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Evaluation of Two Surface Treatments and Two Composite Resins in the Repair of Fractured Veneered Stainless Steel Crowns

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Evaluation of Two Surface Treatments and Two Composite Resins in the Repair of Fractured Veneered Stainless Steel Crowns

by

Jennifer Ellen Barry

A Thesis submitted in partial satisfaction of
the requirements for the degree of
Master of Science in Pediatric Dentistry

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Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

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ABSTRACT OF THE THESIS

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by

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Master of Science, Graduate Program in Pediatric Dentistry
Loma Linda University, August 2002
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Treatment of early childhood caries (ECC) has challenged pediatric dentists. Finding esthetically pleasing yet durable restorations of anterior teeth can be difficult. Veneered stainless steel crowns are an option but clinically, the veneers can fracture. The purpose of this study was to identify the most fracture resistant veneered stainless steel crown and to determine the best method of repair if fractured. The clinical significance is an evaluation of the best method of repairing these fractured crowns. Two surface treatments and two composite restorative materials were evaluated for repair of the fractured veneers. Forty of each of the following crown brands were tested: Cheng, KinderKrowns, NuSmile, and Dura. The original veneers were loaded in a universal testing machine to the point of fracture. The fractured surfaces were treated with aluminum oxide air particle abrasion or roughened with a diamond bur and restored with Herculite XRV Unidose composite or Filtek Z250 composite. The crowns were again

loaded to failure in the universal testing machine. The peak loads at failure of the original and repaired veneers were compared.

KinderKrowns had statistically significantly stronger original veneers than Cheng or NuSmile. The Dura crown was not tested for initial strength because the softer polyethylene veneer caused plastic deformation rather than brittle failure and would not allow for a peak load to be assessed. For NuSmile and KinderKrowns, the original crowns were statistically significantly stronger than the repaired crowns. There was not a statistically significant difference between the strongest Cheng repair and its original. NuSmile and KinderKrowns had no statistically significant difference between the four repair methods. For Dura crowns, roughening with a bur and using Herculite was statistically significantly stronger than the other methods of repair. For Cheng crowns, using air particle abrasion and Z250 produced a statistically significantly stronger repair. There was a statistically significant main effect of crown brand and repair method. There was also a statistically significant interaction effect between crown brand and method of repair. Cheng crowns repaired with air particle abrasion and Z250 were the strongest repairs but results were not statistically significantly greater than the KinderKrown repairs.

INTRODUCTION

By the time some children have their first visit to the dentist, they may already be suffering from early childhood caries, a condition characterized by severe carious lesions affecting the primary teeth. These teeth, particularly in the maxillary anterior region, are often so broken down that crowns or extractions are the only treatment options. An esthetic restoration of these extremely damaged primary teeth has long been a challenge to pediatric dentists.[5-9, 12]

Primary teeth typically have large pulp chambers relative to their shorter, narrower crown dimensions. Their surface enamel has a prismless layer resulting in an etching pattern that bonds less securely than when composites are bonded to the enamel of permanent teeth.[2] Few treatment options have traditionally been available to restore these primary incisors.[4,5,10,13] These alternatives have been limited to polycarbonate crowns, stainless steel crowns, open faced stainless steel crowns, and composite resin crowns. Each of these restorative techniques has distinct advantages and disadvantages.

Polycarbonate crowns have been criticized for their poor esthetics and poor fit.[5] Excessive occlusal wear in these crowns also produces poor clinical retention.[5,15] Polycarbonate crowns can be trimmed gingivally to better approximate the tooth preparation but cannot be crimped. The resulting poor marginal fit can lead to leakage and recurrent caries.[5,15]

Mink and Hill recommended stainless steel crowns for severely carious primary teeth as they are retentive, durable, and easy to place.[14] These crowns come in a variety of sizes, trim readily, and can be crimped for a better marginal fit than other types of crowns. A well-adapted stainless steel crown is the best means of preventing recurrent caries, obtaining long-term retention, and maintaining optimal gingival health.[14] The experienced clinician can place these crowns quickly and easily. This may be important for very young, marginally-cooperative children or children being treated under general anesthesia, where speed and efficiency of treatment is particularly important. Despite the advantages of a stainless steel crown, they present a distinct esthetic disadvantage, especially in the maxillary anterior region, and as a result, many parents are unwilling to choose this option.[18]

To improve the esthetics of anterior stainless steel crowns, clinicians have, for many years, added a composite window into the facial surface. These crowns are commonly known as open face stainless steel crowns. This technique combines the retentiveness of the stainless steel crown with improved esthetics.[11,22,23] The disadvantages include some remaining visible metal and a longer treatment time. First, the clinician must fit and cement the stainless steel crown. A window is cut out of the facial surface. This is then filled with composite and finished. This technique improves the esthetics considerably but cannot be utilized in all situations. Some patients will not tolerate this long procedure and many parents object to the visible metal margins.

Composite resin crowns are an esthetic alternative in the treatment of carious anterior teeth. Resin crowns can restore fractured, malformed, hypoplastic or severely carious primary incisors.[20] Composite crowns are extremely technique sensitive in their placement and require adequate tooth structure, optimal isolation, and patient cooperation. When treating a patient under general anesthesia, some dentists hesitate to place these crowns due to their high failure rate.[7] However, resin crowns are recently enjoying increased success rates due to improved techniques, newer generation bonding agents, and better composite materials.[7,8]

Another attempt to combine esthetics, durability, and ease of placement is the commercially available resin veneered stainless steel crown.[2,18,19,21] The more time-consuming process of the open-faced stainless steel crown is eliminated. As these are traditional stainless steel crowns with a prefabricated facing, resin-veneered crowns can be placed in the presence of hemorrhage and saliva and are much less moisture sensitive than composite crowns.[19] If a composite crown is not an option, parents often prefer these more esthetically pleasing veneered crowns to the traditional stainless steel crowns. While the facing improves the esthetics, the veneer is often prone to fracture.[2,6] A fractured veneer leaves the clinician with the options of replacing the entire crown or attempting to repair the facing. A conventional stainless steel crown can be shaped and contoured to fit the preparation. However, with a veneered stainless steel crown the tooth must be prepared to fit the crown. Consequently, while the initial preparation is the same as that for a stainless steel crown, additional tooth structure must often be removed, especially on the lingual, in order to achieve a proper fit. It is important that the crown not be placed with excessive force to achieve a "snap" fit because this is likely to weaken or fracture the veneer.[17] Due to the veneered facing these crowns cannot be crimped like a non-veneered stainless steel crown. This may result in a compromised marginal seal.

A study conducted by Bakke et al. determined the average biting force of 5- to 10-year-old children to be 36.4 Kg $\pm$ 6.5.[3] Thus, it might be assumed that the biting force of a preschool-age child is less than or equal to that of the 5- to 10-year-old.[19] The average force required to break the veneers on the Cheng, KinderKrown and NuSmile crowns was tested in various studies and found to be greater than the assumed bite force in preschool-age children. Waggoner et al. determined that the force required for fracture was: KinderKrowns (40.50 Kg $\pm$ 5.4), NuSmile crowns (45.6 Kg $\pm$ 8.0), and Cheng crowns

(52.20 Kg $\pm$ 8.5).[19] No studies to date have been performed on the Dura crown. From these results, it is postulated that trauma, not biting forces, may be the principle cause of failure of these resin veneers.[19] There are no studies to date which analyze the effects of intraoral cycling on the failure of the veneers. According to previous studies, the manufacturers' method of bonding the various crown veneers affects the type of failure.[19] Some of the facings fractured and some completely dislodged. Each of these was noted as a clinical failure.[19]

For the Cheng, KinderKrown, and NuSmile crowns, the manufacturers do not recommend crimping of the facial margin. Space Maintainers advertises the Dura crown as a crown capable of being cut with scissors and crimped; however, no studies to date have tested this claim or the fracture-resistance of this crown. In an unpublished study conducted for NuSmile crowns, Vela and Pittman tested three different surface treatments (microabrasion, acid etch, and pumice) in the repair of fractured resin-veneered stainless steel crowns and found that there was no statistically significant difference between the force required to break the original veneers and the repairs for each of the three methods.[17] Bahannan and Lacefield studied three methods of bonding resin composite to stainless steel crowns (Panavia EX, Cover-Up, and Silicoating) and found that significantly higher shear bond strengths of the composite to the stainless steel crown were found when either Panavia EX or Cover-Up were used as compared to Silicoating.[1] Bahannan and Lacefield also found that thermocycling had no statistically significant effect on the bond strength of resin composite bonded to standard stainless steel crowns.[1] In a study testing composite repair, Swift et al. found that air particle abrasion was associated with a higher composite repair strength than hydrofluoric acid (HF) or acidulated phosphate fluoride (APF) when they were used as a surface conditioner.[16] Of the composites tested in their study, Swift et al. found that Herculite XRV had the highest repair strength.[16] A review of the literature revealed no comprehensive studies comparing the repairability of all the various commercially available crowns in regards to both surface treatment and types of composite resins.

The purpose of this study was to test the repairability of four major brands of resin veneered stainless steel crowns using two surface treatments and two composite resins.

The hypothesis is that there is a statistically significant difference in fracture resistance of the repaired crowns among the two different methods of surface conditioning and two types of composite resin used to repair these veneered crowns. The findings may assist the clinician in selecting a resin veneered stainless steel crown and choosing the best method of repair in the event of a fracture.

MATERIALS AND METHODS

A) Experimental Design

This study was designed to test the repairability of several veneered stainless steel crowns currently available on the market. These include crowns made by NuSmile (hybrid composite resin facing), Cheng (poly-glycodimethacrylate resin facing), KinderKrown (hybrid composite resin facing), and Space Maintainers (resin facing made from high-density polyethylene). This study tested the differences between two methods of surface treatment (roughened with a diamond bur or air particle abrasion) and two types of hybrid composite resin (Herculite and Z250) with regard to the repairability and subsequent fracture resistance of veneers from four different manufacturers.

Table 1. Resin veneered stainless steel crown brands and methods of repair.

	Roughened/ Herculite	Roughened/ Z250	Air particle abrasion/ Herculite	Air particle abrasion/ Z250
NuSmile	A1	B1	C1	D1
Dura	A2	B2	C2	D2
Cheng	A3	B3	C3	D3
Kinder	A4	B4	C4	D4

B) Die Preparation

A Columbia Dentoform (Malvern, PA) ivorine right central incisor (Tooth #E) was used to fabricate a master die. The ivorine tooth was prepared using a 699L highspeed carbide bur following standardized procedure for a stainless steel crown preparation with the additional modifications necessary for a veneered stainless steel crown. These modifications included more reduction in all planes in order to allow a passive fit. The tooth was prepared with a facial reduction of 1 mm, incisal reduction of 1.5 mm, lingual and interproximal reductions of 0.5 mm each. A feather edge margin was placed gingivally to complete the preparation. The ivorine tooth was placed in a plaster base measuring 5mm x 5mm x 3mm. Five addition-silicone impressions of the tooth and base were made using Capsil (Precious Chemicals USA, Italy). Fifty wax models were fabricated from these impressions. The models were then invested in FastFire 15 (Whip Mix Corp., Louisville, KY). Using the lost-wax technique, fifty standardized nickel-chromium (Lite Cast B, Ivoclar/Williams, Amherst, NY) dies were fabricated (Figure 1).

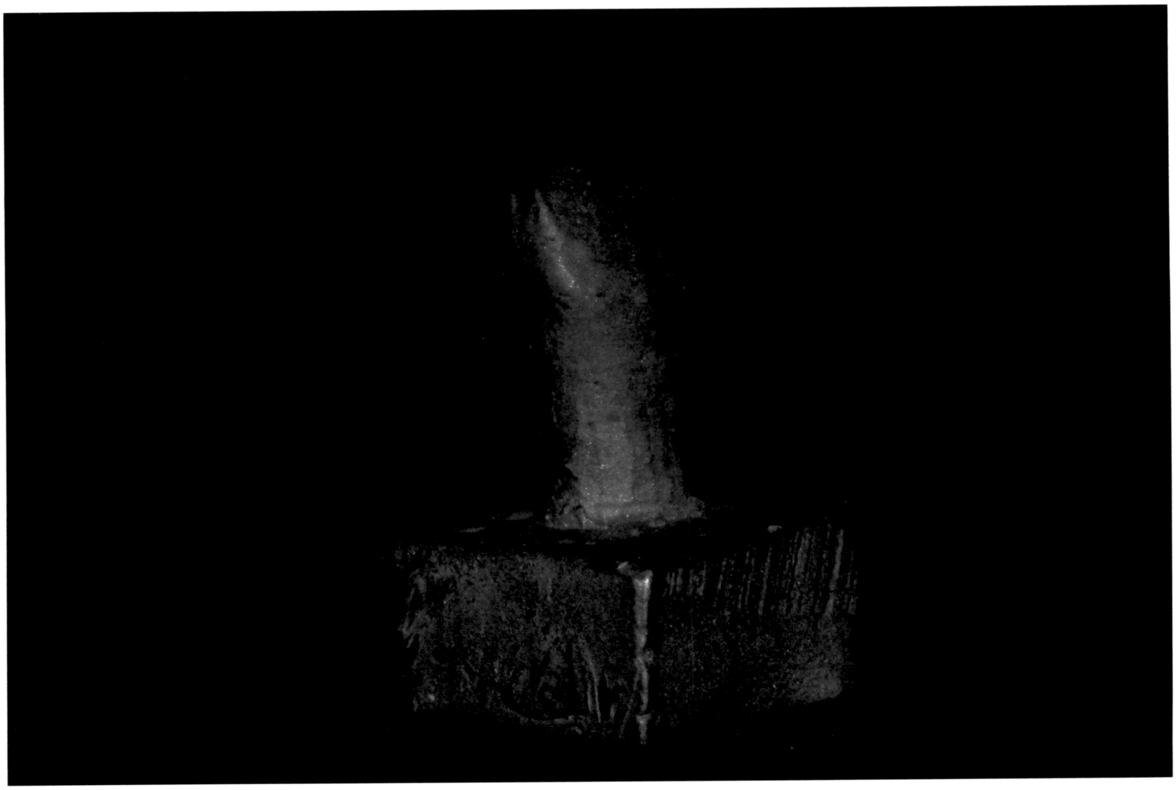

Figure 1. Standardized nickel-chromium die.

C) Testing

The veneered stainless steel crowns used in this study consisted of 40 Cheng crowns (Peter Cheng Orthodontic Laboratories, Philadelphia, PA), 40 KinderKrowns (Mayclin Dental Studios, Minneapolis, MN), 40 NuSmile primary crowns (Orthodontic Technologies, Inc., Houston, TX), and 40 Dura crowns (Space Maintainers Laboratory, Van Nuys, CA). Of the 160 crowns in the study, each subgroup consisted of ten crowns of each brand. Each group of crowns was crimped on the lingual margin as per manufacturers' instructions and cemented on the die with Rely-X ARC adhesive resin cement (3M, St. Paul, MN). After cementation, each die with its cemented crown was immersed in water and placed in a 37°C oven (VWR 1520, San Diego, CA) for twenty-four hours in order to ensure complete polymerization of the resin cement. Each group of crowns was then thermocycled at 5°C and 55°C, for a total of 1500 cycles. A fifteen-second dwell time was used for each water bath, with a 3-second transfer time, for a total of a 33-second cycle (thermocycler tank model GP-200, Thermocycling Test Apparatus, Sabri Dental Enterprises, Chicago, IL). Each die was then secured into a universal mechanical testing device (MTS Model 1125 RENEW, Canton, MA). A flat loading head was selected after a pilot study revealed that it produced the most uniform results. The die was placed in a vise attached to the base of the testing machine and then rotated to an angle of 30-35° lingual to the longitudinal axis of the loading head. The loading head was secured so as to load the die with the force applied to the composite veneer at the incisal edge. This method enabled the force to be directed at the composite facing and not the resin-metal interface (Figure 2). The specimens were loaded at a crosshead speed of 1.0 mm/min until failure. A clinical failure was determined to have occurred if the facing fractured or became dislodged (Figure 3). The peak load at failure of the veneer was recorded in Kg. Two types of failures were noted. When the entire facing fractured off, the surface was prepared as per one of the methods listed and resin was applied directly to the metal. When only a portion of the veneer fractured, the remaining facing was not removed and the fracture site was repaired with composite. In this way, the procedure involved both a resin-to-metal as well as a resin-to-resin bond. Because the crowns were placed into groups prior to the initial loading, they were not randomized in respect to the type of fracture.

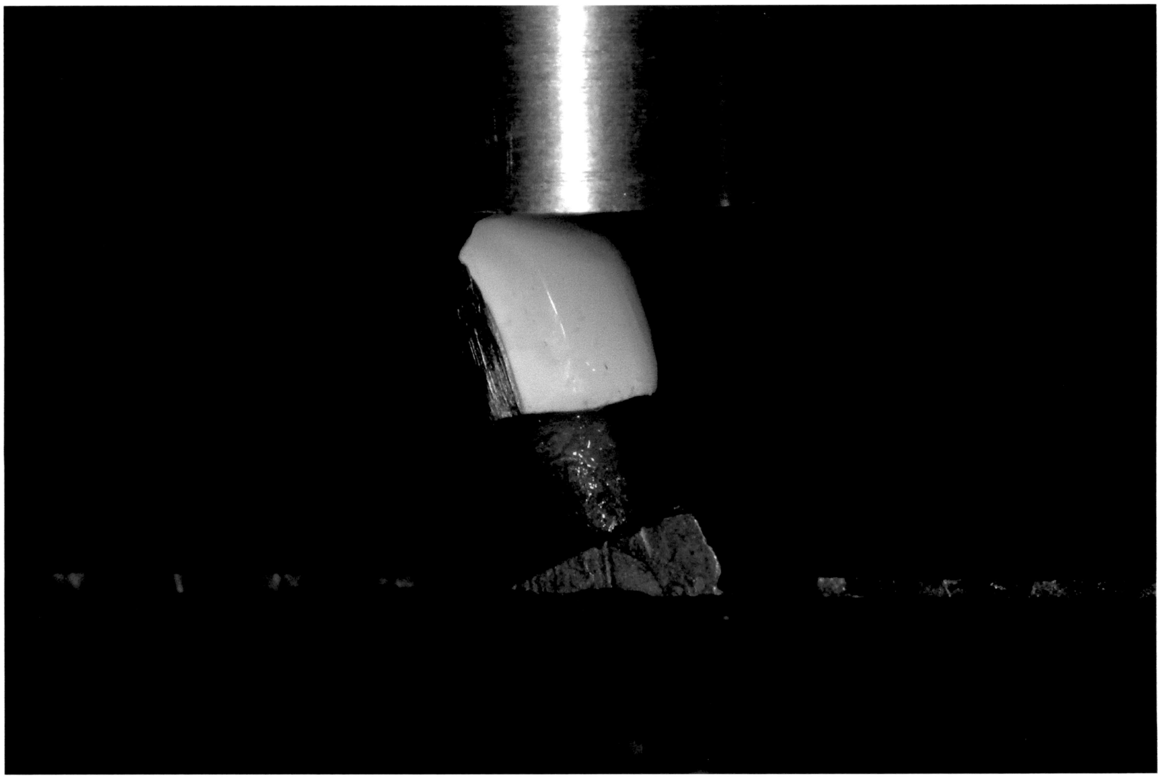

Figure 2. Die with cemented crown loaded in the universal mechanical testing device.

Figure 3. Typical veneer fracture.

Of the 160 crowns tested, each subgroup had ten crowns of each brand. The crowns were divided into two groups and surface treated with either of the following methods: air particle abraded with aluminum oxide (50 micron white, Danville Engineering, San Ramon, CA) or roughened with a diamond bur (#6877k coarse Brasseler bur, Brasseler USA, Savannah, GA) in a Star highspeed handpiece (Den-Tal-Ez, Lancaster, PA) with water spray at a speed of 300,000 rpm (Figures 4 and 5). The air particle abrasion unit used was the Optiblast Work Station (Item 36560, K&D Power Rite, Dist. By Buffalo Dental Manufacturing, Inc., Syosset, NY). In order to standardize the preparation of each group of crowns roughened with the diamond bur, the same A-dec dental unit (Unit 12CJ, SN K966105, A-dec, Newberg, OR) was used throughout the study with the rheostat fully compressed. A new bur was used for each set of ten crowns. Ultra-Etch 35% phosphoric acid etchant (Ultradent Products, South Jordan, UT) was used to etch the test specimens. All samples were then treated with Optibond Solo Plus bonding agent (Kerr Corp., Orange, CA) and light polymerized for twenty seconds with an Optilux composite curing light (Model VCL 401, Demetron Research Corp., Danbury, CT). These groups were then restored using one of two types of composite resin: Herculite XRV Unidose composite resin (Kerr Corp., Orange, CA) or Filtek Z250 composite resin (3M, St. Paul, MN). After the composite resin was applied, the crown was light cured for forty seconds. A series of Sof-lex sandpaper disks (3M, St. Paul, MN) was used to polish the repaired veneers (Figure 6). The repaired crowns were again placed in the 37°C oven for twenty-four hours and then thermocycled between 5°C and 55°C for 1500 cycles.

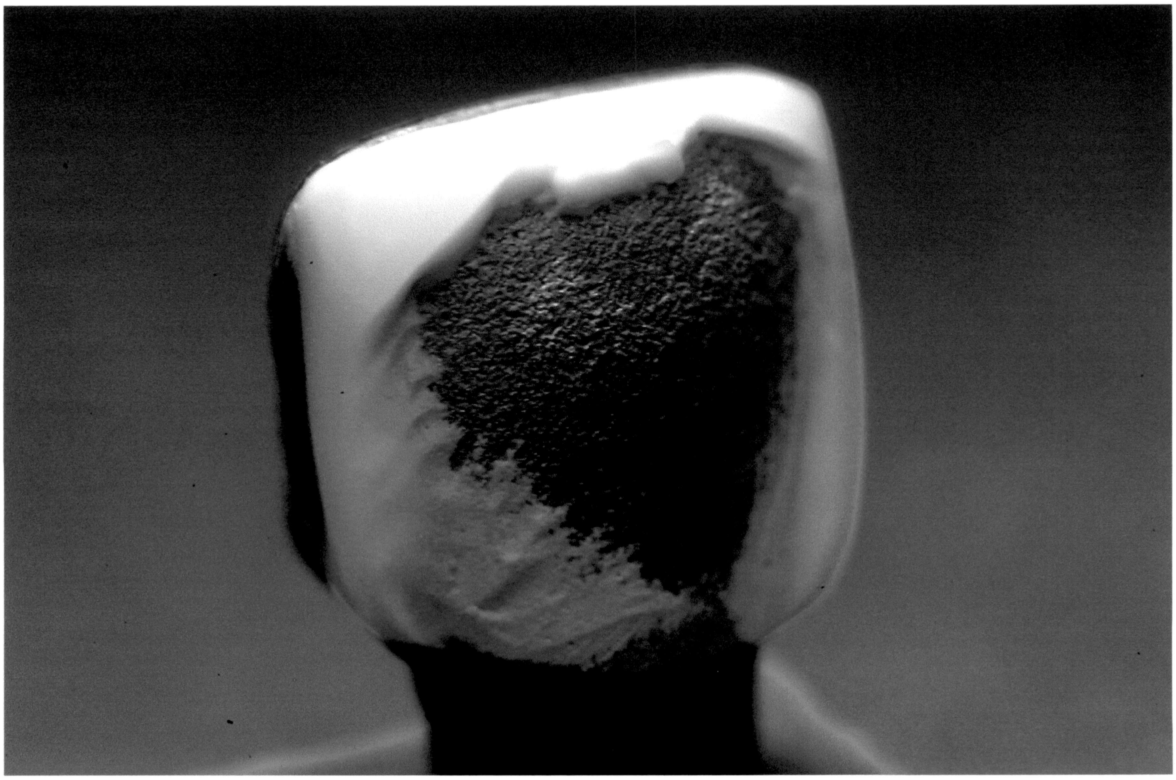

Figure 4. Fractured veneered stainless steel crown surface treated using air particle abrasion.

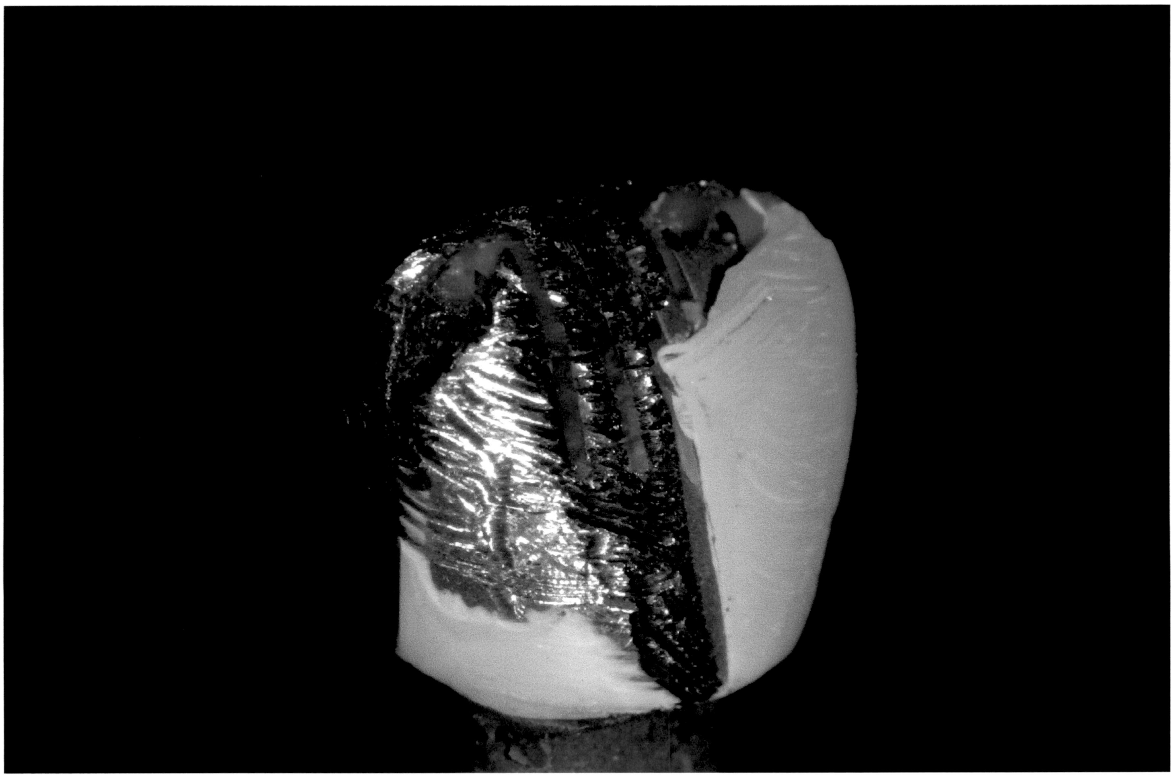

Figure 5. Fractured veneered stainless steel crown surface treated by roughening with a diamond bur.

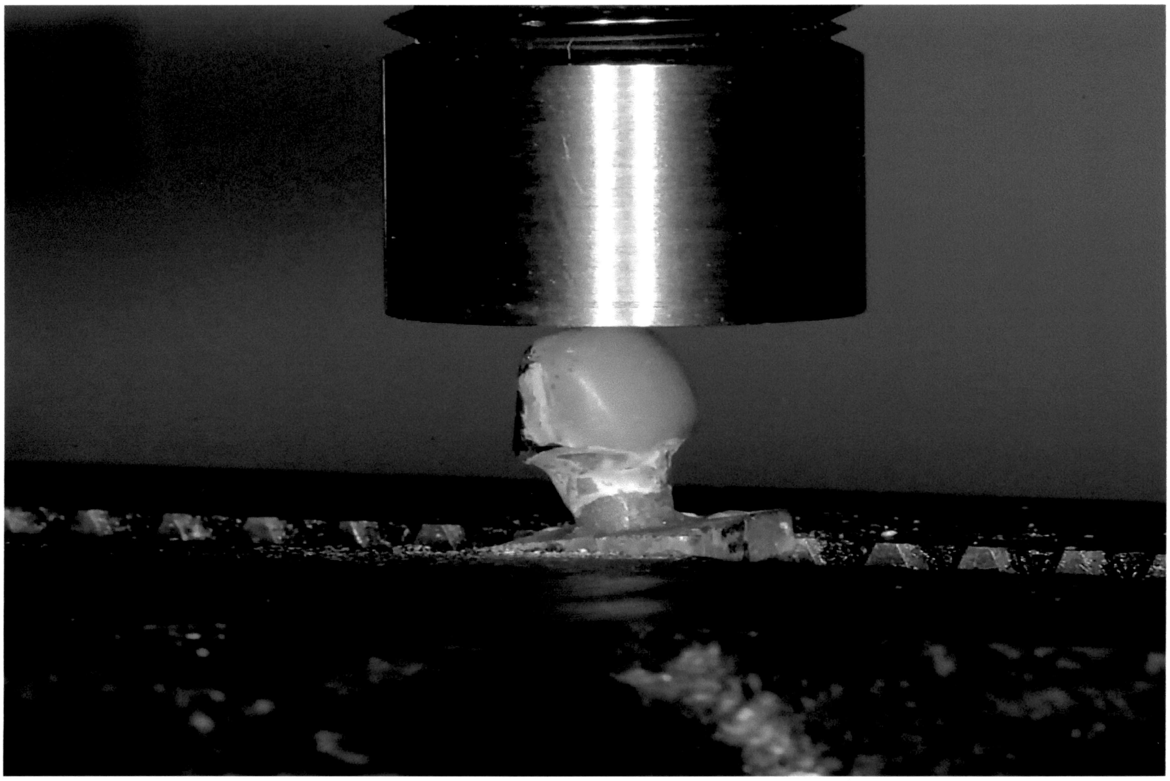

Figure 6. Repaired and polished crown secured into the universal mechanical testing device.

Each die with its repaired crown was then returned to the testing machine. The loading head was again secured so as to load the die with a force applied to the composite veneer at the incisal edge at a similar angle as when the crown was originally tested. The force was applied with the same crosshead speed of 1.0 mm/min. and loaded to failure. The peak load at failure was recorded.

D) Statistical Analysis

The peak load at failure was compared for the original versus the repaired crown. The failure point was determined to be the loading pressure (in Kg) at which the veneer fractured, dislodged or became deformed. The data were analyzed by a two-factor analysis of variance (ANOVA) fixed model at a significance level of $\alpha=0.05$ as the primary statistical method assuming that the data were normally distributed and the variance. When the data were found to not be normally distributed, a non-parametric test was used. The data were analyzed by a Kruskal-Wallis Ranks test (KW) in order to compare sample groups at a significance level of $\alpha=0.05$. When differences were found, a Mann-Whitney U-test (MW) at a significance level of $\alpha=0.05$ was used to compare the various pairs to determine which groups were different.

RESULTS

The peak load at failure of three of the original four groups was compared. The polyethylene composition of the facing by Space Maintainers was not conducive to testing by the universal testing machine as it exhibited plastic deformation rather than a brittle fracture. The KinderKrown, NuSmile and Cheng crowns prior to the repair were found to be statistically significantly different (KW: $p<0.0001$). When compared individually, the facing on the Cheng crown was statistically significantly stronger than that of the NuSmile crown (MW: $p<0.0001$). The facing of the KinderKrown was also statistically significantly stronger than the NuSmile crown (MW: $p<0.0001$). Finally, in comparing the KinderKrown and the Cheng crown, the KinderKrown facing was found to be statistically significantly stronger than the Cheng facing (MW: $p=0.001$). The statistical analysis, therefore, revealed that the KinderKrown had the most fracture resistant crown prior to repair.

For each crown brand, the various methods of repair were then compared (Tables 2 and 3). For the NuSmile crown and KinderKrown, the four repair methods did not produce significant differences in fracture resistance of the crowns (KW: $p=0.493$ and $p=0.307$, respectively). For the Dura crown, roughening with a diamond bur and repairing with Herculite composite was statistically significantly more prone to fracture than the other three methods of repair (MW: roughening and Z250, $p<0.0001$; air abrasion and Herculite, $p=0.029$; air abrasion and Z250, $p=0.035$). When repaired with Z250 composite, there was no statistically significant difference between the Dura crowns that were roughened with a bur versus treated with air particle abrasion (MW: $p=0.105$). For the crowns that were treated with air particle abrasion, there was no statistically significant difference in the Dura crowns repaired with Herculite or Z250 composite (MW: $p=0.631$). The Dura crowns repaired by roughening with a diamond bur and restored with Z250 were statistically significantly stronger than those repaired with air particle abrasion and Herculite composite (MW: $p=0.035$). There were statistically significant differences found within the Cheng repairs. The crowns repaired with air particle abrasion and Z250 were statistically significantly stronger than the crowns repaired using the other three methods (MW: roughening and Z250, $p=0.029$; roughening and Herculite, $p=0.015$; air abrasion and Herculite, $p=0.052$). Of the two groups of Cheng crowns that were surface treated with a diamond bur, those repaired with Z250 were statistically significantly stronger than those repaired with Herculite composite (MW: $p<0.0001$). Of the Cheng crowns repaired with Herculite, there was no statistically significant difference in the repaired fracture resistance between those treated with air particle abrasion and those roughened with the bur (MW: $p=0.912$). There was also no statistically significant difference found between the Cheng crowns roughened with a diamond and repaired with Z250 and those treated with air particle abrasion and repaired with Herculite composite (MW: $p=0.529$).

The peak load of failure of the original forty crowns was compared to the most fracture resistant repaired group of each brand of crown (Figures 7, 8, 9 and 10). In the case of no statistically significant difference in the repairs, the mean value of all four repair groups was used for the comparison. For the NuSmile crowns, the original crowns were statistically significantly stronger than the mean of the repaired crowns (MW: $p<0.0001$). The original KinderKrowns were also found to be statistically significantly stronger than the repaired groups (MW: $p<0.0001$). There is no statistically significant difference between the most fracture resistant Cheng repair and its original (MW: $p=0.224$).

The four groups with the highest repair fracture resistance are: the KinderKrown repaired with air particle abrasion and Z250, the KinderKrown repaired with air particle abrasion and Herculite, the KinderKrown repaired with roughening and Herculite, and the Cheng crown repaired with air particle abrasion and Z250. There was no statistically significant difference between the four groups (KW: $p=0.728$). There was also no statistically significant difference between the Cheng crowns and KinderKrowns repaired with Z250 in either the air particle abrasion (MW: $p=0.579$) and roughening (MW: $p=0.912$) groups. For the Cheng and KinderKrowns repaired with the Herculite composite, there was no statistically significant difference between the two brands when repaired with air particle abrasion (MW: p=0.075). However, the KinderKrowns that were roughened and repaired with Herculite were statistically significantly stronger than the Cheng crowns (MW: p=0.019) with the same method of repair (Figure 11).

Using a two factor analysis of variance (ANOVA) fixed model, the effects of the crown brand versus the effects of the method of repair could be compared. In this way, it was found that there is a statistically significant main effect for crown brand (F=2.939, p=0.035). There is also a statistically significant main effect of method of repair (F=103.178, p<0.0001), indicating that the method of repair does in fact, make a difference in the strength of the repair. The F statistic and its associated p value for interaction indicate that there is a statistically significant interaction effect between crown type and method of repair (F=2.617, p=0.008), meaning that the crown brand and repair method both affect the result of the repair.

Table 2. The mean peak load at failure (in Kg) of the various methods of repair.

	Original	**Herculite/ Roughen**	**Z250/ Roughen**	**Herculite/ Air particle abrasion**	**Z250/ Air particle abrasion**
NuSmile	68.49±18.07	44.62±11.82	51.12±11.34	45.06±11.06	46.81±10.53
Dura	N/A *	15.88±4.16	23.89±3.80	21.35±4.95	21.04±5.05
Cheng	101.48±27.88	57.67±15.84	62.68±11.54	59.71±19.22	86.21±27.90
Kinder	120.87±29.10	77.50±16.70	65.25±15.75	82.21±27.29	79.77±18.95

* The Dura crown was unable to be tested in the original category due to the plastic composition of its facing.
Groups connected by vertical tines are not statistically different.

Table 3. The mean peak load at failure (in Kg) of the different brands of veneered stainless steel crowns.

	NuSmile	Dura	Cheng	Kinder
Original	68.49±18.07	N/A *	101.48±27.88	120.87±29.10
Herculite/ Roughen	44.62±11.82	15.88±4.16	57.67±15.84	77.50±16.70
Z250/ Roughen	51.12±11.34	23.89±3.80	62.68±11.54	65.25±15.75
Herculite/ Air particle abrasion	45.06±11.06	21.35±4.95	59.71±19.22	82.21±27.29
Z250/ Air particle abrasion	46.81±10.53	21.04±5.05	86.21±27.90	79.77±18.95

* The Dura crown was unable to be tested in the original category due to the plastic composition of its facing.

Groups connected by vertical tines are not statistically different.

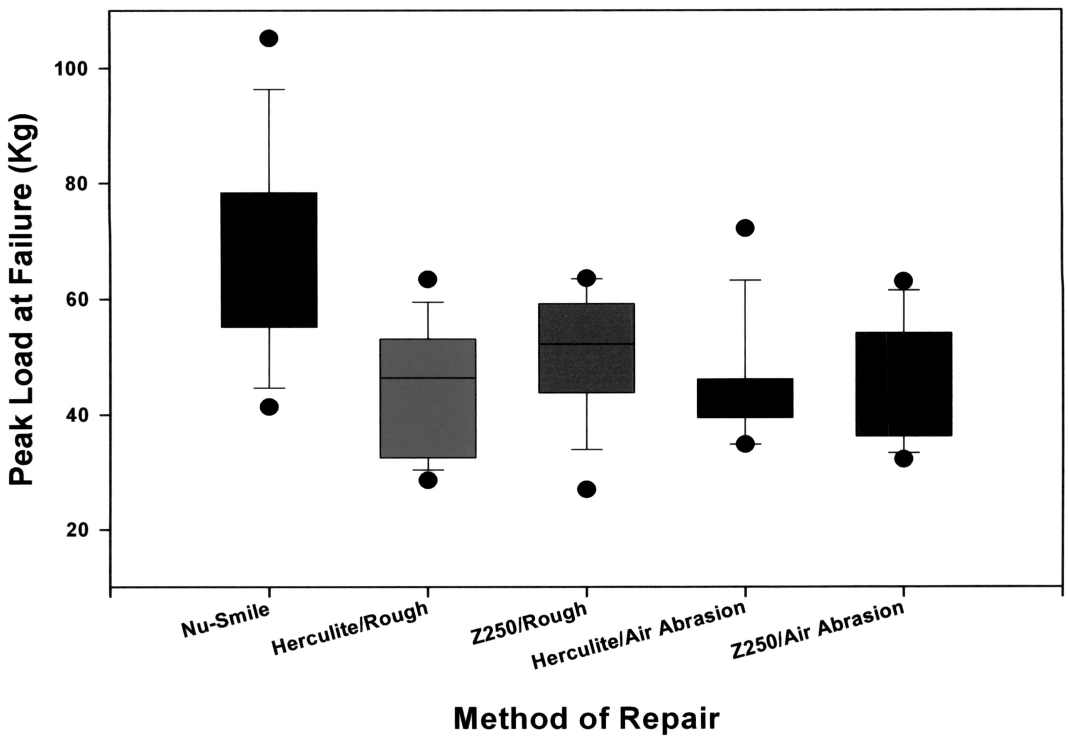

Figure 7. Box-Whisker plot graph showing the peak load at failure for NuSmile crowns and the four methods of repair.

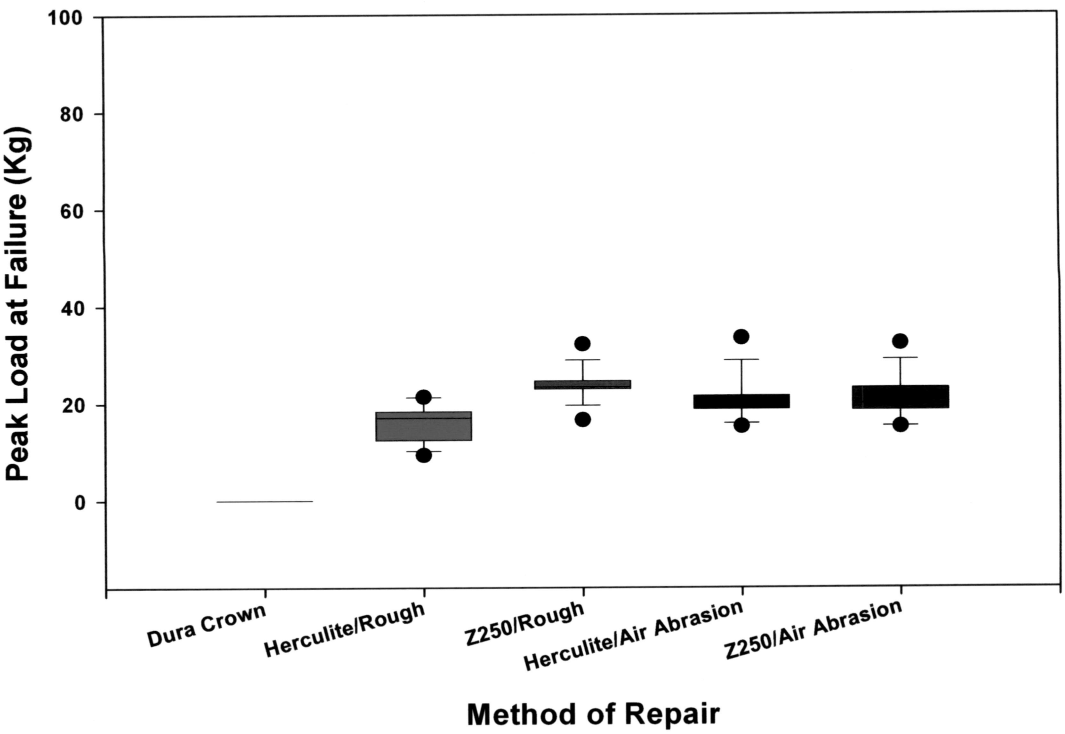

Figure 8. Box-Whisker plot graph showing the peak load at failure for Dura crowns and the four methods of repair.

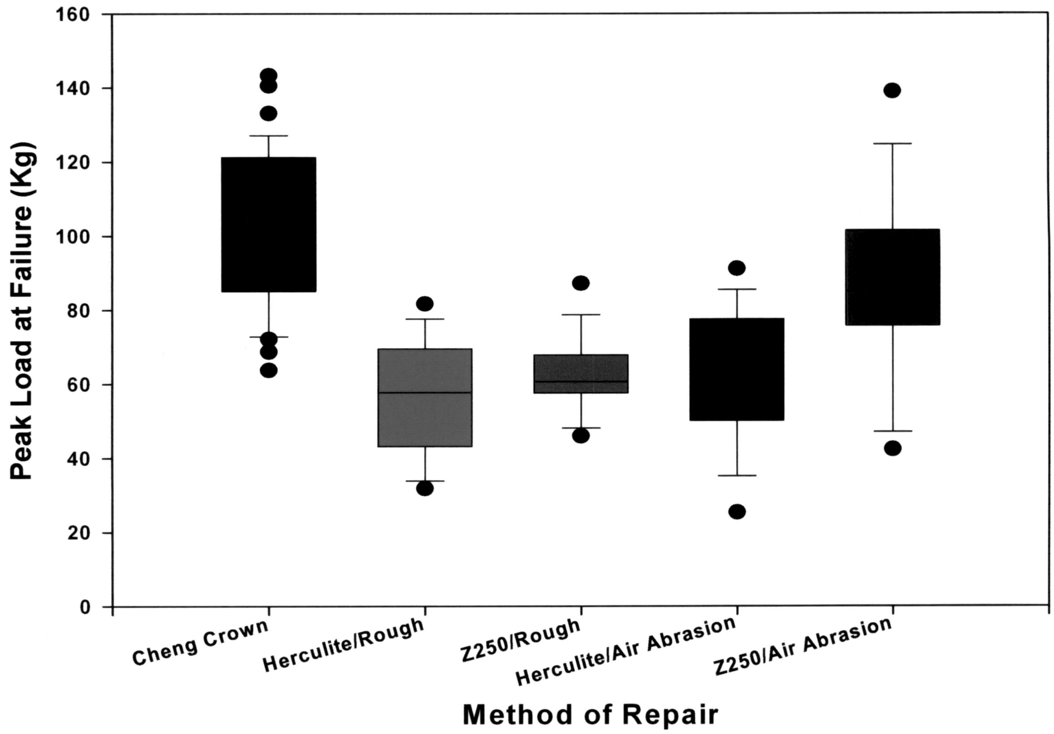

Figure 9. Box-Whisker plot graph showing the peak load at failure for Cheng crowns and the four methods of repair.

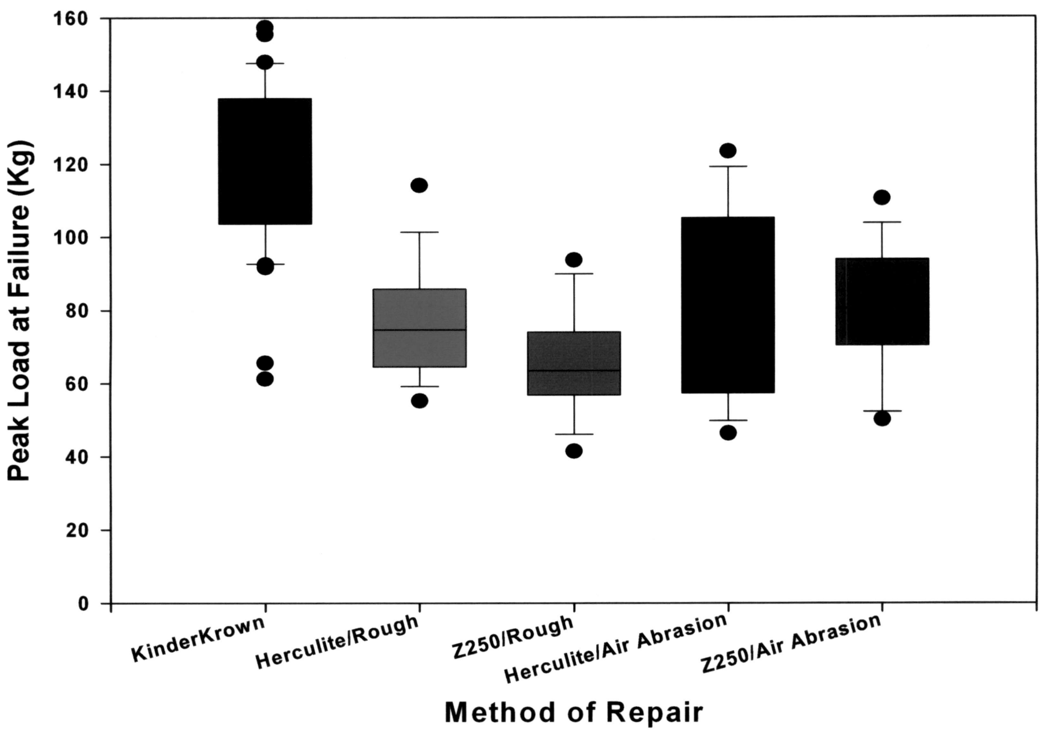

Figure 10. Box-Whisker plot graph showing the peak load at failure for KinderKrowns and the four methods of repair.

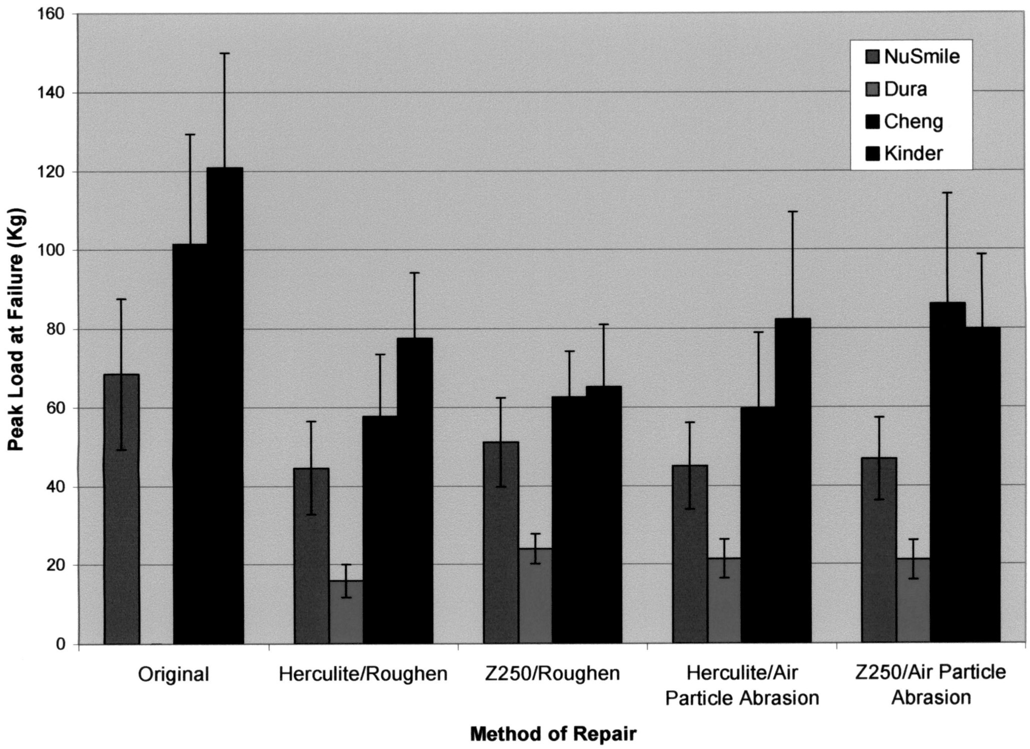

Figure 11. Bar graph comparing the mean strengths of the original versus the four brands of resin veneered stainless steel crowns.

DISCUSSION

The veneered stainless steel crown offers some advantages over other possible restorations for a severely carious primary incisor. It allows for shorter chairside time and is less susceptible to failure due to blood and saliva contamination than the open-face stainless steel crowns or composite crowns. It is also more aesthetically pleasing than a conventional stainless steel crown. One of the disadvantages, however, is the possibility of fracture of the facing, leaving an otherwise intact stainless steel crown. Therefore, it is important to determine the most fracture-resistant brand of veneered stainless steel crowns as well as the best method of repair in the event of fracture. The results of this study provides information as to which is the best combination of crown and repair method. According to this study, upon initial placement, the KinderKrown had the highest manufactured resin-to-metal bond strength facing. Although statistically significantly weaker, the Cheng crown had the second most fracture resistant facing followed by a significantly less durable NuSmile crown. Although the exact method of bonding the various facings to the crowns are proprietary secrets, fracturing the facing off reveals certain information about the method of bonding of each of the manufacturer's crowns. One can speculate that a combination of chemical bonding and the slots uniquely placed in the KinderKrown's stainless steel crowns provide the mechanical retention needed to resist fracture (Figure 12). The Cheng crown has a combination of a chemical bond and a metal mesh welded to the stainless steel crown (Figure 13). NuSmile crowns utilize chemical and mechanical retention via an alumina blasted bonding surface (Figure 14). Finally, the Dura crown's facings were adhered via a chemical and mechanical retention consisting of a spot welded metal meshwork (Figure 15).

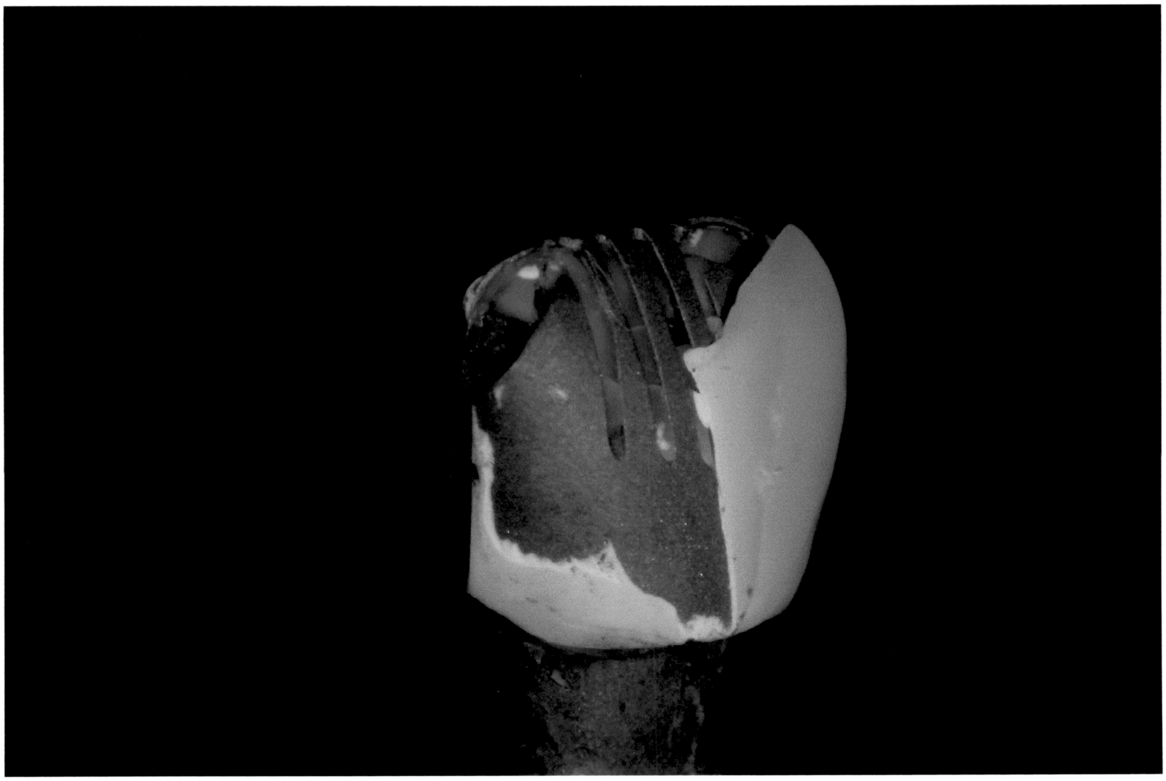

Figure 12. KinderKrowns showing precut slots in the stainless steel crown.

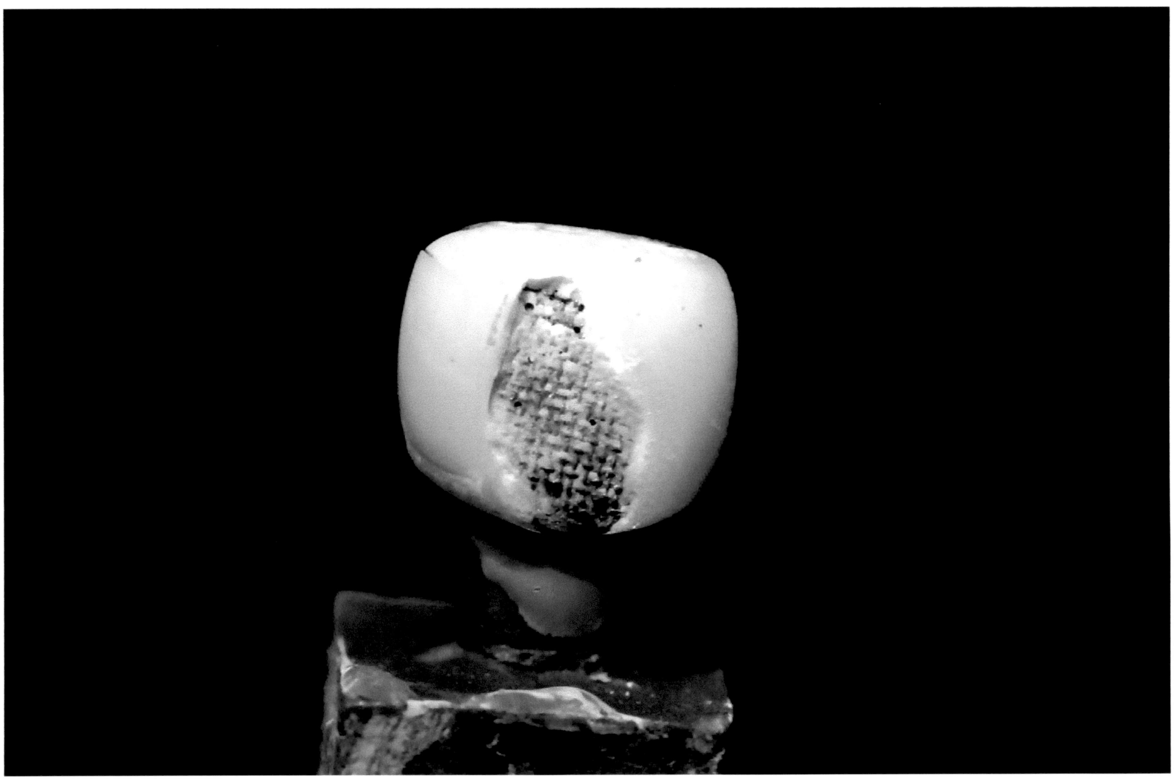

Figure 13. Cheng crown showing a welded metal meshwork.

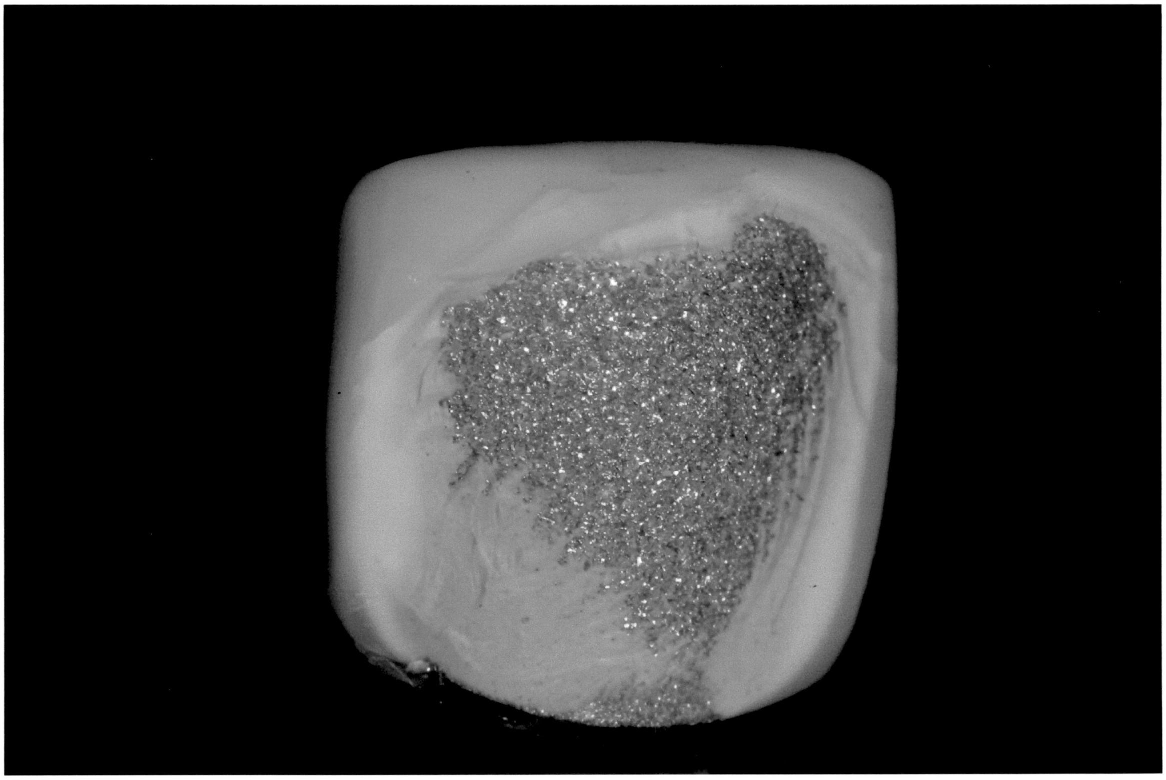

Figure 14. NuSmile crown showing an alumina-blasted bonding surface.

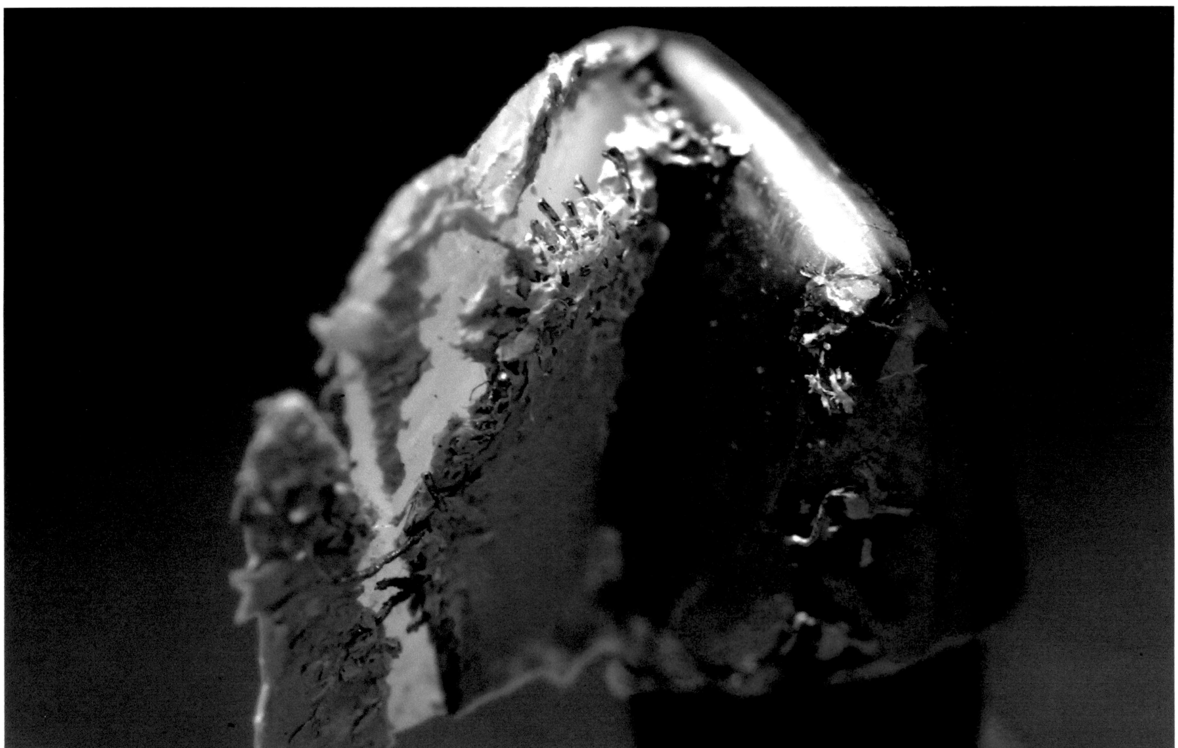

Figure 15. Dura crown revealing a spot-welded metal meshwork.

This study proposed to test the major brands of veneered stainless steel crowns currently available on the market. As a result, the newly-developed Dura crown was included in the study. There have been no published studies to date testing the durability (clinically or in-vitro) or repairability of this crown. Upon beginning the initial testing, it became clear that the polyethylene facing would prohibit it from being tested in the same method as the others. When a force was applied to this crown, the facing exhibited a plastic deformation rather than an actual fracture and therefore, a point of fracture could not be determined (Figure 16). Therefore, this brand had no initial value for peak load at failure but was still repaired with the various methods in order to determine how the brand fared in repair durability in comparison to the others on the market.

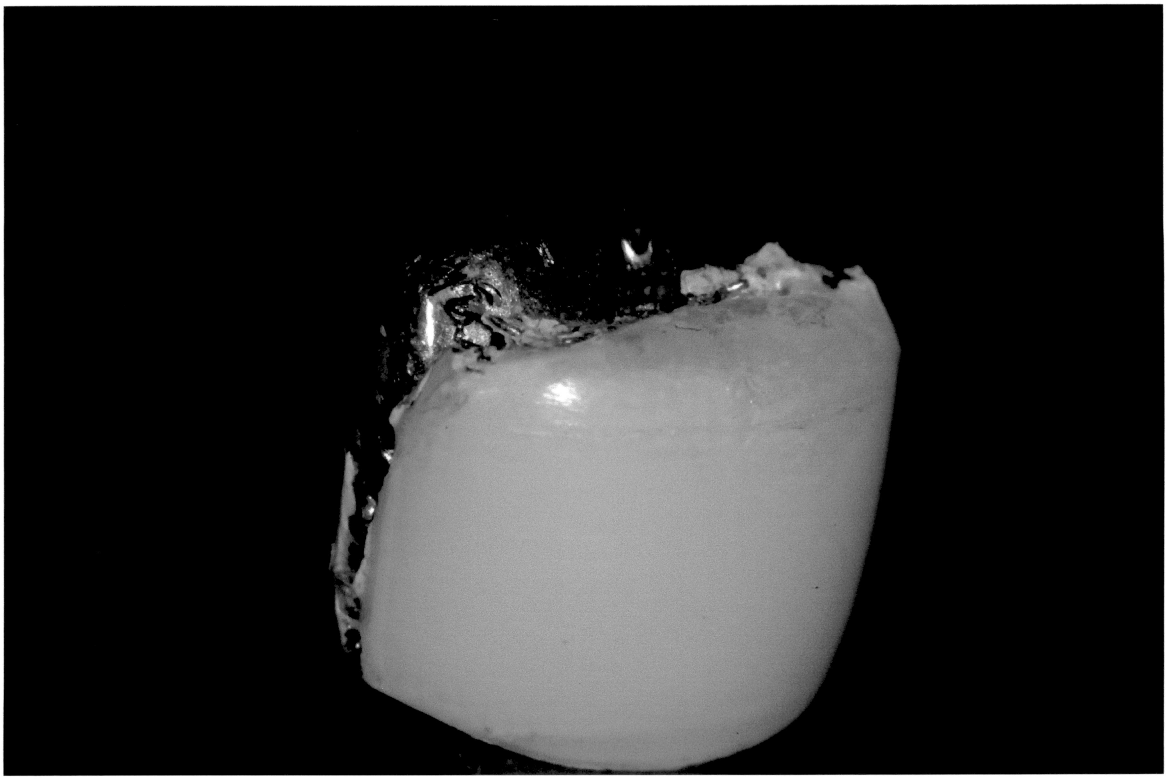

Figure 16. The plastic deformation that occurred with the Dura crown as a result of its softer polyethylene facing.

When analyzing the repaired crowns, the data exhibited a few outliers. These outliers may be due to the small degree in difference in placement of the original versus the repaired veneer in the universal machine. There may also be variations in the placement of the composite by the manufacturers.

Based on the results of the two-way ANOVA, when a fracture occurs, there is clearly a statistically significant main effect in the original selection of crown type. In other words, the brand of crown used does affect the strength of the veneer. There is also a statistically significant main effect in the method of repair of this fracture and thus, the means of repair is important in the overall strength of the repaired crown. The results of this study show that there is not one particular best crown and method of repair. The Cheng and KinderKrowns resulted in the most fracture resistant repairs. Although there is not one repair method that is the most fracture resistant for all crown types, the method of repair plays a significant role in the strength of the repair. Finally, there is a significant interaction between the crown type and the repair method chosen. As a result, the method of repair used for the particular brand of crown is important in the strength of the repair. Based on this study, the Cheng crown repaired with air particle abrasion and Z250 composite was statistically significantly stronger than the other methods of treating the Cheng crown. For the KinderKrown there was no significant difference in any of the methods of repair. There was no statistically significant difference in the strength of repair of the Cheng crown repaired with air particle abrasion and Z250 composite as compared with the four KinderKrown repairs.

This study aimed at testing methods of repair that would likely be used by a clinician when presented with a fractured facing. The clinician would likely attempt to surface treat the stainless steel crown by roughening it with a diamond bur or using an air particle abrasion unit. Empirically, neither method of surface treatment was better in this study, however, one method or the other may have worked slightly better in combination with the other factors involved. For example, the crowns that were repaired with Herculite, air particle abrasion was more successful than roughening with the diamond bur. Another critical step in the process of crown repair is the bonding agent used for the repair. In this study, Optibond Solo Plus bonding agent was selected as it is a standard adhesive on the market and is a widely used bonding agent found in many dental offices. A further study would be useful to test various types of bonding agents to determine the most fracture resistant method of repair. The final factor in the repair process is the composite used in the repair. This study tested two different types of composite by comparing the results of Herculite and Z250, both popular products used by many clinicians. Herculite was selected because it is a softer, more flexible composite while Z250 was chosen because it is a harder, tougher composite. As such, we compared two hybrid composites but compared a low versus a high modulus composite. Further studies could compare other types of composite to determine if there is a better class or brand of composite for this type of repair. With the exception of the KinderKrown group that was repaired by roughening with a bur and using Z250 composite, in general, with any given brand, the crowns repaired with Z250 faired slightly better than those with the Herculite but the results were not necessarily statistically significant.

During the testing process, a cylindrical shearing jig was used in the universal mechanical testing device to create the load. A distributed load rather than a point load was used in order to more uniformly reproduce the force for every crown. In a clinical situation, the trauma to one of these veneered stainless steel crowns may produce a distributed or a point load force. In the cases of a point load force, the average bite force needed for fracture would be much lower than the average test forces at failure. This may explain why many veneers fracture at a lower force in vivo than when tested in this study.

While there may be other factors, such as aesthetics, that influence a practitioner's choice of veneered stainless steel crown, the results of this study enable the clinician to make an informed selection when choosing the most durable veneered stainless steel crown on the market. More importantly, when presented with a fractured veneer, the dentist will be able to select the most appropriate method of achieving a lasting repair.

CONCLUSIONS

1. KinderKrown had the highest manufacturer's bond strength, followed by the Cheng and NuSmile crowns.
2. For the NuSmile and KinderKrown brands, there is no statistically significant difference in the methods of repair.
3. For the Cheng crowns, the method using air particle abrasion and Z250 was significantly stronger than the other methods of repair.
4. KinderKrown was found to be statistically significantly stronger than the Cheng crown when repaired by roughening and Herculite but was not statistically better than all other methods of repair.
5. Regardless of the repair method, Dura crowns had the lowest bond strength of all the crowns.

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APPENDIX

	Nu Smile A1	Herculite Rough A1 Rpr	Z250 Rough B1 Rpr	Herculite APA C1 Rpr	Z250 APA D1 Rpr	Dura A2	Herculite Rough A2 Rpr	Z250 Rough B2 Rpr	Herculite APA C2 Rpr	Z250 APA D2 Rpr
1	78.40	55.51	59.17	44.59	34.46	*	12.45	25.60	20.92	32.29
2	61.91	52.53	52.50	46.18	47.79		11.01	22.93	15.22	15.40
3	73.92	28.59	51.95	39.48	54.10		18.15	23.59	20.60	21.04
4	74.52	48.17	57.87	34.85	42.05		21.06	24.59	18.80	20.15
5	106.50	32.26	27.00	41.10	36.24		9.35	32.17	24.10	15.15
6	78.34	32.52	43.84	42.46	49.43		17.07	22.61	21.50	19.80
7	66.02	63.39	40.86	40.65	59.96		21.36	23.15	21.35	18.59
8	91.67	35.53	63.36	54.23	32.24		18.32	23.03	16.54	25.61
9	68.89	53.09	63.57	34.89	62.99		13.14	24.62	21.04	23.12
10	44.68	44.62	51.12	72.16	48.79		16.87	16.59	33.40	19.27
11	106.62	44.62	51.12	45.06	46.81		15.88	23.89	21.35	21.04
12	82.50	11.82	11.34	11.06	10.53		4.16	3.80	4.95	5.05
13	61.73	26.48	22.19	24.54	22.51		26.22	15.89	23.21	24.01
14	64.44									
15	42.57									
16	46.53									
17	53.33									
18	60.81									
19	61.37									
20	68.18									
21	76.19									
22	80.58									
23	56.74									
24	64.42									
25	67.21									
26	53.62									
27	72.97									
28	101.07									
29	53.08									
30	103.86									
31	85.76									
32	50.55									
33	69.31									
34	90.08									
35	44.68									
36	40.18									
37	68.01									
38	58.91									
39	71.98									
40	37.56									
Mean	68.49									
SD	18.07									
CoV	26.38									

* The Dura crown was unable to be tested in the original category due to the plastic composition of its facing.

	Cheng A3	Herculite Rough A3 Rpr	Z250 Rough B3 Rpr	Herculite APA C3 Rpr	Z250 APA D3 Rpr
1	185.30	45.22	67.56	55.34	101.44
2	123.50	57.00	50.18	65.07	110.44
3	143.29	71.55	59.11	79.89	75.81
4	121.59	68.87	87.22	91.21	77.18
5	140.58	68.22	46.01	53.59	42.43
6	159.51	57.67	62.19	53.86	138.96
7	124.19	36.94	70.25	77.55	79.93
8	76.02	31.85	67.90	50.14	51.82
9	123.58	57.67	57.57	25.34	90.32
10	105.26	81.67	58.78	45.07	93.74
11	68.75	57.67	62.68	59.71	86.21
12	90.06	15.84	11.54	19.22	27.90
13	85.05	27.46	18.42	32.19	32.36
14	96.58				
15	105.15				
16	133.11				
17	127.16				
18	89.59				
19	73.94				
20	101.23				
21	72.83				
22	89.75				
23	88.48				
24	62.13				
25	85.19				
26	122.77				
27	103.14				
28	120.23				
29	99.28				
30	112.79				
31	96.58				
32	112.56				
33	75.70				
34	84.83				
35	56.95				
36	98.88				
37	63.76				
38	72.15				
39	92.46				
40	75.22				
Mean	101.48				
SD	27.88				
CoV	27.47				

	Kinder A4	Herculite Rough A4 Rpr	Z250 Rough B4 Rpr	Herculite APA C4 Rpr	Z250 APA D4 Rpr
1	137.85	55.22	41.50	123.29	89.41
2	99.20	71.69	74.01	46.39	110.38
3	92.45	114.06	56.83	87.05	70.42
4	140.11	88.54	50.69	57.35	96.90
5	104.05	71.09	63.68	105.08	54.36
6	167.02	64.52	86.15	69.14	71.24
7	163.17	77.50	63.34	53.16	50.15
8	120.90	83.54	57.45	114.93	76.78
9	146.74	63.12	93.64	98.35	84.30
10	122.21	85.74	65.25	67.36	93.80
11	169.62	77.50	65.25	82.21	79.77
12	114.72	16.70	15.75	27.29	18.95
13	157.34	21.55	24.14	33.19	23.76
14	144.26				
15	155.38				
16	141.20				
17	173.72				
18	117.59				
19	103.62				
20	132.83				
21	123.07				
22	141.32				
23	94.70				
24	123.21				
25	123.34				
26	112.81				
27	113.11				
28	125.81				
29	100.07				
30	105.38				
31	123.53				
32	109.34				
33	93.14				
34	61.26				
35	91.71				
36	102.39				
37	65.65				
38	45.59				
39	147.79				
40	127.69				
Mean	120.87				
SD	29.10				
CoV	24.08				