type. The majority of crowns demonstrated adhesive failure.

Discussion

There have been several studies that have recommended the stainless steel crown as the treatment for multi-surface caries on primary molars,[18] and as the preferred restoration after pulp therapy on primary molars. [8] As esthetics become more important in dentistry for the permanent dentition, there is a desire for esthetic alternatives for the primary dentition.

Anterior pre-veneered stainless steel crowns were subjected to a similar experiment with a loading force 148 degrees to the incisal edge. It was found that the range of force to veneer dislodgment (kg) was (40.51 +/- 5.4) Kinder Krowns, (45.6 +/- 8.0) Nu- Smile Crowns, (45.6 +/-8.0) Cheng Crowns, (52.2 +/- 18.5) Whiter Briter Crowns. [13] A Scheffe's post hoc comparison demonstrated that the Whiter Biter group were significantly stronger than the other three groups. The results of our study are the first to quantify in-vitro load to fracture values of pre-veneered posterior stainless steel crowns. The range of force to veneer dislodgement (kg) was (98.54 +/- 21.17) NuSmile Crowns, (85.28 +/- 24.29) Cheng Crowns, Kinder Krowns (74.43 +/- 14.79).

There was a statistically significant ($\alpha = 0.01$) difference between three types of crowns when comparing the load to fracture values $P<.001$. NuSmile crowns required significantly more force to cause failure than Kinder Krowns $P<0.001$. This was the only significant difference. There was no significant difference between Cheng and Nusmile crowns. There was no significant difference between Cheng and Kinder crowns. Adhesive failure was the most common type of failure, followed by mixed failure.

A similar study evaluated the fracture resistance of anterior veneer facings and it was determined that these veneered crowns are resistant to forces greater than the average bite force of a 5-10-year-old child. [13]

No direct comparison between anterior and posterior crowns can be made, but it is evident that veneered crowns are subject to veneer fracture with occlusal loads. The greater strength of one crown type over another may be insignificant if the forces of in-vitro loading consistently exceed the loads generated in the primary dentition.

Kamegai et al, reported the bite force in 2584 northern Japanese school children. The findings revealed that the average bite force was 182.2 N in males and 203.4 N in females of nursery school children; 374.4 N in males and 330.5 N in females of primary school children.[19]

The bite force of 30 children ranging from 3-5.5 years were divided into three groups; normal occlusion, posterior cross bite, and open bite. The means of maximum bite force were reported to be 213.17 N, 249.63 N, and 241.19 N respectively. [20] This bite force was measured between the first and second primary molars.

Another study measured bite force in a sample of 457 subjects from 6 to 20 years old. The mean maximum bite force was found to increase from 78 N at 6 to 8 years to 176 N at 18 to 20 years. [21]

When clenching, the molar teeth resist more compression than the anterior teeth, because of the proximity of the lateral pterygoid and masseter muscles. [22] Waggoner (1995), evaluated the fracture resistance of anterior veneer facings and it was determined that these veneered crowns are resistant to forces greater than the average bite force of a 5-10-year-old child. [13]

The literature shows variability in the posterior bite force of children. The highest load to failure value in our study was 136 kg or 1,333 (N). This maximum load to failure is far above the highest mean biting force of 329(N) in 3-5 year olds. [21] The minimum load to failure in our study was 41 (Kg) or 402(N), which is also above 329(N) or 33.5 kg, the minimum biting force recorded in children 3-5 years old.

This may suggest that the crowns are resistant to the static loading of forces well above those found in the primary occlusion. This is not the definitive test of the strength of the crowns. Although the crowns did not fail in the range of the normal biting force of children, they have been reported to fail clinically. It may be that early micro-fractures due to loads within the mean biting force of children are formed. The micro-fractures then propagate leading to catastrophic failure. Fatigue may be the cause of clinical failure rather than a one time static load.

One of the limitations of this study is that it is an in-vitro study. The methodology of static loading can simulate clinical failures, either crown fracture or loss of fixation, but can result in variable results with large standard deviations. [24] One problem is that the static loading of the crowns is artificial. It is an isolated load to the functional buccal cusp of a lower second molar. In-vivo forces and do not occur in a simple 180 degree axial direction. The chisel was chosen to distribute the force rather than a pin point contact, but this shape is not anatomical.

NuSmile Crowns (Figure 10) tended to have a more flat buccal cusp compared to Cheng (Figure 11) and Kinder Crowns (Figure 12). There was more anatomy in the occlusal surface and cusps of Cheng and Kinder crowns. The distribution of forces when the chisel made contact with the NuSmile crowns may have been broader, and thus the veneer able to withstand greater loads. Forces applied to the more anatomical buccal cusps of Cheng and Kinder crowns had a first point of contact on a more rounded cusp. This could have generated shear forces in a narrower surface area and caused failure sooner.

This experiment was done dry, and this limits the information on how these crowns may perform with the effect of water sorption. Static loading of crowns in vitro can be used to simulate clinical failures, either crown fracture or loss of fixation, but they are variable. [24] One source of variability may have been subtle differences in cementation orientation between the three groups. The forces in the mouth are dynamic and involve fatigue.

Although the crowns seem to withstand static load forces greater than those generated by children, there is clinical evidence that shows veneer failure. Evidence of clinical performance on anterior crowns was reported by Roberts et al. 2001.[25] They completed a retrospective analysis of 38 crowns in 12 children. The average time of examination was 20.7 months. They reported a 32% had loss of some facing and 24% had a complete loss of facing. They noted that parental satisfaction with prefabricated resin-faced SSC's was excellent, but they had a high rate of failure.

A pilot study that evaluated the clinical success of esthetic posterior crowns reported that after 6 months all of the esthetic crowns were intact, but they resulted in poor gingival health. [15] A follow-up study after 4 years of evaluation reported that after 4 years all of the crowns showed chipping of the facing and had a very poor esthetic appearance. [16]A study comparing open-faced and veneered crowns on primary molars (18 open-face and 15 veneered) over the period of 18 months reported a success rate of 95% for veneered crowns versus 80% for open-faced crowns. This difference was not significant. [26]

Composite has been used on crown facings for fixed partial dentures but it has been found not to be suitable because of its low mechanical strength and poor wear resistance.[23]

The results of this study seem to support the clinical data reported. The veneer facing on these crowns fracture clinically and they fracture with dynamic loads placed on the buccal cusp. Visual examination after fracture revealed that each manufacturer attempts to retain the veneer in a different manner. The majority of the crowns in this study had an adhesive failure of the veneer.

Previous studies have looked at the bond strength of composite to stainless steel and have reported values ranging from 10.29-18.81 MPa. [27] Improvements of this bond could be improved by increasing the surface area on the stainless steel.

Tofukuji et al [28] used thermoset resin to veneer stainless steel crowns. They found that when the resin was attached to an orthodontic cleat on the crown this provided more strength and mechanical stability. The engineering of the crowns in this study are proprietary secrets and the exact method of bonding and manufacturing is unknown. The NuSmile crowns appear to use a sputter coated intermediate surface that provides a large increase in surface area for bonding (figure 7). The Cheng crowns rely on a mesh type of framework to bond to (figure 8). The Kinder crowns had holes perforated the facial surface near the buccal cusp that may aid in retention of the veneer (figure 9). Although, the exact mechanism is not known, there are significant differences in strength that may be attributed to differences in design or in the material properties of the veneer.

Repair of the crowns may be an option. One study reported repairing a pre-veneered stainless steel crown with composite and determined that the in vitro shear forces of the repair materials were lesser than bond forces of the original veneer material to the stainless steel.[29]

Future studies could look a cyclic loading of these crowns to determine their longevity in-vitro before veneer failure occurs. Future studies could also look into more detail at the mechanism of failure or into esthetic alternatives that do not involve the use of thick veneers. Different angles and locations of static loading using an anatomical upper primary molar may lead to more clinically relevant results. A clinical trial using a similar sample size with the same crowns used in this study could provide useful clinical information.

Conclusions

1) Nusmile crowns were the most resistant to fracture $P<0.001$.

2) Kinder Crowns were the least resistant to fracture $P<0.001$.

3) All crown types fractured at a load that was greater than published mean biting force values for preschool aged children.

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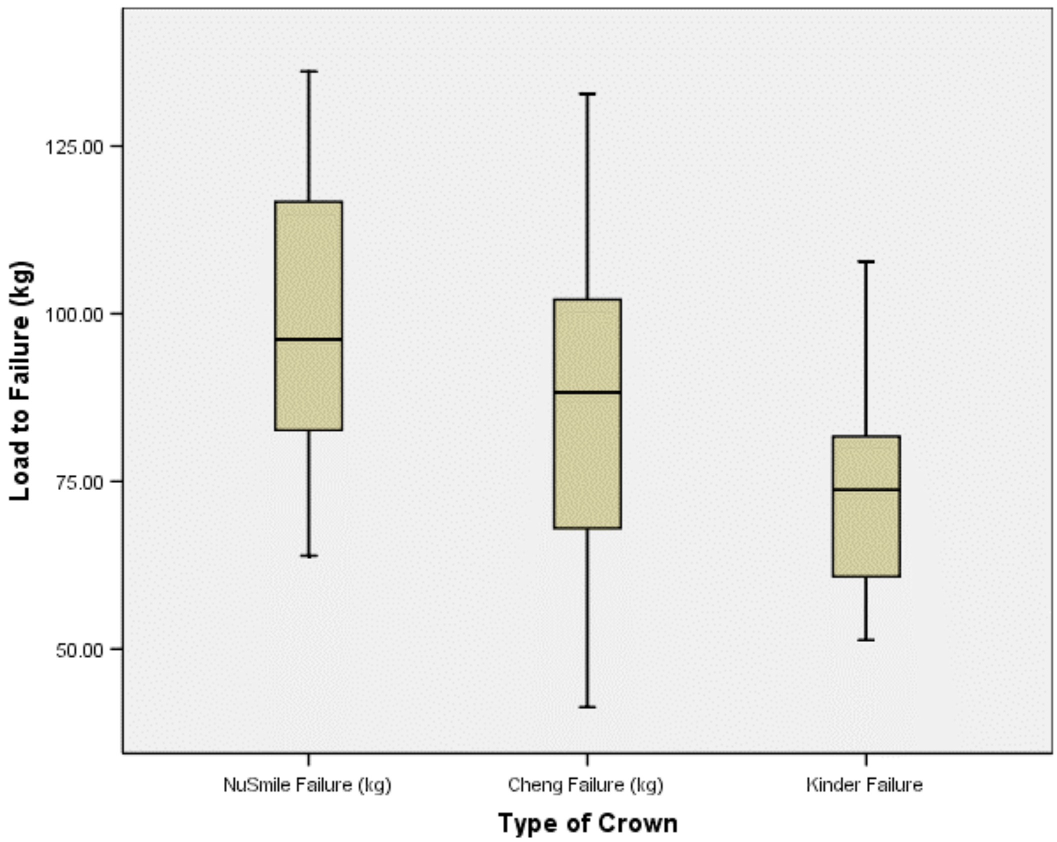
125.00
100.00
75.00
50.00
Load to Failure (kg)
NuSmile Failure (kg)
Cheng Failure (kg)
Kinder Failure
Type of Crown

Table 1. Veneered Crown Manufacturers

Crown Name	*Manufacturer*
NuSmile Crowns	Orthodontic Technologies, Inc. Houston TX.
Cheng Crowns	Mayclin Dental Studio, Inc. Minneapolis, MN
Kinder Krowns	Peter Cheng Orthodontic Laboratory Philadelphia, PA

Crown Name	*Force (Kilograms) +/- SD*
NuSmile Crowns	98.54 +/- 21.17
Cheng Crowns	85.28 +/- 24.29
Kinder Krowns	74.43 +/- 14.79

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Load to Failure of Esthetic Primary Molar Crowns

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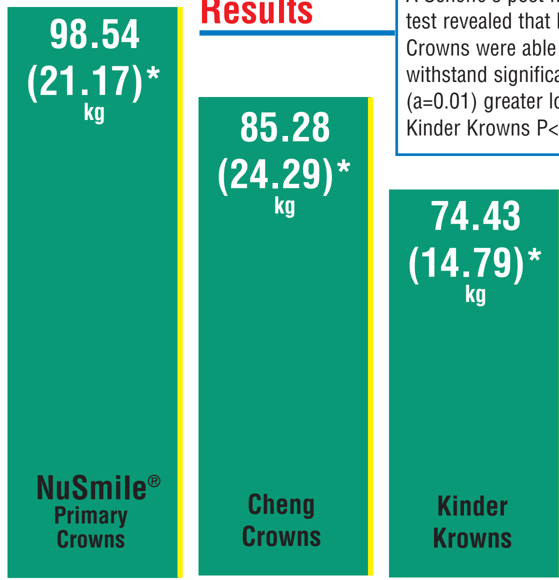
Procedure

Three brands of 75 total pre-veneered crowns were used for testing. A rod was centered to make contact with the maximum convexity of the buccal cusp tip. Each individually mounted crown was loaded at a crosshead speed of 0.01 in/minute along the long axis until there was fracture and a loss of the veneer. Failure was defined as the point at which any portion of the veneer delaminated from the SSC.

* Means with standard deviations in parentheses
Data on file

Results



A Scheffe's post hoc test revealed that NuSmile® Crowns were able to withstand significantly (a=0.01) greater loads than Kinder Krowns P<0.01.